Joint Proceedings of the 27th Soil Science Society of East Africa and the 6th African Soil Science Society Conference

Theme:

"Transforming rural livelihoods in Africa: How can land and water management contribute to enhanced food security and address climate change adaptation and mitigation?."

20 - 25 October 2013
Nakuru, Kenya

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THEME

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Nakuru, Kenya

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TABLE OF CONTENTS

PAGE

FOREWORD

This publication contains joint proceedings of the 6th Africa Soil Science Society (ASSS) and the 27th Soil Science Society of East Africa (SSSEA) conference proceedings Nakuru, Kenya from 20-25 October 2013. The conference critically analyzed Land and Water Management (LWM) technologies, innovative products and services; and strategies benefiting small-scale agriculture in Africa. This 6th ASSS Conference followed the previous 5th Conference held on 22-28 November 2009 in Yaoundé, Cameroon, and the 27th SSSEA followed the 26th meeting held at Jinja Uganda on 21-25 November 2011. The SSSEA and the ASSS decided to pool resources and have a joint Africa-wide conference.

A particular focus of this joint conference was the contribution of LWM in the Agricultural Product Value Chains (APVS's), addressing threats and opportunities associated with climate change, and scaling up of proven technologies for transformational impact on the livelihoods of African small-scale farmers.

In addition, land use planning and policy was addressed during this conference. In line with the comprehensive Africa Agriculture Development Programme (CAADP's) goal of eliminating hunger and reducing poverty through agriculture, the conference touched on the pillars relating to sustainable land management; market access; increasing food supply and reducing hunger.

This was achieved through presentations on research findings, technology dissemination and adoption. The conference featured invited keynote speakers in plenary sessions, followed by sessions of related thematic oral and poster presentations.

Apart from these proceedings, a major output of the conference was publication of a book entitled "***Transforming Rural Livelihoods in Africa,*** *The contribution of land and water management to enhanced food security and climate change adaptation and mitigation in the African continent*, Edited by Walter Leal Filho, Anthony O. Esilaba, K. P. C. Rao and G. Sridhar.

During the conference, the first ever Soil Atlas for Africa was officially launched. The conference resolved that the role of soils and Soil Science in ensuring food security and providing other key ecosystem services be given appropriate recognition. These are fundamental for sustainable production and adaptation to climate variability and climate change.

Anthony O. Esilaba PhD
CHAIRMAN, SSSEA

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The organizing committee of the 6th Africa Soil Science Society (ASSS) and the 27th Soil Science Society of East Africa (SSSEA) conference acknowledges with sincere gratitude all individuals and institutions who contributed in one way or another to the successful organization of the conference. The ASSS and the SSSEA acknowledge, with appreciation, the efforts and contributions of the Kenyan government, Kenya Agricultural Research Institute (KARI), ICRISAT, AGRA, NACOSTI, MEA Ltd, Virginia Tech, Australian Agency for International Development (AusAID), the University of Sydney and JRC for supporting this conference.

We offer our appreciation to the editorial committee members of these proceedings including Drs. Cyrus Githunguri, Stephen Kimani, Anthony Esilaba, John Lekasi, Mary Baaru, Anne Muriuki, Sospeter Nyamwaro, Maina Muniafu, Catherine Kibunja, Nesbert Mangale, Prof. Charles Gachene, Ms. Fredah Maina and Mr. Peterson Njeru.

Last, but not least we acknowledge the Kenya Executive Committee including Dr. Anthony Esilaba (Chair), Dr. Stephen Kimani (Secretary), Ms. Fredah Maina (Treasurer), and other members namely Dr. Maina Muniafu, Dr. Esther Gikonyo, and Dr. Mark Korir

Joint Communiqué of the 6th Africa Soil Science Society (ASSS) and 27th Soil Science Society of East Africa (SSSEA) conference

25 October, 2013, Nakuru, Kenya

1. The Africa Soil Science Society (ASSS) and the Soil Science Society of East Africa (SSSEA) held their 6th and 27th Joint International Congress in Nakuru, Kenya from 20-25 October 2013.
2. The ASSS was founded in 1986 as a non-profit making scientific organization grouping scientists working in the area of soil science and application of soil information in Africa. The Society promotes and fosters Soil Science in all its facets and gives support to regional and national societies.
3. The SSSEA was founded 1975. It is a non-political and non -profit making organization that draws membership from individuals, soil scientists, agronomists, socio-economists and corporate organizations for purposes of advocating, raising awareness and coordinating EAC actions on soils as a vital resource for achieving sustainable development. It draws membership from East Africa Community member countries of Kenya, Uganda, Tanzania, Rwanda and Burundi. The society promotes linkages between food security, ecosystem services, sustainable development and poverty reduction by addressing the sustainable management of soils at all levels based on the best science available and considering the diverse regional contexts.
4. The conference, which was opened by the representatives of the Kenyan authorities, was attended by over 200 participants from countries across the Africa, Europe, America, Asia, and Australia.
5. The focus of the conference was on the contribution of Land and Water Management (LWM) to food security in the context of climate change and in line with the strong of soil scientists across Africa to support: 1) the African Union's/NEPAD comprehensive African Agriculture Development Programme, in particular pillar no 1 "sustainable land and water management"; and 2) the Nairobi Declaration on the African Process for Combating Climate Change. While these issues were covered during the ASSS 5th conference in Cameroon in 2009 as future goals of the ASSS, the conference shared and discussed research findings around Agricultural Production Value Chains, addressing the threats and opportunities associated with climate change, and scaling up of proven technologies and innovations for transformational impact on the livelihoods of African small-scale farmers. In addition, land use planning and policy was addressed during this conference.
6. Up-to-date information, which was shared among participants and the media including radio and television, will be published in proceedings, books, pamphlets, leaflets, special issues of international journals. The outputs from the conference will also contribute towards informing the African Ministerial Conference on the Environment (AMCEN).
7. Recognizing and re-affirming the expertise and commitment of its members, the ASSS and the SSSEA are ready to support widespread dissemination and use of knowledge from research and from experiences of projects dealing with sustainable land management; and also to implement urgent actions to meet the current and future challenges in Africa. For this purpose, African soil scientists call for a political support and for a significant increase of investments to result in an increased productivity and preservation of soil resources, in particular by African governments. Increasing investments from national resources would be an expression of an important political willingness of African states, which may help catalyse contributions from development partner agencies and the international community.
8. It is paramount that the role of soils and Soil Science in ensuring food security and providing other key ecosystem services are given appropriate recognition. These are fundamental for sustainable production and adaptation to climate variability and climate change. In this context ASSS and the SSSEA and their members are committed to:
   i). Engage ASSS and SSSEA members and other relevant national institutions into generating, improving and disseminating quality soil data for supporting actions and policies

particularly with regard to sustainable land management. In this regards, efforts should be made to capitalize existing analogue data and information from national soil bureau in a way to develop solid soil databases.

ii). Strengthen the role of land and water management and soil quality preservation in national policies and development plans.

iii). Explore the possibilities for scaling up climate-smart agricultural practices developed by the scientific research community in order to contribute increasing the adaptive capacity of vulnerable populations and institutions.

iv). Engage for the first time in these conference series, the focal stakeholders- the farmers, in which the issue of how best soil research outputs can be passed on to them was discussed.

9. During the congress, the first ever Soil Atlas for Africa was officially launched by the Principal Secretary representing the Honorable Minister of Agriculture, Livestock and Fisheries, Kenya. This initiative, coordinated by the Joint Research Centre of the European Commission and the ASSS, is an outcome of a multi-stakeholder partnership (FAO, ISRIC, IUSS, and soil science experts from Africa and Europe). The atlas is a collection of vital information on African soils and highlights the importance of this non-renewable resource. The atlas aims to raise awareness at all levels – from politicians to the general public - of the significance of soil to the economic wellbeing across Africa. It is a much-needed source of information for policy makers and researchers and will be the basis for a pan-African assessment on the state of soil resources.

10. The new Executive Bureau for the period 2013-2015 was elected as follows: President; Martin Yemefack, Secretary General: Cyrus Githunguri; Vice Sec Gen: Dr. Justice Nyamangara; Treasurer: Ms. Gisele Tapsoba; Ex officio: Lamourdia Thiombinano; Auditor 1: Vincent Aduramigba-Modupe Auditor 2: Dr. Nyambilila Amuri

11. The ASSS and the SSSEA acknowledge, with appreciation, the efforts and contributions of the Kenyan government, Kenya Agricultural Research Institute (KARI), ICRISAT, AGRA, NACOSTI, MEA Ltd, Virginia Tech, Australian Agency for International Development (AusAID), the University of Sydney and JRC for supporting this conference.

12. We are convinced that through better knowledge of soil function and sustainable use of lands at national and continental levels, soils and soil science will contribute towards continual sustainable development and food security. Participants therefore expressed their commitments to strengthen their national and sub-regional soil science societies in order to actively contribute to the ASSS business. We need actions, not words!

THEME 1: ENHANCING APPLICATIONS OF ADAPTATION AND MITIGATION TO CLIMATE CHANGE VARIABILITY AND CHANGE

Evaluation of rainfall data reconstruction techniques and variability indices in the drier zones of the central highlands of Kenya

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Abstract

Understanding spatial-temporal variability of climatic indices is an imperative facet to agricultural productivity and Natural Resource Management (NRM). Predominantly, meteorological stations are sole sources of climatic data but only limited to single locations. In sub-Saharan Africa, the predominant setbacks in analyzing hydro-meteorological events are occasioned by either lack, inadequate or inconsistent meteorological data. Like in most other places, the rainfall data within Mbeere district and the neighbouring stations are scarce with missing data making their utilization a challenge. Mbeere district represents a semi-arid region with low potential in terms of agricultural production. This study sought to determine the most appropriate geostatistical interpolation approach for spatial and temporal reconstruction of rainfall data in Mbeere based on the gauged data from the neighbouring meteorological stations. Rainfall data of the neighbouring stations were acquired and captured in the Microsoft Excel spreadsheet where missing data gaps were filled through correlation functions derived from elevation versus recorded rainfall amounts. Linear functions were derived and fitted into the GIS environment tool combined with the digital elevation model (DEM) for orographic construction of monthly average maps starting from January 2001 to December 2008 using various interpolation techniques. The performance of the various interpolation methods were assessed using root mean square errors (RMSE), mean absolute errors (MAE) and correlation coefficient (R) statistics and utilizing rainfall data from specific research site for validation. Based on the study results, the Kriging technique was identified as the most appropriate Geostatistical and deterministic interpolation techniques that can be used in spatial and temporal rainfall data reconstruction in the region. Finally, based on the constructed data, updated average monthly and annual rainfall maps of Mbeere district were produced.

Key Words: RMSE, IWM, Kriging, Spline, Geostatistical Interpolation.

Introduction

Geographic information systems (GIS) and modelling have become dominant tools in agricultural research and, natural resource management (NRM). Thus, spatial and temporal estimates of climatic data are increasingly utilizing GIS modelling and applications (Collins & Bolstad, 1996) with prime intent of optimizing agricultural production. There is need for accurate and inexpensive quantitative approaches to spatial data acquisition and interpolation. In Kenya, smallholder farmers in the densely populated central highlands are resource deprived operating below the agricultural potential. They have been experiencing declining crop yields due to low, erratic and unreliable rainfall (Mugwe *et.al.,* 2006). Reduced rainfall has led to low soil water availability for crop productivity. Although water is limiting, it is either the rainfall distribution or lack of it that affect crop growth and final yields. However, to optimally utilize rainfall in the rain-fed agricultural system in the study area, understanding its occurrence, patterns and distribution both temporally and spatially through hydrological and meteorological analysis is required. Thus, information on rainfall events (rainfall data and patterns), flow depths, discharges, evapotranspiration, among other meteorological data for this region is required. However, most data in the meteorological stations in Mbeere are inconsistent, unrecorded or missing; leading to more discrete and unreliable data for analysis apart from the main stations themselves being several kilometres from the target area.

Utilization of the spatial tools, Inverse Distance Weighted (IDW), Spline and Kriging interpolation techniques are some of the applications exhausted in the ArcGIS tool essential for data reconstruction.

Kriging is a Geostatistical gridding and flexible technique that has proven useful and popular in many fields and is supported by the ArcGIS software. This technique generates visually appealing maps from intermittently spaced data. Kriging attempts to convey the trends produced by data, so that, for instance, high points being joined along a ridge rather than be isolated by bull's-eye form of contours. This depends on the user-specified parameters during data input. It integrates anisotropy as well as the underlying trends in an efficient and natural way (Yang *et al.,* 2006). Unlike the other interpolation techniques supported by the ArcGIS Spatial Analyst, Kriging utilizes an interactive analysis of the spatial trends of the events represented by the z-values before selecting the accurate estimation technique for spawning the output surface. IDW interpolation overtly implements the premise that things that are close to each other are more identical than those that are farther apart. Thus, predictably, values close to the gauged point have predominant influence on the generated value on assumption that the gauged value has a local influence which diminishes with distance. Spline technique estimates values via a mathematical function which minimizes general surface curvature, resulting into an even surface that interconnects all the input points. Conceptually, the gauged points are extruded up to the height of their magnitude.

This study sought to utilize computer applications of ArcGIS tools to reconstruct rainfall data through appropriate and reliable techniques that employ geostatistical or deterministic interpolation techniques. To do this appropriately, homogeneity testing and frequency analysis were other objectives. The output of this study is invaluable to farmers, researchers and model users, for planning, designing and implementing effective and efficient agricultural programs and projects locally, regionally, and at national scale.

Materials and methods

Selection of the study area

The study was conducted in Mbeere District in the Central Highlands of Kenya. Mbeere district lies in the Lower Midland 4 and 5 Agro-ecological zones (Jaetzold *et.al*., 2007) on the Eastern slopes of Mount Kenya at an altitude of between 700 m to 1200 m above the sea level (a.s.l.). The mean annual temperature ranges from 20.7o C to 22.5o C with soaring evapotranspiration trends. The area receives an average annual rainfall of between 700 mm to 900 mm. The rainfall received is bimodal with long rains (LR) from mid March to June and short rains (SR) from late October to December hence two cropping seasons per year. The site soils are predominantly Ferric (Jaetzold *et al.,* 2007). Various agricultural-based studies have been carried out in the region hence the rationale behind its selection. According to (Mugwe *et al.,* 2006), the region has experienced drastic declines in its productivity potential rendering its populace resource poor. There is a secure tenure system on land ownership but underscore in productivity due to inadequate information on the rainfall patterns. The prime cropping activity is maize intercropped with beans though livestock keeping is equally dominant. Some of the distinctive characteristics of this region are summarized in Table 1.

Selection of study sites and data collection methods

Mbeere district was purposively identified and primary and secondary data from five gauging stations were collected. Much of the primary data was acquired from the ongoing recordings at Embu, Kamburu, Kindaruma, Machang'a and Kiritiri Meteorological stations. Additionally, long term secondary data was acquired from the Kenya Meteorological Department in Nairobi. Further, supportive analyzed data was found in academic publication such as scientific papers, journals and resource books.

Results

Rainfall Averages

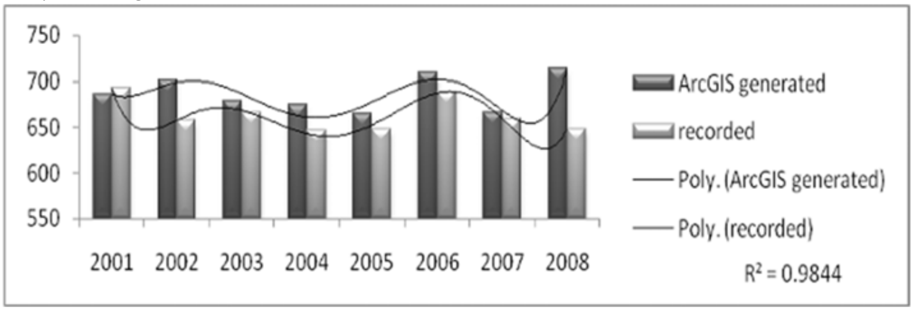

Figure 1: Comparative outlook of the generated and recorded amount of Mbeere District (Rainfall in mm Vs. Years)

The results indicate a correlated trend amid the generated and recorded data.

Homogeneity testing and frequency analysis (rainbow-iupware)

The frequency analysis utilized normal probability distribution with various transformations for different months. Weibull method for estimating probabilities and method of moment (MOM) parameter estimation method were also utilized in all the analysis. The means, standard deviations, Kolmogorov-Smirnov Test and R-Square are shown in Table 4.

Table 1: Data transformations and distribution tests before frequency analysis

Month	Transformation	Kolmogorov-Smirnov Test (K-S)	Non Nil values(n)	Mean	Std Dev.	R2 (%)
Jan	cube root	0.1500	29	2.9	1.4	96
Feb	cube root	0.1146	22	2.7	1.2	97
Mar	square root	0.1557	32	10.1	3.3	96
Apr	square root	0.0560	32	17.2	3.9	98
May	square root	0.1457	32	12.4	4.2	94
Jun	log 10	0.0797	32	1.3	0.3	98
Jul	square root	0.0620	32	5.1	1.4	99
Aug	log 10	0.0805	32	1.5	0.3	98
Sep	square root	0.0826	32	5.2	2.3	98
Oct	square root	0.0817	32	12.2	4.6	98
Nov	square root	0.0961	32	15.4	3.3	98
Dec	square root	0.1240	32	8.0	3.6	96

Table 2: Frequency analysis results; Probability of exceedence and return periods of monthly rainfall events

Probability of exceedence (%)	Return period (year)	Magnitude (rainfall mm)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20	5	64	40	164	419	253	41	40	53	50	258	331	117
40	2.5	30	16	118	330	181	26	30	37	33	179	264	74
50	2	20	9	100	295	154	22	26	32	27	149	237	59
60	1.67	12	3	84	262	129	18	22	27	21	122	212	45
80	1.25	2	0	50	193	79	12	15	19	11	70	159	18

Spatial rainfall interpolation (ArcGIS spatial analyst application)

The resultant annual rainfall maps of the three spatial interpolation methods are shown in Figure 2, 3 and 4 whose source is ArcGIS 9.0 version. The patterns in the maps resulted mainly from the patterns generated from the mapping of the index value (the mean annual precipitation) and were influenced also by the special local conditions (elevation) including the nonexistence of altitudinal variability of the parameters of the distribution function and the interpolation methods used. From a statistical point of view, the spatial distribution of quantiles is theoretically better underpinned in the regional Kriging approach than in the other methods tested.

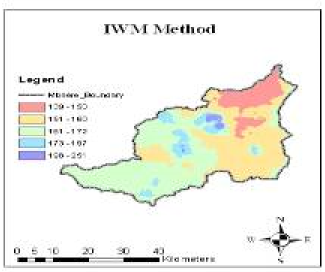

Figure 2: IWM Average Rainfall Map

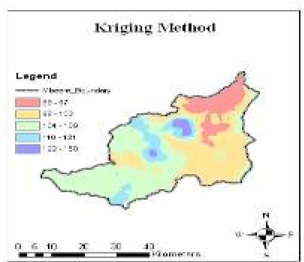

Figure 3: Kriging Average Rainfall Map

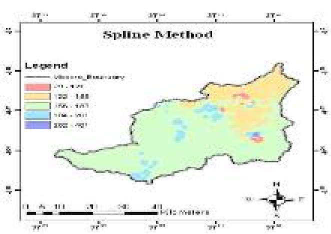

Figure 3: Spline Average Rainfall Map

Discussion

Homogeneity test

This test was intended to establish whether the collected date came from the same population. From the results, the number of outliers (the values that were not considered) was zero. Similarly, the Number of

NIL-values (values above threshold) was also zero. Thus, the cumulative deviation had to be rescaled by dividing the initial and last values of the standard deviation using this equation;

$$S_k = \sum_{i=1}^{k}(X_i - \overline{X}) \qquad k = 1, \ldots, n \qquad (1).$$

Critical Figures for the test-statistic that test the significance of the departures from homogeneity were also plotted in the Homogeneity plot menu as well (3 horizontal lines). None of the cumulative deviation crossed any one of the horizontal lines and hence no homogeneity of the data set was rejected at all the levels of probability.

Frequency analysis

The frequency analysis utilized normal probability distribution with assorted transformations for different months. Weibull method for estimating probabilities and method of moment (MOM) parameter estimation method were also utilized in all the analysis. The means, standard deviations, Kolmogorov-Smirnov Test and R-Square are shown in Table 1.

In this study, the probability of exceedence at 50% was considered for analysis (Table 2). The months of January, February, June, July, August and September are characterized with low rainfall averages of between 9 mm and 32 mm. for any agricultural planning, these periods were considered dry season, while the other remaining months as wet season. The region is thus characterized by two rainfall seasons; of short rains and long rains (Figure 1). Being a dry land region, maize, beans, are some of the crops that the study recommends for wet seasons. On the other hand, millet, and sorghum could do well during the dry season.

Interpolation

The resultant annual rainfall maps of various spatial interpolation methods are shown in Figures 2, 3, and 4. The resultant patterns of spatial distribution for each map were an outcome of the generated patterns from the mapping of the index value (the mean annual precipitation). Besides, they were influenced by the spatial local conditions (elevation) including the nonexistence of altitudinal variability of the parameters of the distribution function and the interpolation methods used. From a statistical point of view, the spatial distribution of quantiles is theoretically better underpinned in the regional Kriging (Figure 3) approach than in the other methods tested. For this study, Kriging was extended by the regional regression for each index value for areas whose terrain or other controls could have contributed to the spatial variability of the trends. Despite the fact that usual mapping methods like Spline and IDW are considered ample only for simple climate patterns, here, their application was considered justified both by the properties of the data and the respective maps generated. Both methods presume that the modelled value is not dependent on spatial location. Additionally, they premise that variance of the differences amid two values predominantly is dictated by the distance between them but not locational variability. On the other hand this common feature showed that the results of both methods exhibit visually and numerically similar results (Figure 2 and 4).

Conclusion and recommendations

The study showed that the rainfall patterns of Mbeere are generally homogenous. Before frequency analysis of the rainfall data is done, various transformations are essential for the data to follow particular probability distribution patters. Weibull method for estimating probabilities and method of moment (MOM) parameter estimation methods proved to be sufficient for the task. The purpose of the study was to produce average maps of annual precipitation as rainfall indexes which could be used in agricultural planning. In follow up investigations the mapped information could be further processed by different interpolation methods such as IDW, Spline and Kriging for temporal and spatial reconstruction of precipitation values. Kriging appeared to be the best technique despite showing high sensitivity to inconsistent density of the stations in the district, which was an initial limitation hence Kriging, this technique could be the method of choice. However, it still has some limitations including the high amount of required calculations, the need for expert judgment and the impossibility of normalizing the indices for a few months.

Finally, it is recommended that within the month's rainfall frequency analysis might be essential in order to better understand rainfall characteristics such as onset and cessation. Understanding these patterns is crucial especially for better farm management practices by the small scale farmers of Mbeere district and in the Central Highlands at large

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Promotion of climate resilience for increased incomes and livelihoods in Sub-Saharan Africa

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Abstract

This paper highlights measures which can be put in place by stakeholders to improve incomes and livelihoods in semi-arid regions of Africa through reduced vulnerability to climate variability and promotion of climate resilience in development investments, enhancing biodiversity, increasing yields and lowering greenhouse gas emissions. Climate change is expected to be one of the major threats to sustained economic growth leading to extended poverty in semi-arid regions of sub Saharan Africa (SSA). The areas of highest vulnerability are the health sector, food production, biodiversity, water resources, and rangelands. Climate change will likely create increasingly high temperatures and dry conditions across much of the globe in the next 30 years, especially along large parts of Eurasia, Africa and Australia. Many of the world's most densely populated regions will be threatened with severe drought conditions. It will likely have a profound and negative impact on livelihoods of many rural and urban communities, which could lead to changes in land use. It is estimated that the Eastern regions of Africa will experience reduced average rainfall (although some areas may experience increased average rainfall) exposing agriculture to drought stress and a rise in temperature. The situation will be worsened by the interaction of multiple stresses factors occurring at various levels, which will negatively impact agricultural productivity.

Many policy makers in governments are unaware of this long-term climatic impact, often leading to land use changes, and governments have low or no adaptive strategies or capacity to make people aware of climate change and climatic impacts in the long-term. Adaptation and mitigation strategies are two general responses to manage effects of climate change and variability. Although adaptation represents the best coping option against agricultural output reduction and hence resulting in improved livelihood of small holder farmers; mitigation actions will contribute to global efforts of greenhouse gas emissions reduction, sequestration of carbon as practical measures for climate change recovery, taking advantage of the carbon storage capacity of tropical environment and improving ecosystem services of the natural resource.

Keywords: Climate change, arid semi-arid lands, key interventions.

Introduction

Climate change is expected to be one of the major threats to sustained economic growth that will lead to extended poverty in sub Saharan Africa (SSA).The situation is similar to other semi-arid regions of Asia. The areas of highest vulnerability are the health sector, food production, biodiversity, water resources, and rangelands. Climate change will likely create increasingly high temperatures and dry conditions across much of the globe in the next 30 years, especially along large parts of Eurasia, Africa and Australia (Cooper *et al*., 2013. Many of the world's most densely populated regions will be threatened with severe drought conditions. It will likely have a profound and negative impact on livelihoods of many rural and urban communities, which could lead to changes in land use. Smallholder farmers provide up to 80% of the food in developing countries, manage the majority of the farmland, and many live in some of the most vulnerable and marginal landscapes that experience unpredictable rainfall patterns. Drylands occupy 41% of the earth's land area and are home to 2 billion people. About 50 per cent of the world's livestock is supported by rangelands, and some 44 per cent of cultivated areas are in dry lands. However, more than 12 million hectares of arable land are lost to land degradation and desertification every year and the rate is

rising as a result of climate change (Jeannette van de Steeg *et al.*, 2012; www.unccd.int, 2012). Land degradation affects 40 per cent of the earth's surface and damages the livelihoods of some 2 billion people living in dry lands, especially women and youth. Land degradation in dryland regions is a driver of climate change. Yet the linkages between climate change and dryland degradation have so far scarcely featured in climate change policy debate. Desertification and land degradation are reducing the capacity to sustain ecosystems and human livelihoods. Despite this, dry lands in semi-arid regions still play a major role in global agriculture production.

Agriculture directly depends on climatic factors for crop and livestock production. Agricultural practices are also indirectly affected by landscape and environmental changes brought about by climate change. It is the SSA countries whose economies heavily depend on agriculture (cultivation of crops and livestock production) and forestry that are particularly vulnerable to climate change and variability, and will bear about 80% of the effect (Mandelson *et al*. 2006). Several industries and investments in SSA are agro-based. Declining agricultural output is likely to affect value chains. Though of smaller magnitude, a reduction in agricultural GDP can affect the rate of industrialization and the overall development process of many SSA countries and constrain creation of non-farm rural and urban employment opportunities through backward and forward linkages to service and manufacturing sector activities (Hanmer and Naschold, 2000, Kanwar, 2000; Kogel and Furnkranz-Prskawetz, 2000).

It is projected that several ecosystems will experience a number of climate related stresses. It is estimated that especially the Eastern regions of Africa will experience reduced average rainfall (although some areas may experience increased average rainfall) exposing agriculture to drought stress and a rise in temperature (Cooper *et al*., 2013). The situation will be worsened by the interaction of multiple stresses factors occurring at various levels. For example heat and drought stresses often occur simultaneously. Combined, these affects will negatively impact agricultural productivity. According to the Secretary General of the UN, Ban Ki-Moon, "Continued land degradation – whether from climate change, unsustainable agriculture or poor management of water resources, is a threat to food security, leading to starvation among the most acutely affected communities and robbing the world of productive land ((John Pender *et al*., 2009)

In addition, many policy makers in governments are unaware of this long-term climatic impact, often leading to land use changes. Governments have low or no adaptive strategies or capacity to make people aware of climate change and climatic impacts in the long-term. Climate change is expected to reduce yields of major crop staples and will condemn portions of currently cultivated land into unsuitable status for cultivation across many parts of SSA. It is estimated that yields of tropical grain crops are expected to be reduced by 5 – 11 % by the year 2020 and by 11 - 46 % by 2050 (Rosenzweig and Parry, 1994; Schlenker and Lobell, 2010; Blanc, 2012), negatively impacting on the small scale farmers who solely rely on rain-fed agriculture for their livelihood (. Projected GDP losses in SSA are estimated to range between 0.2 to 2% by 2100 (Tol 2002a). National adaptation and mitigation planning is urgently needed. In addition, low agricultural productivity has increased pressure on traditional grazing lands by expanding cultivation into rangelands. This has lead to more rapid degradation of rangeland ecosystems.

If the ultimate effect of climate change and variability is not attended to, it may contribute to political instability and migration, at both intra- and regional levels. A recent survey conducted by IFPRI with the support of World Bank identified migration as one of the major adaptation strategies among the communities in semi-arid environments. (World Bank 2000; IFPRI 2010) A number of regions/sub-regions across SSA have just emerged from, or are experiencing conflicts. A new wave of ecological refugees will spark a series of conflicts among communities and complicating the development agenda of several SSA countries, if there is no action to reduce the effects of climate change now(UNFCCC undated). A good baseline study to complement earlier efforts on the possible effects of climate change in vulnerable, poor countries is therefore urgently needed, before sustainable mitigation measures can be implemented that will stabilize or stimulate economic growth in the long-term.

Adaptation and mitigation strategies are two general responses to manage effects of climate change and variability. Although adaptation represents the best coping option against agricultural output reduction

and hence resulting in improved livelihood of small holder farmers; mitigation actions will contribute to global efforts of greenhouse gas emissions reduction, sequestration of carbon as practical measures for climate change recovery, taking advantage of the carbon storage capacity of tropical environment and improving ecosystem services of the natural resource (FAO 2001;World Bank 2012). The African Development Bank (AfDB) for example has developed their Climate Risk Management and Adaptation (CRMA) strategy which outlines key priority areas of intervention in order to manage the risks posed by climate change.

The goal as stated in the strategy document is "to ensure progress towards eradication of poverty and contribute to sustainable improvement in people's livelihoods taking into account CRMA". Specific objectives of the CRMA are to reduce vulnerability within the Regional Member Countries (RMCs) to climate variability and promote climate resilience in past and future Bank financed development investments making them more effective. This will then be used to build capacity and knowledge within the RMCs to address the challenges of climate change and ensure sustainability through policy and regulatory reforms."

To achieve these objectives the AfDB considered supporting three areas of intervention namely:

a) Climate Proofing" investments to ensure that development efforts are protected from negative impacts of climate change, climate variability and extreme weather events.

b) Support the development of Policy, Legal and Regulatory Reforms which creates an enabling environment for the implementation of climate risk management and adaptation interventions.

c) Knowledge Generation and Capacity Building for local farmers, investors, extension agents, district executives or policy makers to help mainstream climate change and manage climate risks.

Over time, some SSA countries have also developed their climate change policy plans including the National Adaptation Programme Actions and National Appropriate Mitigation Actions. Investments are needed in building up assets, implement recommended promising technologies/practices (e.g. water harvesting, storage, irrigation system, introduction of drought tolerant high yielding crops, value addition) and improving risk management capacity. As acknowledged by Stern (2006), the biggest threat climate change poses to economic growth is the use of inefficient mitigation and adaptation policies and practices (Stern, 2006). To improve the efficiency of these actions, it is important that they are based on accurate spatio-temporal impact diagnosis, and supported by a greater public understanding of these strategies and individual roles.

Unfortunately significant gaps of knowledge exist on the most appropriate interventions to use. Many actors (government, agencies and investors) are asking what options exists and which should be implemented to improve the livelihoods of the rural poor. The bottom-line costs and/or benefits of these interventions need to be known if they are to be planned and implemented and investments sources to support their development. Therefore, there is need to therefore to continue grappling with ideas, as well as ways and means which can contribute towards improved incomes and livelihoods in semi-arid regions of Africa through reduced vulnerability to climate variability and promotion of climate resilience in development investments, enhancing biodiversity, increasing yields and lowering greenhouse gas emissions.

Key interventions

There is need first of all to quantify vulnerability to climate change, adaptation approaches by systematic monitoring across landscapes and identify barriers to successful mainstreaming of these adaptation measures in country national plans.

This needs to be followed by developing, promoting and adapting site specific mitigation/adaptation measures for various crop-livestock land use systems.

Thirdly, development of Policy, Legal and Regulatory frameworks in order to create an enabling environment for the implementation, promotion and scaling of climate risk management and adaptation interventions needs to be emphasized.

Sub-Saharan Africa also needs to build Capacity to mainstream climate change and manage climate risks for various land use systems.

Expected outputs from the interventions

i) Vulnerability to climate change, and climate change impacts quantified and mainstreamed in country national development, management and policy plans.

ii) Site specific adaptation and mitigation measures for various crop-livestock land use systems developed and promoted in arid and semi-arid areas

iii) Policy, Legal and Regulatory frameworks developed and promoted and scaled in order to create an enabling environment for the implementation of climate risk management and adaptation interventions.

iv) Capacity to mainstream climate change and management of climate risks for various land use systems by national scientists, agriculturalist, environmental experts and policy makers developed.

Expected Outcomes of the interventions:

i) Implemented country development plans embrace, adopt and mainstream climate change impacts at national and regional/county levels

ii) Improved incomes and livelihoods in semi-arid regions through yield increases in crop-livestock production systems, reduced crop and livestock losses and reduced greenhouse gas emissions as a result of implemented adaptation and mitigation measures for climate change.

iii) Action plans on climate risk management and adaptation interventions implemented in project countries.

iv) Trained national scientists, agriculturalists, environmental experts and policy makers mainstream and implement climate change and management of climate risks for various land use systems in project countries.

Expected impact:

i) Impact on livelihood: Improved household incomes and livelihoods, improved national GDPs. The ultimate beneficiaries are resource poor farmers and other members of the rural and peri-urban poor associated with the agricultural sector. These benefits will be realized through reduced vulnerability, raised adaptive capacity and higher income.

ii) Impact on food security benefits on rural and urban populations, and

iii) Impact on environmental health and carbon storage at both local on global public goods.

iv) Although the notion of securing win-win-win outcomes for these dimensions is appealing (Global Donor Platform 2009; FAO 2009a), we have to recognize the possibility of trade-offs among these dimensions (Campbell, 2009; FAO, 2011)

Proposed theory of change

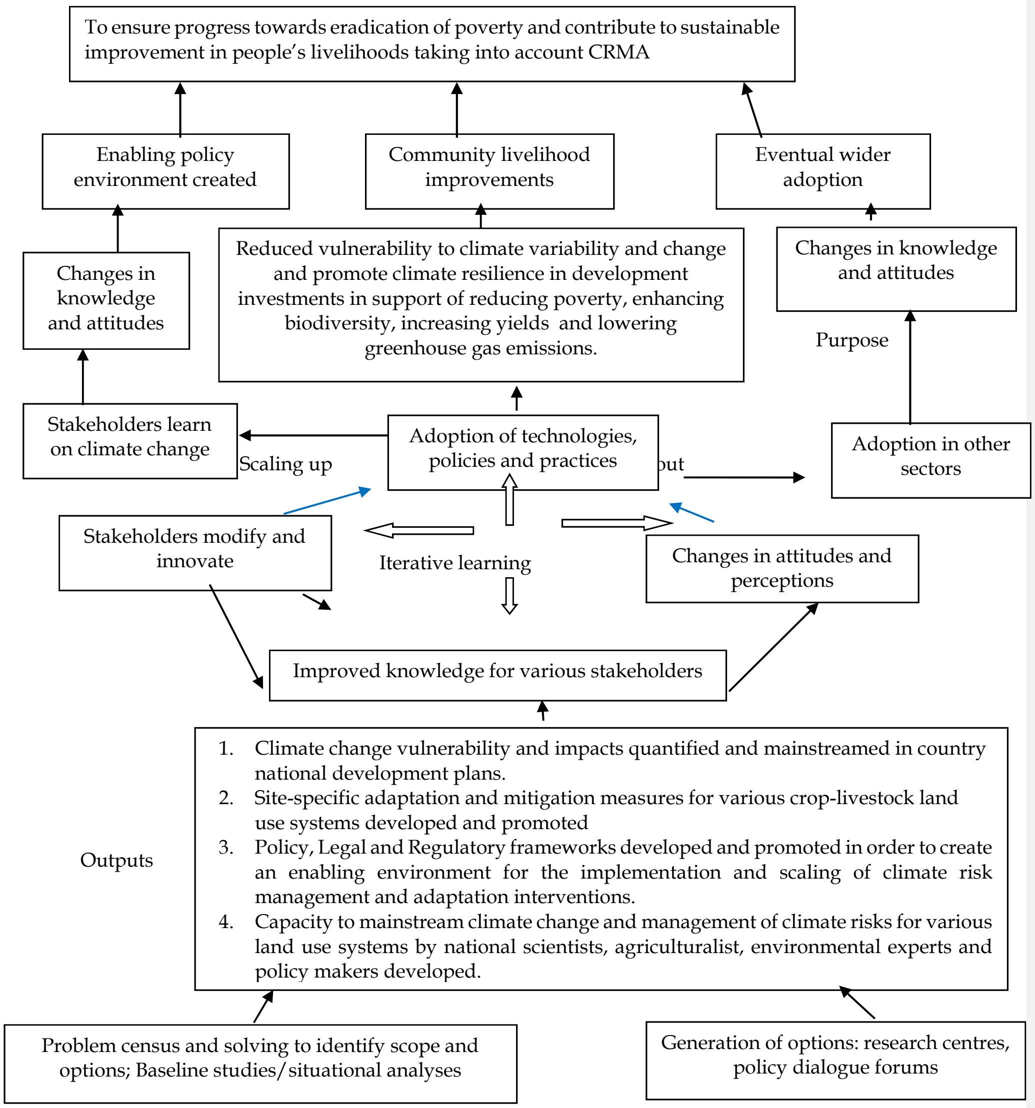
Reduced vulnerability to climate variability and change and promotion of climate resilience requires development of investments in support of reducing poverty, enhancing biodiversity, increasing yields and lowering greenhouse gas emissions. This will be achieved through the following preconditions. Firstly, the project will undertake a quantification of vulnerability to climate change, adaptation approaches and identify barriers to success mainstreaming of these adaptation measures in country national plans. This

will this include identifying key metrics of vulnerability in crop-livestock systems, rangelands, agricultural systems. Secondly, the formulated projects will need to develop, promote and scale climate change adaptation and mitigation measures for various crop-livestock, land use systems in arid and semi-arid areas. Thirdly the formulated projects will require to undertake activities that promote development of policy, legal and regulatory frameworks in order to create an enabling environment for the implementation of climate risk management and adaptation interventions. Finally the proposed projects will need to build capacity to mainstream climate change, manage climate risks for various land use systems as well as mainstream gender along selected agricultural product value chains.

Indicators for these preconditions which will be used to assess the performance of the interventions will be an inventory of vulnerable groups, adaptation approaches, and barriers to mainstreaming these approaches in sub-Saharan Africa. A wide range of climate change adaptation and mitigation measures will need to be promoted and scaled. These will include improved land use planning, improved agricultural practices that enhance soil carbon stocks, better livestock management, use of drought tolerant crops, improved irrigation and water use efficiency, and rain water harvesting. A set of policy documents will then need to be developed for the participating countries from which action plans will be generated and implemented. Researchers, extension workers, policy makers and other relevant stakeholders will be trained and then subsequently use this knowledge and share it with other parties to achieve project overall goal. Training will include simulation modeling, greenhouse gas emission measurements, carbon stocks measurements, and participation in carbon credits market for participating countries.

Expected Impact pathway

This is explained in the diagram below.



Partnerships

Building strong partnerships will form an essential component of implementing projects using this approach. Essentially, this may be worked out as consortia with complementary partnerships in order to ensure the long-term impact of this initiative and provide the greatest opportunity for knowledge transfer. Partners will include, but are not limited to:

i) Consultative Group of International Agricultural Research (CGIAR) Centres

ii) Non-governmental and community based organizations for rural development

iii) National agricultural research systems

iv) Ministries responsible for National Adaptation Programmes of Action (NAPAs)and Nationally Appropriate Mitigation Actions (NAMAs)

v) Regional clean development brokers

vi) Climate change Units

vii) Gender mainstreaming experts

viii) Private sector

ix) Development partners

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The effect of a dry agro-ecological zone on selected growth and yield parameters of three elite cassava genotypes grown in Mutomo Sub-County of Kitui County in Kenya

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Abstract

Communities in the drylands engage in different farm activities in attempting to make their economic ends meet. Such activities include growing of crops and trees to supplement returns from livestock rearing. The major impediment to agricultural production in the rangelands is lack of sufficient soil moisture and soil nutrients to make crops attain their physiological maturity. Cassava, a crop which is highly drought tolerant is ideal for such environments with sufficient soil moisture. Cassava has a very high potential of becoming a major source of carbohydrates and cash income to farmers in semi-arid regions and in high potential areas of Coast, Central and Western regions of Kenya. KARI-Katumani has bred cultivars tolerant to cassava mosaic disease and acceptable to farmers. Three promising cassava cultivars, EX-Mariakani, I 96/00067, and MM96/5280 were grown onfarm under rainfed conditions in October 2012 in Mutomo Sub-County in Kitui County. The cultivars were subjected to normal farmers' cultural practices. The cassava plants were harvested 12 months after planting and evaluated on selected growth parameters. Cultivar EX-Mariakani, had much taller plants, number of marketable tuberous roots, weight of mother stock and stems per plant, higher stay green ability and leaf retention scores than cultivars I 96/00067 and MM96/5280. Cultivar I 96/00067, though not significantly different, had much higher marketable tuberous roots yield than cultivars EX-Mariakani and MM96/5280. The three cultivars had a moderate cassava mosaic disease infection and white scale infestation scores suggesting that they had similar qualities. Cassava cultivars, EX-Mariakani, I 96/00067, and MM96/5280 performed well in this dry agro-ecological zone and their multiplication and distribution to farmers in Mutomo should continue aggressively. EX-Mariakani seems to have more superior drought tolerance capability than I 96/00067, and MM96/5280.

Keywords: cassava seed systems; food security crop; mitigating crop failure, climate change; adaptation; semi-arid, drought prone food deficit areas.

Introduction

According to Keya *et al*. (2006) communities in the drylands engage in different farm activities in attempting to make their economic ends meet. Such activities include growing of crops and trees to supplement returns from livestock rearing (Carlos 2004; Itabari *et al*. 2004). Keya *et al*. (2006) noted that the major impediment to agricultural production in the rangelands is lack of sufficient soil moisture and soil nutrients to make crops attain their physiological maturity. As such, in order to improve crop and tree production in these areas, sustainable improved sustainable onfarm water harvesting and storage methods and integrated soil fertility management programmes are required in order to mitigate effects of drought. Cassava (Manihot esculenta Crantz) is grown widely throughout East Africa and is a major source of calories and cash income to farmers in Coast, Central and Western regions of Kenya and has high potential in the arid and semi-arid regions (EARRNET, 1998; Githunguri, 1995). Cassava has become an important staple food with high potential for livestock and industrial uses in East Africa (EARRNET, 1998). Constraints to cassava production in Kenya include cassava mosaic disease, green mite, bacterial blight, mealybug, lack of adequate disease and pest free planting materials, poor cultural practices, presence of high levels of

cyanogenic glucosides in some cassava clones (Githunguri, 2006; Lusweti *et al.,* 1997), lack of planting materials and markets (Githunguri *et al.,* 2008). While cassava mosaic disease causes appreciable cassava yield reduction, the presence of hydrocyanic acid lowers the quality of cassava roots and has been the major reason for rejection of cassava cultivars in Eastern Kenya. Communities in Eastern Kenya eat either raw or boiled cassava (Githunguri, 1995). KARI-Katumani has bred cultivars tolerant to cassava mosaic disease and acceptable to end-users (Githunguri *et al*, 2003). As such, it was deemed necessary to use some of these cassava cultivars to mitigate the rampant food insecurity in the arid and semi-arid areas. The objective of this work was to subject some of the elite cassava cultivars and clones to participatory field evaluation, multiply and distribute the best to farmers within Mutomo sub-county in Kitui County and other selected semi-arid areas.

Materials and methods

Three promising cassava cultivars, EX-Mariakani, I 96/00067, and MM96/5280 were grown onfarm under rainfed conditions in October 2012 in Mutomo Sub-County in Kitui County. The cassava cultivars were planted in non-replicated plots of 15m x 15m in eight farms. The cultivars were subjected to normal farmers' cultural practices. The cassava plants were harvested in October 2013 and evaluated on selected growth parameters. The exercise was conducted under the guidance of research staff. The selected growth parameters included plant height (cm), number and weight (Kg) of marketable and unmarketable tuberous roots, and weight (Kg) of mother stock and stems per plant. Stay green ability and leaf retention were evaluated using a scoring scale of 1- 5 where 1, 2, 3, 4 and 5 represented very good, good, moderate, poor and very poor, respectively. Cassava mosaic disease infection and white scale infestation were evaluated using a scoring scale of 1- 5 where 1, 2, 3, 4 and 5 represented no apparent, mild, moderate, severe, and very severe field symptoms seen, respectively. The data collected was subjected to analysis of variance using the method described by Gomez and Gomez (1984) and the treatments means were separated using the Least Significant Difference (LSD) test using the SAS statistical package (SAS 1990).

Results and discussion

According to Tables 1, 2 and 3, even though the differences were not statistically significant, cultivar EX-Mariakani, had much taller plants, number of marketable tuberous roots, weight of mother stock and stems per plant, higher stay green ability and leaf retention scores than cultivars I 96/00067 and MM96/5280. According to Table 3, cultivar I 96/00067, though not significantly different, had much higher marketable tuberous roots yield than cultivars EX-Mariakani and MM96/5280. Table 4 shows the three cultivars had a moderate cassava mosaic disease infection and white scale infestation scores suggesting that they had similar qualities.

Table 1: The effect of a dry agro-ecological zone on selected growth parameters 12 months after planting of three elite cassava genotypes grown in Mutomo Sub-County of Kitui County in Kenya during the 2012 -2013 cropping season

Treatment	Plant height (cm)	Stay Green Ability	Leaf Retention Score
EX-Mariakani	73.3	2.75	3.0
I 96/00067	50.8	2.00	2.0
MM96/5280	46.6	2.00	2.0
Means	56.9	2.25	2.0
E.S.E.	9.19	0.323	0.5
S.E.D.	13.00	0.456	0.6
LSD	31.81	1.117	1.6
S.E.	18.39	0.645	0.9
CV (%)	32.3	28.7	39.3

Table 2. The effect of a dry agro-ecological zone on number of marketable and unmarketable tuberous roots 12 months after planting of three elite cassava genotypes grown in Mutomo Sub-County of Kitui County in Kenya during the 2012 -2013 cropping season

Treatment	Number of marketable tuberous roots	Number of unmarketable tuberous roots
EX-Mariakani	7.25	4.0
I 96/00067	5.25	5.0
MM96/5280	4.75	5.0
Means	5.75	4.0
S.E.D.	2.173	1.6
E.S.E.	1.537	1.1
LSD	5,317	3.9
S.E.	3.073	2.3
CV (%)	53.4	51.5

Table 3: The effect of a dry agro-ecological zone on yield parameters 12 months after planting of three elite cassava genotypes grown in Mutomo Sub-County of Kitui County in Kenya during the 2012 -2013 cropping season

Treatment	Weight (Kg) of marketable tuberous roots	Weight (Kg) of unmarketable tuberous roots	Weight (Kg) of mother stock / plant	Weight (Kg) of stems / plant
EX-Mariakani	2.2	0.9	0.6	3.0
I 96/00067	3.9	1.2	0.4	2.5
MM96/5280	1.8	1.5	0.4	2.5
Means	2.6	1.2	0.4	2.7
E.S.E.	0.88	0.59	0.17	0.20
S.E.D.	1.25	0.83	0.24	0.28
LSD	3.06	2.03	0.59	0.69
S.E.	1.77	1.17	0.34	0.40
CV (%)	67.7	100.1	76.9	14.9

Table 4: The effect of a dry agro-ecological zone on cassava mosaic disease infection and white scale infestation scores 12 months after planting of two elite cassava genotypes plants grown in Mutomo Sub-County of Kitui County in Kenya

Treatment	Cassava mosaic disease infection score	Cassava white scale infestation score
EX-Mariakani	3	3.0
I 96/00067	3	3.3
MM96/5280	3	3.0
Means	3	3.1
E.S.E.	0.4	0.1491
S.E.D.	0.6	0.2108
LSD	1.5	0.5419
S.E.	0.9	0.2981
CV (%)	30.5	9.6

This means that three cassava cultivars, EX-Mariakani, I 96/00067, and MM96/5280 seem to be performing well in this dry agro-ecological zone and their multiplication and distribution to farmers in Mutomo should continue aggressively. Special attention should be given to EX-Mariakani which seems to have more superior drought tolerance capability than I 96/00067, and MM96/5280. There is need to investigate further the culinary differences if any, between the three cultivars.

Conclusions

Cultivar EX-Mariakani seems to be more drought tolerant than the improved I 96/00067, and MM96/5280. Its multiplication and distribution to farmers in Mutomo should continue aggressively. There is need to investigate further the culinary differences if any, between the three cultivars.

Recommendations and way forward

It is important to involve farmers in varietal evaluation and selection right from the start. Breeders should consider incorporating the highly desirable culinary qualities in local cultivars in the high yielding early maturing disease resistant improved clones in order to accelerate adoption of improved cultivars. There is need to multiply the three cultivars and distribute them to farmers in Mutomo and other areas in semi-arid eastern Kenya.

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Cassava farming transforming livelihoods among smallholder farmers in Mutomo a semi-arid district in Kenya

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Abstract

Purpose - To assess the impact the introduction of elite cassava had on the livelihoods of participating farmers in Mutomo using photography and focused group discussions. Design/methodology/approach - Included literature review, interviews, photography, physical observations, and focussed group discussions. Findings - The study established that climate change is real and has negatively affected smallholder farmer families in Mutomo and as such it was prudent to introduce drought tolerant crops like cassava in order to improve food security as a climate change adaptation technology. It was evident the elite cassava varieties from KARI were supplying the much needed carbohydrates in an affordable form. The assessment also established water scarcity is a major development-limiting factor in Mutomo that needed urgent attention. The Mutomo community had shed "Mwolyo" the hand-out mentality through adoption of appropriate technologies for this place like growing, processing, marketing, and consumption of cassava. Cassava roots were mainly marketed as fresh roots for chewing and boiling. Cassava cuttings and cakes on sale in the Mutomo market suggested that demand for cassava was rising and only need upscaling. Being dominated by agro-pastoralists, it was obvious that cassava and other crops that take more than four months before being harvested do not fit well into the system and this is an area that has to be addressed to pre-empt potential conflicts. Originality/value -This is the first case study based article that focuses on the potential of using cassava as a drought mitigating crop in Mutomo a semi-arid area in Kenya

Key words: Cassava, climate change, adaptation, semi-arid areas.

Introduction

Cassava (Manihot esculenta Crantz) produces about 10 times more carbohydrates than most cereals per unit area, and are ideal for production in marginal and drought prone areas, which comprise over 80% of Kenya's land mass (Githunguri *et al.*, 1998; Githunguri, 2002; Nweke *et al.*, 2002). A cassava plant possesses several growth parameters and physiological processes which can be used to measure its ability to produce adequate yield under various abiotic and biotic stresses (Ekanayake *et al.*, 1997a; Ekanayake *et al.*, 1997b; Ekanayake, 1998; IITA, 1982, 1990a; Osiru *et al.*, 1995). According to these authors, some of these parameters include long fibrous roots, shedding of leaves, leaf area index, leaf water potential, moderate stomatal conductance, transpiration rate, water use efficiency, crop growth rate and dry matter accumulation in the tuberous roots. Cassava can reach its production potential only where the attributes of the environment best match the crop requirements. Breeding and selection of varieties according to prevailing environmental characteristics can ensure optimal performance (IITA, 1990b).

The cassava commodity system has four main components: production, processing, marketing and consumption. Linking them is the key to successful cassava products development. Strong ties with both

public and private institutions engaged in research, extension and social development are essential in the accomplishment of this linkage. The exact character of these linkages will vary according to the stage of the project in technology generation and transfer (Githunguri *et al.,* 2006). Plant breeders can contribute to better productivity and quality, agronomists to improvements in cultural practices and cropping systems, and agro-ecologists to the proper analysis of resource management issues. In order to enhance the commercial achievement of Economic Recovery Strategy (ERS) goals, the Government of Kenya in collaboration with development partners has established the Kenya Agricultural Productivity Project (KAPP) (Ministry of Agriculture (MoA), 2005). The KAPP uses thematic concepts with demonstrative multi-sectoral approach to address agricultural challenges. In this regard, the cassava value chain project was funded by KAPP to enhance cassava production, processing and marketing in Kenya and beyond our borders, especially the Common Market for Eastern and Southern Africa (COMESA) region and Europe (Kadere, 2002; Mbwika, 2002). In Eastern Kenya cassava is eaten either raw or boiled (Githunguri, 1995). Despite its great potential as a food security and income-generating crop among rural poor in marginal lands, its utilization remains low. The potential to increase its utilization is enormous with increased recipe range (Githunguri, 1995) and provision of adequate clean planting material. One of the major constraints to cassava production in the arid and semi-arid areas includes lack of adequate disease and pest free planting materials (Obukosia *et al.,* 1993) exacerbated by the slow multiplication rates of 1:10. KARI-Katumani has bred cultivars tolerant to cassava mosaic disease and acceptable to end-users (Githunguri *et al*, 2003) whose multiplication and distribution is being attained through irrigation. Other constraints to cassava production in Kenya including semiarid eastern include lack of adequate disease and pest free planting materials, poor cultural practices, lack of appropriate storage and processing technologies, poor market infrastructure (Githunguri and Migwa, 2003; Lusweti *et al.,* 1997). KARI-Katumani has developed cassava varieties that are widely adapted to diverse agro-ecological zones, high yielding, early bulking, drought resistant/tolerant, resistant to major biotic and abiotic stresses and have good root quality (Githunguri *et al.,* 2003; Githunguri, 2004). KARI-Katumani has recognized the importance of involving farmers in their selection and breeding research programmes as suggested by Bellon (2001) and Fliert and Braun (1999). One of the objectives of this project was to establish demonstration plots and select entrepreneurial farmers for commercial cassava planting material multiplication and distribution to farmers in semi-arid Eastern Kenya in a bid to improve food security as a climate change adaptation technology. Mutomo district situated in Kitui County in semi-arid Eastern Kenya was one of the areas that were selected for the establishment of a cassava seed system.

Materials and methods

Cassava agronomic demonstrations, seed multiplication and distribution programmes were established in order to assure processors of a steady supply of tuberous roots. To ensure sustainable supply of planting materials, farmers who were willing to grow cassava on at least a quarter of an acre of their farm were selected to participate in planting materials multiplication and distribution in the selected project sites, Kibwezi (Kwa-Kyai), Mukuyuni, Mutituni, Matiliku, and Mutomo. Elite cassava cultivars grown under sprinkler irrigation at KARI Masongaleni and Kiboko Sub-Centers situated in Kibwezi and Makindu districts were harvested and distributed to several farmers who had shown interest in growing cassava in the project sites. In 2009, Revitalization of Indigenous Initiatives for Community Development (RINCOD), a local non-governmental organization carried out needs assessments in Mutomo. During these assessments, community groups agreed to start the Mutomo Cassava Production and Processing Association (MUKAPA). The project involved more than 100 households and over time, it has established high-yielding, disease and drought-resistant cassava varieties developed by the Kenya Agricultural Research Institute (KARI). During project initiation, the community selected three farms for cassava propagation and planted 10,000 cuttings on each with support from RINCOD and KARI. From these three farms, all the 100 members were then supplied with cuttings. During the last quarter of year 2012 and 1st quarter of 2013, A team of journalists, extension and research officers went out on a fact finding tour to assess the impact the introduction of elite cassava had on the livelihoods of participating farmers in Mutomo using photography and focussed group discussions.

Results and Discussions

The use of the elite cassava varieties has had several benefits among the Mutomo community. Figure 1 shows the Mutomo Meteorological Officer collecting dairy weather data. According to the officer, they are mainly concerned with temperature, armyworm, and rainfall data. Rainfall in Mutomo is scarce and erratic, while temperatures are generally high and the area prone to armyworm infestations especially during good seasons and that is why it is crucial to monitor these parameters.

Figure 1: Mutomo Meteorological Officer collecting (i) Max. Temperature, (ii) Armyworm, and (iii) rainfall data

A team of journalists, extension and research officers visited a typical Mutomo farmer's homestead to get a first-hand experience of what he/she goes through in a normal day (Figure 2). This farmer like most others has been growing maize and beans religiously season after season despite frequent crop failures. Changing the farmer's attitude towards the growing of these crops is a major challenge in tackling food insecurity in this area. Like the pictures depict, poverty levels and food insecurity are very high. The empty granary is a constant and stark reminder of the frequent crop failures that have occurred in that area since year 2003. The owner of this homestead works as a night guard in Mutomo town and as such he had been able to install a small solar panel that is able to light four bulbs and run a small radio. Learnt climate change is real and has negatively affected Mutunga's family. It was sad to see the farmer's abandoned empty granary due to climate change since year 2003. The team realized how lucky the farmers in high potential areas are and the urgency there is in creating awareness among them about the utter need for them to preserve, conserve and improve their environment jealously. There is real need to introduce drought tolerant crops like cassava in this area if food insecurity is going to be addressed.

Figure 2: Mutunga's homestead (i and ii) and a (iii and iv) granary which has been empty for several failed seasons since year 2003– this is typical of a smallholder farmer in Mutomo who has been growing maize and beans

Figure 4 shows the beginning of a typical day of a smallholder farmer in Mutomo. The farmer and his family which included the family cat were enjoying boiled cassava for breakfast. Due to the high poverty levels in the area the most of the farmers cannot afford to buy bread for breakfast. The family heartily shared the little cassava- breakfast which was really moving. The pictures suggest cassava is important in supplying the much needed carbohydrates in an affordable form. However, since this is a predominantly "boil and eat" society, it is important to introduce only low cyanogenic cassava cultivars. In addition, it is crucial to train cassava consumers on how to detoxify cassava through appropriate processing.

Figure 4: Mutunga enjoying cassava breakfast together with his grandchildren, son and family cat enjoying

After the farmer had taken cassava breakfast with his family the team walked to his main farm which was about 20 minutes away. During the walk the team of officers was able to observe other resident farmers going to fetch water in a common well situated near the farmer's main farm (Figure 5). Looking at the heavy traffic consisting of both livestock and human beings going to collect water at the same well, it was realized that water scarcity is a major development-limiting factor in this area that needs urgent attention. Figure 5 shows Mutunga's daughter in-law and other neighbours fetching water from a dry riverbed well situated 3 km away from their homestead. In this area the donkey is the preferred mode of transporting water from the communal wells. It was heartrending to watch a whole population including men, women, and children, and their livestock going for water in just one watering place where there was not enough of it. However, it was encouraging to realize that the community here was doing all it can to make ends meet and that they had shed "Mwolyo" the handout mentality through adoption of appropriate technologies for this place like growing, processing, marketing, and consumption of cassava.

Figure 5: Smallholder farmers fetching water in a communal well situated in a dry riverbed over 3 km away from most homesteads

Water scarcity in Kanzilu is a major challenge as is clearly evident from the pictures in Figure 6. Children and women scoop water from a typical shallow well in Kanzilu location in Mutomo for domestic use and for their donkeys, cows and goats. As is also evident getting clean water is also a major challenge. There is need to introduce project s that supply adequate clean water in this area alongside those addressing food insecurity. Transporting water and watering livestock in Kanzilu is a major occupation mainly conducted by women and children.

Figure 6: Children and women scoop water from a typical shallow well in Kanzilu location in Mutomo for domestic use and for their donkeys and other livestock

Water scarcity in Kanzilu, a village in Mutomo, is a major challenge in the lives of residents and has to be addressed through diverse approaches. According to Figure 7, cassava is a mitigating technology. The farmer's cassava farm had been maliciously grazed by goats which unless addressed is a major potential area for conflict between farmers and agro-pastoralists. It was difficult to understand why anybody in their right frame of mind would want to deliberately graze his goats on the farmer's farm. However, on the flipside this demonstrates the importance and resilience of cassava as a drought mitigating technology in Mutomo. The farming system in Mutomo is dominated by agro-pastoralists and it is apparent that cassava and other crops that take more than four months before being harvested do not fit into the system as farmers release their livestock to graze communally after maize has been harvested. This is an area that has to be addressed if cassava farming is going to be adopted. However, the farmers understand this and they fence the parts of their farms that have crops that take longer than four months to mature.

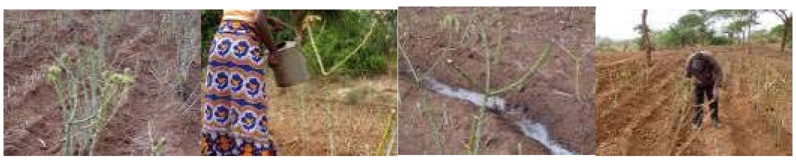

Figure 7: Watering cassava in Mutunga's farm in Kanzilu village in Mutomo which had been grazed and defoliated by goats maliciously belonging to agro-pastoralists

According to Figure 8, cassava was mainly marketed as fresh roots for chewing by men to improve their virility. Cassava cuttings were also on sale in the Mutomo market suggesting demand for cassava was rising. Cassava cakes were also on display in the market. The photographs suggest that cassava products were popular in Mutomo and that is why they were on sale. Cassava roots, cuttings, and cakes were on sale in the open-air market.

Figure 8: A typical day in Mutomo Market: (i) a vendor selling cassava & assorted fruits; (ii) cassava roots for chewing on sale; (iii) cassava stakes on sale; and (iv) cassava-based baked products on sale

At the Mutomo Bakery, cassava was being chipped, dried in a solar drier, milled and bread baked using the same flour mixed with wheat flour in various ratios. A loaf of cassava bread was retailing at K. Shs 42. Figure 9 shows a demonstration on how to make a cassava-based cake which has a ready market in Mutomo.

Figure 9: (i) Cassava cake ingredients; (ii) cassava cake dough being spread in the pot ready for baking; (iii) and (iv) cassava cake is finally ready for serving; and (v) Mutheu can hardly wait to taste the cassava cake

Conclusions and Recommendations

Climate change is real and has negatively affected smallholder farmer families in Mutomo. There is urgent need to introduce drought tolerant crops like cassava in Mutomo in order to address food insecurity. It was evident the elite cassava varieties from KARI have brought several benefits among the Mutomo community. Due to the high poverty levels in the area the most of the farmers cannot afford to buy bread for breakfast and as such cassava is important in supplying the much needed carbohydrates in an affordable form. Water scarcity is a major development-limiting factor in Mutomo that needs urgent attention. As such there is need to introduce projects that supply adequate clean water in this area alongside those addressing food insecurity. The Mutomo community was doing all it can to make ends meet and that they had shed “Mwolyo” the handout mentality through adoption of appropriate technologies for this place like growing, processing, marketing, and consumption of cassava. Cassava roots were mainly marketed as fresh roots for chewing by men to improve their virility. Cassava cuttings were also on sale in the Mutomo market suggesting demand for cassava was rising. Cassava cakes were also on display in the market suggesting that cassava products were popular in Mutomo and only need upscaling. The farming system in Mutomo is dominated by agro-pastoralists and it is apparent that cassava and other crops that take more than four months before being harvested do not fit well into the system as farmers release their livestock to graze communally after maize has been harvested. This is an area that has to be addressed to pre-empt potential conflicts. However, the farmers understand this and they fence the parts of their farms that have crops that take longer than four months to mature.

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Influence of agroclimatic conditions and fertilizer use on different pest mite management options in cassava production

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Abstract

Cassava production is reported to be constrained by low soil fertility, pests and diseases coupled with poor rainfall amount in Sub-Sahara Africa (SSA). In a study on the infuence of agro-climatic conditions, fertilizer use and inclusion of biological control agents in comparison with chemical control, it was found that environmental factors played a major role to root yield. Higher moisture led to increased beneficial predacious mites while fertilizer input increased final yield of the crop. Cassava green mite (CGM) Mononychellus progresivus Doreste management option choice depended on the prevailing agro-climatic conditions of the sites. The cool-wet site had the least pest spider mite pest and fairly moderate number of predacious mites with root yield being of the medium (28 t ha-1) while hot-dry conditions of the eastern lowlands had higher CGM numbers and subsequently the least yield weight (13 t ha-1). The highest leaf damage score of cassava was 3-4 severity level per leaf of the hot-dry eastern lowlands. The warm-humid coastal site plot had the least pest densities and highest predacious mites, subsequently with the highest yield of >30 t ha-1. Thus, environmental conditions fluctuations resulted to the pest and beneficial predacious mite population dynamics peaks and drop during the production period with the final root yield as the resultant product in relation to soil fertility and moisture inputs.

Key words: environmental conditions, biological, chemical, natural, yield, cassava.

Introduction

Cassava Manihot esculenta Crantz (Euphorbiaceae) production is usually constrained by low fertility levels, poor and low rainfall distribution amounts, and pests and diseases in most Sub-Sahara Africa (SSA) (Yaninek, 1994; Zundel *et al*., 2007; Ande *et al*., 2008). The East African cassava fields suffer similar conditions (Kariuki *et al*., 2005; Fermont *et al*., 2008). Improved genotypes have led to increased root yield with some farmers preferring to continue to grow their local cultivars. Of the various production constraints drought and low soil fertility levels have been pointed out as of priority (Fermont *et al*., 2009; Yaninek *et al*., 1989). Cassava production has been reported as being labour intensive when cost-benefits are analyzed yet some farmers' perception is that it is cheaper to cultivate cassava than cereals and legumes (Fermont *et al*., 2009). As reported elsewhere cassava research has mainly been on pests in the east African region with little comparison of other constraints and how much they contribute to the final root yield (Fermont *et al*., 2009; Hillocks, 2002).

Through classical biological control the cassava green mite Mononychellus progresivus Doreste pest has only been successively controlled in the warm-humid coastal region of East Africa and the region around Lake Victoria (Kariuki *et al*, 2005). With the present scenario of little consideration of the agronomic practices which lead to higher yield in relation to genotype potential, it was found important to study the effect of prevailing environmental conditions and evaluate management options where beneficial predacious mites were not present.

This study undertook to demonstrate the importance of agro-climatic conditions, soil fertility and biological agents for higher root yield.

Materials and methods

Study sites and inputs

Four study sites were established in Kenya to evaluate effect of fertilizer input, manure and acaricides on management of cassava herbivore pests in 2011-2012. The sites were at Kiboko (02° 12.872 S, 037° 42.960 E), Katumani (01° 34. 858 S, 037° 14.580 E), Embu (00° 31.642 S, 037° 28.971 E) and Mtwapa (03° 16.024 S, 04° 02.930 E), at agro-ecological zones LM5 (dry lowlands), LM4 (hilly midlands), UM2 (upper midlands) and CL3 (wet coastal lowlands), respectively. The predacious mites (biological agents) were introduced in the biological block when the crop was four months after planting. Spray regimes were carried out according to recommended rates of 25ml/20 liter water volume of Abamectin and Chloropyrifos 3 months after planting (MAP) and repeated after every two months up to harvest time at the end of the seven months of production period.

Soil fertility and property levels of the sites were taken at 0-20cm depth at the beginning of the experiment (Table 1). Mineral fertilizer NPK 17:17:17 was applied at 50kg ha-1 while manure subplots had 2.8t ha-1. The manure material nutrient values from cassava fodder and animal droppings used were as shown in Table 1. A control of No-fertilizer input was factored in for comparison as the farmer practice. The experiment was a complete randomized block design (CRBD) of biological (predacious mites), natural, convectional (Abamectin) and an insecticide (Chloropyrifos) as main plots. A local cultivar X-Mariakani was used throughout the study period with spacing of 1x1m. Treatment blocks had four-metre paths among themselves to reduce spillover effect. Site plot weeding was carried out according to requirement with Mtwapa (wet coastal) leading with six weeding while Katumani had the least of three weeding times.

Table 1: Soil and manure chemical properties at Katumani, Mtwapa, Kiboko and Embu plots (2011/12)

Site plot	pH	Macronutrients (g/kg)					Micronutrients (mg/kg)				Soil texture (%)		
		N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	Sand	Clay	Silt
Katumani	4.7	3.4	0.02	0.9	3.3	0.2	195.0	2.3	3.3	118.7	59	30	11
Mtwapa	4.9	1.9	0.01	0.1	1.7	0.1	57.8	0.1	3.3	80.7	69	30	1
Kiboko	7.4	1.6	0.04	0.2	1.5	0.3	0.2	0	0	-	61	18	11
Embu	6.7	3.1	0.01	0.5	2.0	0.4	0.2	0.0	0.0	1.64	42	56	2
*Manure	8.4	20.4	7.1	8.8	19.1	1.4	7.7	0	0	172.8	-	-	-

*Manure material composting ratio was 40:3:20 tons of goat, chicken droppings and cassava fodder ensiled in a pit for two months.

Data collection

Monthly monitoring of mite pests occurrence on cassava was observed in the study plots during plant development up to harvest. Pests and predacious mite numbers/leaf were scored from the fourth mature leaf of plant apices. The damage scored was taken from severity level of 1-5 (1=No damage score, 2: ≤25% leaf damage, 3: ≤50% damage, 4: ≤75% damage and 5:=100% wilted leaf) (Yaninek *et al.*, 1989). Cassava fresh root yield weight (kg) was taken on the seventh month. Monthly meteorological data of the years 2011-12 was availed by the meteorological station staff of Mtwapa, Katumani, Kiboko and Embu.

Data analyses

Analysis of variance was carried out to determine mean significance difference of yield weight (tons), and meteorological monthly data difference of the sites with GenStat Discovery 3 VSN (2010) software. Regression analysis effect of CGM numbers to yield fresh weight was explored with SPSS (2009).

Results

Prevailing climatic conditions

Monthly mean rainfall (mm) was highest in Embu (127.0 mm), followed by Mtwapa (106.8 mm) during the production period of 2011 (Table 2). Kiboko (supplemented with 960 mm of irrigation water) had the least amount of rainfall of 64.0 mm. Mean monthly temperature was highest in Mtwapa (26.8° C), followed by Kiboko site with 24.8° C. Relative humidity was highest at Mtwapa site (77.3%) of the warm-humid site. While Embu of the eastern midlands was described as cool and wet, the rest of eastern sites of Kiboko and Katumani were hot-dry in respect to mean monthly temperatures and rainfall amounts. All the three considered agro-climatic conditions were significantly (P<0.001) different at the four sites. Rainfall amount was lower in 2012 production period at the four sites but temperature and relative humidity regimes were closely similar to the previous year.

Table 2: Site plot climatic conditions during study months in the years (2011-12)

ear	Site	GPS	rainfall (mm)	Temp (°C)	RH (%)	Description
2011	Kiboko	02° 12' 872 S 037° 42' 960 E	64.0a + I*	24.8a	82.9a	Hot, dry
	Katumani	01° 34' 858 S 037° 14' 580 E	69.5a	19.5b	64.1b	Warm, dry
	Embu	00° 31' 642 S 037° 28' 971 E	127.0b	17.2c	63.4b	Cool, wet
	Mtwapa	03° 16' 024 S 040° 02' 930 E	106.8b	26.8d	77.3c	Hot, wet
	P		<0.001	<0.001	<0.001	
2012	Kiboko	02° 12' 872 S 037° 42' 960 E	42.7a +I*	23.6a	83.9a	Hot, dry
	Katumani	01° 34' 858 S 037° 14' 580 E	41.7a	19.9b	58.6b	Warm, dry
	Embu	00° 31' 642 S 037° 28' 971 E	119.6b	17.7c	63.8c	Cool, wet
	Mtwapa	03° 16' 024 S 040° 02' 930 E	104.7b	26.6d	76.0d	Hot, wet
	P		0.016	<0.001	<0.001	

Mean parameter (rainfall, temperature and relative humid) across columns were significantly different (P<0.05) of 5% significant level (Fishers Least Significant Difference) at the sites. Kiboko plot had supplementary irrigation (+I*) of 960mm for the seven months production period

Pest and predacious mite infestations

Cassava green mite (CGM) pest in the sites was significant (P<0.001) in 2011 production period (Table 3). Kiboko led with the highest number of 128.1, 119.4 mites per leaf for NPK and manure subplots, respectively. The subsequent leaf damage score (DS) was highest at Kiboko of 3 (for NPK and manure) and Katumani 2, 3 severity levels for NPK and manure, respectively. Highest number of predacious mites was at Mtwapa, 11.9 and 8.7mites/leaf for NPK and manure subplots, followed by Kiboko subplots of NPK and manure with 5.2 and 6.3mites/leaf respectively, in the same production period.

The following year (2012) CGM densities were highest at Kiboko of 90.1 and 78.2 mites /leaf of NPK and manure subplots followed by Katumani of 64.3 and 59.2 of similar fertility plots. The least CGM numbers were scored at Embu of 4.0 and 3.2 mites/leaf for NPK and manure subplots. Damage score was highest at Katumani and Kiboko of 3 and 4 severity levels. Predacious mite numbers were highest at Mtwapa (10.2) and Kiboko of 8.2 mites/ leaf.

Effect of soil fertility on yield

It was observed that manure and mineral (NPK 17:17:17) fertilizers significantly (P<0.05) increased yield of cassava root at Kiboko, Embu and Mtwapa in 2011 (Table 3). The highest root yield among the sites was realized at Kiboko of 34.2 t ha-1 on manure subplot of the Chloropyrifos insecticide treatment plot. The second highest yield (33.0 t ha-1) was from the same Kiboko site of the subplot of NPK (17:17:17) fertilizer. Mtwapa plot of the coastal site followed with 31.5 t ha-1 for the manure subplot of the biological control management. Katumani site had the least root yield of 8.1 t ha-1 of No-fertilizer subplot and of the natural pest control management option. During the production period of year 2012, Mtwapa and Kiboko site plots led with the highest root yield of 35.6 t ha-1 of NPK (17:17:17) subplot of the same Chloropyrifos treated main plot. The least yield was realized at Katumani No-fertilizer subplot of 13.2 t ha-1 of the natural pest control management option.

Effect of pest management option on yield

At Kiboko site, significant (P<0.05) yield difference was realized from the main plot under insecticide Chloropyrifos treatment plot leading with 34.2 t ha-1 for the manure subplot in 2011 (Figure1). Further, the Abamectin treated plot at the same hot-wet Kiboko site followed with 33.0 t ha-1 in the NPK subplot. The least yield was realized at the hot-dry Katumani plot of 13.1 t ha-1. Embu site of the cooler and wet region had significant yield (P<0.05) of 28.6 t ha-1 in the Chloropyrifos treatment where natural control option plot had 23.5 t ha-^{1}.

In 2012 the irrigated Kiboko and rain-fed Mtwapa site plots had a tie of significantly (P<0.001) highest yield of pest control treatment of Chloropyrifos of 35.6 t ha-1 (Table 4). Similarly, the drier Katumani site plot had significant (P<0.001) yield of 17.8 t ha-1 on the Chloropyrifos treatment compared to 13.6 and 12.3 t ha-1 of predacious mite (biological) and Abamectin treatments, respectively.

Table 3: Cassava green mite pest, predacious mites densities /leaf, damage score (DS) and the respective mean yield for each control option

Year	Site	AEZ	Fertilizer	Mites /leaf		DS	Yield (t ha-1) on different CGM control options			
				CGM	Predators	1-5	Biological	Natural	Abamectin	Chloropyrifos
2011	Kib.	LM5	NPK.17:17:17	128.1a	5.2ab	3a	30.0a	29.7a	33.0ab	29.9a
			Manure	119.4ab	6.3a	3a	32.1a	31.4a	30.7a	34.2ad
			No-fertilizer	109.1b	2.6abc	2b	29.2a	21.7b	27.3a	22.4b
	Kat.	LM4	NPK.17:17:17	65.2c	0.0c	2b	14.5b	15.2c	14.5b	13.4c
			Manure	77.3c	0.2c	3a	17.4b	17.3c	18.2b	15.5c
			No-fertilizer	47.2d	0.1c	2b	10.3b	8.1d	9.5b	10.0c
	Emb.	UM3	NPK.17:17:17	9.1e	5.1bc	1c	24.2c	26.8a	25.6c	28.6d
			Manure	5.2e	3.4bc	1c	26.6c	27.2a	27.2c	28.7a
			No-fertilizer	5.3e	3.8abc	1c	26.5c	23.5b	26.4c	26.6a
	Mtw.	CL3	NPK.17:17:17	13.4e	11.9d	1c	28.4a	22.0b	28.2a	25.3a
			Manure	13.0e	8.7e	1c	31.5a	27.6b	31.2a	29.2a
			No-fertilizer	16.0e	11.6d	1c	24.8ab	24.1a	24.6b	18.6c
		SED, P		6.6, <0.001	1.2,<0.001	0.3,0.003	5.0,0.063	2.4,0.001	3.7, 0.010	3.5, 0.002
2012	Kib.	LM5	NPK.17:17:17	90.1a	7.3a	2a	32.2a	31.9a	33.8a	35.6a
			Manure	78.2a	7.8a	3b	34.3a	30.5a	33.2a	34.3a
			No-fertilizer	68.0a	8.2a	4c	26.42b	28.6a	29.2a	29.1a
	Kat.	LM4	NPK.17:17:17	64.3b	0.2b	4c	14.1c	15.1b	14.0b	15.0b
			Manure	59.2b	0.0b	3b	16.5c	13.8b	17.2b	15.2b
			No-fertilizer	55.4b	0.1b	2a	13.6c	13.2b	12.3b	17.8b
	Emb.	UM3	NPK.17:17:17	4.3c	3.2cd	2a	25.1b	26.0c	27.7c	28.6c
			Manure	3.2c	4.1c	1d	26.3b	25.5c	26.2c	26.2c
			No-fertilizer	4.0c	2.5cd	1d	25.3b	24.4c	25.2c	27.9c
	Mtw.	CL3	NPK.17:17:17	10.2c	10.2e	1d	29.4b	31.4a	32.1a	35.6a
			Manure	8.1c	9.3e	1d	33.1b	30.2a	34.3a	34.4a
			No-fertilizer	12.3c	7.4a	2a	29.2b	29.5a	29.2a	29.8a
		SED,P		4.5, <0.001	0.6, 0.018	0.6, 0.018	2.6,0.001	2.0, 0.004	2.8, 0.001	2.5, <0.001

Similar letters across columns denote no significant (P>0.05) difference of the parameter (Fishers Least Significant Test)

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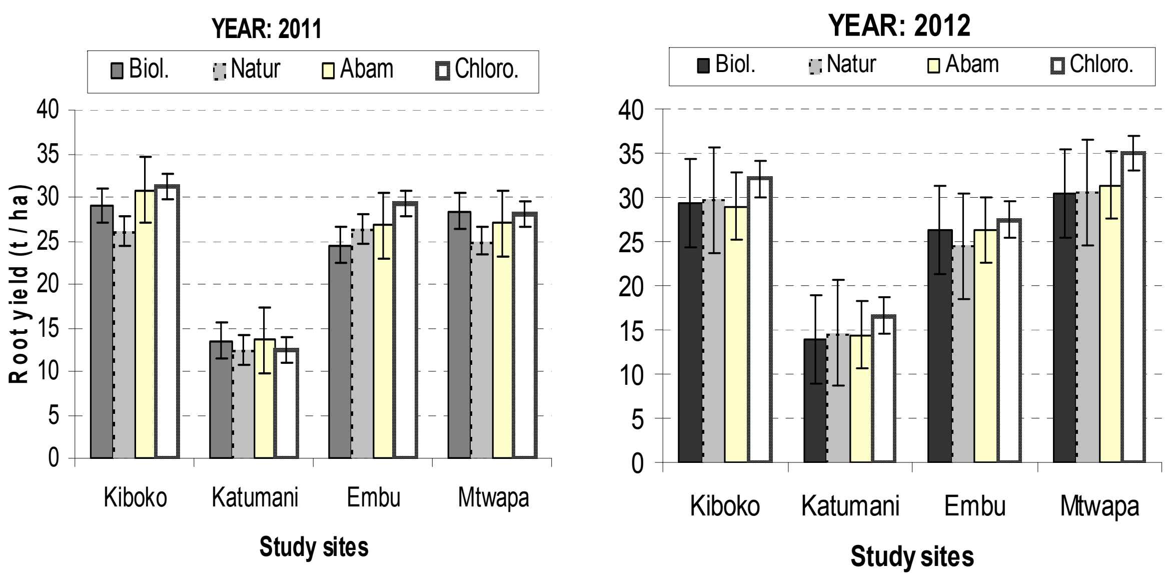

Figure 1: Mean (± SE) Yield difference at the study site plots under various pest management methods; Biol.(biological), Natur (natural), Abam (Abamectin) and Chloro (Chloropyrifos)

Cassava green mite densities effect to yield

Regressing CGM density numbers to fresh yield weight (t) under specific management options at the various sites demonstrated that the pest had negative effect to the root weight (Table 4). Yield was significantly (t-values, $P<0.05$) correlated to CGM numbers in 2011 Kiboko, Katumani, Embu and Mtwapa. In 2012, plots in Embu and Mtwapa had some effect of CGM densities to fresh root yield.

Table 4: Regression effect of CGM densities to yield on the various control options in Kenya (2011-12)

Site /description	Control option		2011	2012
Kiboko (hot, dry)	Biological	Slope	24.7	70.2
		t-value	2.4	5.0
		P	0.054	0.125
	Natural	Slope	21.9	51.3
		t-value	2.9	8.3
		P	0.022	0.076
	Acaricide	Slope	33.0	47.8
		t-value	21.8	6.8
		P	0.000	0.093
Katumani (warm, dry)	Biological	Slope	16.2	16.0
		t-value	7.9	2.5
		P	0.000	0.243
	Natural	Slope	15.5	5.6
		t-value	5.5	0.528
		P	0.001	0.091
	Acaricide	Slope	21.9	34.9
		t-value	14.6	3.5
		P	0.000	0.182
Embu (cool, wet)	Biological	Slope	24.2	30.1
		t-value	5.8	9.8
		P	0.001	0.065
	Natural	Slope	32.5	52.3
		t-value	8.4	13.4
		P	0.000	0.047
	Acaricide	Slope	24.2	34.9
		t-value	5.8	3.4
		P	0.001	0.181
Mtwapa (warm, wet)	Biological	Slope	43.6	27.5
		t-value	3.1	26.6
		P	0.018	0.024
	Natural	Slope	32.6	32.6
		t-value	24.5	24.6
		P	0.026	0.026
	Acaricide	Slope	35.1	13.5
		t-value	6.7	1.7
		P	0.000	0.335

Discussion

Influence of environmental factors

Farmers in most SSA countries grow cassava without application of any soil fertility or pest management input (Ande *et al*., 2008; Fermont *et al*., 2009; Yaninek *et al*., 1989). The drier lowlands of SSA bear the highest damage of the cassava green mite pest (Hillocks, 2002; Yaninek and Schulthess, 1993; Zundel *et al*., 2007). From the results of the present study both higher rainfall amounts and optimum temperature led to higher root yield with low leaf damage score at the study sites. Higher optimum temperature in the presence of increased moisture led to higher numbers of predacious mites. Increased predacious mites at the warm-humid (Mtwapa) and the hot-wet (Kiboko) sites were as a result of higher moisture as Mutisya *et al* (2011) demonstrated on the phytoseiid Typhlodromalus aripo De Leon. At the drier (Katumani) site plot, predacious mites were visibly low adding to higher densities of the pest mite and subsequently to lower yield (Yaninek *et al*., 1989; Kariuki *et al*., 2005). Manure or mineral fertilizers increased yield at all the sites (Ayoola, 2006; Amanullah *et al*., 2007). Where rainfall amounts / moisture content were high, higher soil fertility input increased the root yield five fold. These results indicated that in the wet agro-ecological systems cassava crop would give fairly higher yield even when no production inputs were applied as long as the agro-climatic conditions were conducive to the plant growth (Cock and Rosa, 1975; Connor *et al*., 1981). Cassava crop is reported to perform best within the temperature range of 25 to 29 °C (Cock, 1984). The lower yield in the cooler midlands regions of eastern upper hilly masses (Embu) of Kenya demonstrated this scenario (Cock and Rosa, 1975). From the results the optimum temperature, plus the increased rainfall amount (>1200mm) led to lesser CGM infestations and higher number of predacious mites (Yaninek *et al*., 1989; Amanullah *et al*., 2007). At foremost cassava requires optimum moisture then modest soil fertility within the optimum temperature range of >24<30 °C as reported by various workers of Asia and West Africa (Ande *et al*., 2008; Cock and Rosa, 1975; Alves, 2002). Kenya's varied agro-climatic conditions reflects similar results with the warm coastal strip of warm-wet conditions giving advantage to the beneficial predacious mites which eventually suppress the pest mites (Kariuki *et al*., 2005; Onzo *et al*., 2008; Yaninek *et al*., 1987). The sandy soils of the coastal region enabled fast deep root penetration for more nutrient adsorption hence the higher yield even when no fertilizer was applied. This plants ability to absorb deep-soil nutrients could explain why farmers' perception is that cassava does not require fertilizer as reported by various workers (Fermont *et al*., 2008, 2009; Ayoola, 2006). On the contrary cassava like any other crop, will always give higher root yield when fertility is adequate and within the range of optimum temperature and rainfall amounts (Howeler, 2002; Sanginga and Woomer, 2009).

Effect of various pest management options

Basic agronomic inputs are necessary for higher root yield (Hillocks, 2002; Alves, 2002). The present study has analyzed effect of various pest management options of CGM and found that there was difference in the final root yield across different pesticide treatment plots. The explanation from Yaninek *et al* (1989) is that while cassava suffers 10 to 30% dry matter loss from pest mites during dry period, it recovers 25 to 45% when sufficient rains return. Higher mortalities of the pest mites are realized with increased relative humidity regimes on the plant canopy (Bourdreaux, 1959). The predacious mites effectively lower pest mite densities below economic injury levels when optimum conditions of the latter prevail (Onzo *et al*., 2008; Mutisya *et al*., 2011). The different pest management methods of biological, chemical and cultural options indicated that the best bet management choice would depend on environmental considerations in specific agro-climatic conditions of the region. For the warm-wet coastal (Mtwapa) site no advantageous use of chemical (acaricide) control could be justified for use since the rainfall distribution and amounts kept the pest mites at low numbers and the beneficial predatory mite densities were higher than any other site and thus low leaf damage (Yaninek *et al*., 1989; Bakker, 1993). The effect of this was no yield difference for the biological and acaricide control options at the coastal site. The hot-dry site plot (Katumani, Kiboko) presented a situation where the pest mite densities were high, leading to higher leaf damage index of 3-4 severity levels and specifically low yield at Katumani where no irrigation supplement was applied. Consequently this hot-dry environment had higher pest numbers scored (Yaninek *et al*., 1987). Use of Abamectin spray positively reflected higher yield levels for inorganic and manure plots at the hot-dry sites.

The low pest mite numbers at the cool-wet site in the presence of abundant predatory mites justified no chemical spray in such agro-climatic conditions (Yaninek, 1994; Kariuki *et al.,* 2005). Thus, environmental conditions describe pest and predacious mite population dynamics during the production period.

Conclusions

These results demonstrate that cassava production constraint is mainly drought stress in the hot-dry regions which is aggravated by pest mite damage in the absence of reduced beneficial predatory mites. For the cool-wet site medium yield was mostly as a result of less optimum temperature regimes as an ecological requirement of the plant development. With increase of temperature and less rainfall amounts as a result of climate change phenomenon higher mite damage will be realized and subsequently lower root yield. The most important environmental factors deduced from the study were fertilizer and moisture (rainfall/irrigation) inputs for better plant health and higher final root yield.

Recommendation

This conclusively indicated that farmers in the warm-wet regions would continue getting higher yield with less plant leaf damage from pest mites. Further, government extension personnel within east Africa could be able to appropriately share information with farmers on the fact of the little benefits of spraying cassava green mite since environmental factors and beneficial predatory mites suppress the pest where rainfall amounts are high.

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Determinants of farmers' choice of technological options for adapting to climate variability: A case of eastern Uganda

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Abstract

Adaptation is considered an appropriate response to climate change and variability. Recent studies in climate research suggest the need to focus on adaptation research that seeks to investigate actual adaptations at the farm level, as well as the factors that appear to be driving them. Information on farmers' level empirical evidences is essential in informing policy and development strategies that attempt to boost farmers' adaptation to the changing climate. Based on this, the study uses the Heckman sample selectivity model to identify farmers' perception and adaptation to climate variability in Eastern Uganda. Adaptation to climate variability and change requires that farmers using traditional techniques of agricultural production first notice that the climate has altered, and then identify potentially useful adaptations or actions and implement them. Data for this study was obtained from 353 household interviews, 23 Key Informant Interviews and 9 focus group discussions drawn from three sample districts of Mbale, Pallisa and Sironko. This study shows that farmer's perception of rainfall adequacy or variation is significant in explaining farmers' decision to adopt adaptation technologies. Other factors that positively and significantly affect farmer's choice of adaptation technology are; gender of head of household, household size, and access to output markets. This study finds no significant relationship between technology adoption and extension services, unlike most studies. Yet, access to information showed positive relationship with technology adoption. The results underscore the need for appropriate weather information to guide decision making of which adaptation technologies to adopt, combined with farmers knowledge of changing climate. In addition, household socio-economic factors and access to markets should not be ignored in the design and implementation of adaptation measures. This can be supported by building social protection mechanisms at community level, or supporting households to build economic assets if labour is to be hired. Lastly, in provision of extension services, the mode of extension service delivery, the messages and the targeting is critical if extension is to contribute to technology adoption and subsequently increased agricultural productivity.

Key words: climate variability, adaptation, technology adoption, eastern Uganda.

Introduction

The agricultural sector in sub-Saharan African (SSA) continues to be confronted with multiple shocks and crises, threatening the endowment of the sector and impeding efforts at attaining the millennium development goals (MDGs), and core Comprehensive African Agriculture Development Programme (CAADP) pillars (Chuku and Okoye, 2009; World Development Report [WDR], 2009). Rainfall variability influenced by large scale inter-seasonal and inter-annual variability resulting in frequent extreme weather events is among the major risk factors affecting agricultural production and food security in the sub region (Christensen *et al.,* 2007; Easterling *et al.,* 2007; Haile, 2005).

Managing rainfall risk is important in agriculture not only for the direct impact that rainfall has on production, but also for the tendency of most farmers to be risk averse (Cabrera *et al.,* 2009). Risk aversion implies that farmers do not optimize their farm-plan for an upcoming season with average market and climate condition, instead, they continue to adopt conservative management strategies that reduce negative impacts in poor years, but at the expense of higher average productivity and profitability, inefficient use of

resources, and sometimes accelerated natural resource degradation (Rosenzweig and Binswanger, 1993; Zimmerman and Carter, 2003).

Impacts of climate variability on crop yields depend on both technological considerations and farmers' response to changing environmental conditions (Ruttan, 1996). Increasing observations emphasize the importance of managing climate risk to the optimization of crop/varietal choice especially in marginal areas (Di Falco *et al.,* 2006; Kurukulasuriya and Mendelsohn, 2006a), and farm income (Jones *et al.,* 2000; Kumar *et al*., 2004). Kassie *et al*. (2009) and Kato *et al*. (2009) demonstrated the importance of organic farming, and soil and water conservation techniques respectively as adaptation strategies to climate variability, in specific farming systems. In eastern Uganda, some of these and other crop and land management practices have been observed at farm level (Kansiime, 2012).

Except the few qualitative attempts made so far by Kansiime (2012) and Nabikolo *et al*. (2012), there has been no study undertaken in eastern Uganda to analyze factors affecting the perception and adaptation to climate change. However, any policy and development strategy that attempts to boost farmers' adaptation to the changing climate should be based on farmers' level empirical evidences. Recent studies also suggest the need to focus on adaptation research that seeks to investigate actual adaptations at the farm level, as well as the factors that appear to be driving them (Maddison, 2006). Based on this need, this study provides empirical evidence of the factors that influence farmers' choices of adaptation technologies in Eastern Uganda. This study uses the selection model assuming that farmers only make a choice to adopt adaptation technologies if they perceive change/risk associated with rainfall or climatic conditions.

Materials and methods

Study area and rationale

The study was carried out in eastern Uganda. The region comprises 32 districts in three distinct agro-ecological zones (Wortmann and Eledu, 1999). The AEZs are largely determined by the amount of rainfall, which drives the agricultural potential and farming systems and range from sub-humid to semi-arid (Global Resources Information Database [GRID], 1987). They also capture variability in altitude, soil productivity, cropping systems, livestock systems, and land use intensity.

The region is affected by climate change and variability, characterized by a combination of poverty, drought, floods and landslides, and natural resource degradation. All these challenges constrain crop production, increasing crop failure, leading to poverty. There is need therefore to develop options for adapting to climate variability and reducing its risk effects on agriculture, the key source of livelihoods for people in this region. To achieve this, factors conditioning farmer's adaptation options should be clarified first. This study selected this region with a view that the findings would add value to local communities, local stakeholders and government as they work towards ensuring effective adaptation.

A cross section of household survey of farmers was conducted in August-September 2012. The survey covered three districts, randomly selected, one from each of the agro-ecological zones. The sample districts that were selected, and included in this study are; Mbale, Pallisa and Sironko. Three hundred fifty three households were interviewed, 23 key informants and 9 focus group discussions involving 104 participants. Sample size was reached using coefficient of variation technique (Nassiuma, 2000).

Model specification

Analytical approaches that are commonly used in adoption decision studies involving multiple choices are the multinomial logit (MNL) and multinomial probit (MNP) models. Binary probit or logit models are employed when the number of choices available is two (whether to adopt or not). These models have been employed in climate change studies pertaining to the conceptual similarities in agricultural technology adoption and climate change. For instance, Nhemachena and Hassan (2007) employed the multivariate probit model to analyse factors influencing the choice of climate change adaptation options in Southern Africa. Other studies that analyze such joint endogenous decisions include use of multinomial logit model for crop selection (Kurukulasuriya and Mendelsohn, 2006a), livestock choice (Seo and Mendelsohn, 2006), and adaptation strategies (Hassan and Nhemachena, 2008).

When decision process by farmers to adopt a new technology requires more than one step, models with two-step regressions are employed to correct for the selection bias generated during the decision making processes (Heckman, 1976). For instance William and Stan (2003) employed the Heckman's two- step procedure to analyze the factors affecting the awareness and adoption of new agricultural technologies in the United States of America. Other studies employing the same methodologies include; Deressa *et al*. (2008), Kaliba *et al*. (2000), Kurukulasuriya and Mendelsohn (2006b), Maddison (2006), and Yirga (2007).

This study used the Heckman's two- step probit model to analyze factors determining farmers' choice of adaptation technologies. For model estimation, the first step involved analysis of perceptions of climate variability (selection model) and the second step is adoption of adaptation technologies, conditional on the first stage of perceived change in climate (outcome model). The probit model for sample selection assumes that there exists an underlying relationship between the selection and outcome models given by:

$Y1 = b'X + U1$

$Y2 = g'Z + U2$

Where, X is a k-vector of regressors, Z is an m-vector of repressors; the error terms U1 and U2 are jointly normally distributed, independently of X and Z with zero expectations. The independent variable Y1 is only observed if $Y2 > 0$. Thus the actual dependent variable is:

$Y = Y1$ if $Y2 > 0$, Y is a missing value if $Y2 \leq 0$

The latent variable Y2 itself is not observable, only its sign. $Y2 > 0$, if Y is observable, and $Y2 \leq 0$ if not. If the sample selection problem is ignored and Y regressed on X using the observed Y's only, then the Ordinary Least Squares (OLS) estimator of b will be biased, because:

$E[Y1 | Y2 > 0, X,Z] = b'X + rsf(g'Z)/F(g'Z)$

Where F is the cumulative distribution function of the standard normal distribution, f is the corresponding density, s2 is the variance of U1, and r is the correlation between U1 and U2. When $r \neq 0$, standard probit techniques yield biased results. Thus, the Heckman probit model provides consistent, asymptotically efficient estimates for all parameters in such models (StataCorp, 2003).

Model variables estimation

Dependent variables. The model considered two dependent variables one for the outcome equation (Adaptation options) and the selection equation (perception of climate variability). In estimating adaptation options, farmers were asked if they had adopted any specific actions to sustain their crop in the field based on perceived climate variability. The study estimated a dichotomous choice model for technology adoption, TAD, where TAD = 1 if farmers reported to have adopted one or more technologies in response to CV, and TAD = 0 otherwise.

To estimate farmers' perceptions, farmers were asked whether they have observed any change in rainfall pattern; and their perception of rainfall adequacy in the preceding agricultural season (August –November 2010, the base season for this study). Questions on rainfall adequacy included; whether rain came and stopped on time, whether there was enough rain at the beginning and during the growing season and whether it rained at harvest time. The responses for these questions were dichotomized in such a way that those who respond "on time" coded into one and others (early /late) into zero.

Explanatory variables

The variables hypothesised as affecting adoption of adaptation technologies (outcome model) included; the household's endowment of human capital (gender, age, education of household head, size of household), physical capital (land, livestock), and financial capital (household income, off farm income); institutional factors (extension on crop and livestock, use of credit, access to weather information and distance to input and output markets), and rainfall variables. The agro-ecological zone where the household is located is also added to control for the possibility that more favourable zones might be more likely to adopt some new technologies. The AEZs are represented by the three sample districts – Mbale,

Pallisa and Sironko (Table 1). In the following, the variables are described and the researcher's a prior expectation about their relationship to the dependent variables.

Table 1: Summary statistic for study variables

Variable	Description	Mean	Std. Dev.	Predicted sign
Dependent variables				
Technology adoption (TAD)	Inventory of technologies was obtained and TAD = 1 if farmer is using a particular technology 0 otherwise.	0.71	0.46	
Farmer perception of CV	Farmer has perceived climate change, measured by rainfall variability and adequacy (1=Yes, 0=No)	0.91	0.28	
Independent variables				
Gender	Gender of household head (1=Male, 0=Female)	0.84	0.36	+/-
Age	Age of the household head in years	44.93	14.89	+/-
Experience	Farming experience of the household head in years. Years of farming as the primary source of livelihood.	19.71	14.89	+
Education	Level of education of the household head measured on a scale where 1=none, 2=Primary, 3=Secondary, 4=Tertiary	2.14	1.13	+
Household size	Number of household members	7.05	3.75	+
Off farm income	Farmer has off farm income source (1 = Yes, 0=No)	0.52	0.50	-
Livestock	The number of cattle, sheep and goats owned by the Household (TLUs)1	0.90	0.06	+
Credit	Farmer has access to credit formal or informal (1=Yes, 0=No)	0.44	0.50	+
Farm size	Total farm size in hectares	1.06	0.94	+
Extension	Farmer has access to extension services (1=Yes, 0 = No)	0.39	0.49	+
Weather information	Farmer has access to weather forecast information (1=Yes, 0=No)	0.70	0.46	+
Input market	Distance to input market in km	4.81	4.19	+
Output market	Distance to output market (km)	3.84	5.59	+
Rainfall index	Subjective index constructed from responses of a set of questions related to rainfall timeliness, amount and distribution (1 is the desired situation, and 0 otherwise)	0.19	0.11	+
Local agro-ecology	Local agro-ecology represented by the study districts. Dummy = 1 if Pallisa			+

For the selection model, it was hypothesized that, gender, age, farming experience, and education of head of household; access to weather information, and access to extension services, influence the awareness of farmers to climate variability and change. A set of dummy variables describing the local AEZs (represented

1 TLU: Total Livestock Unit; conversion factors: cattle (0.50), sheep and goats (0.10), pigs (0.20), and poultry (0.01). Source: FAO (2005); Chilonda and Otte (2006)

by study districts) are included in anticipation of climate variability and change being more pronounced in some AEZs than in others. The distribution of the main variables as well as their predicted impact is presented in Table 1.

Results

Farmers' perceptions of climate variability

In order to understand farmers' perceptions of rainfall variability, a series of questions were asked related to rainfall adequacy in the previous growing seasons?. Over 90% of the farmers interviewed had perceived change in rainfall pattern. The rainfall subjective index averaged 0.19 (19%), which indicates that farmers perceive rainfall to be very variable and not desirable. Farmers' generally reported late onset of rain, poor distribution within the season, and sometimes early cessation.

Considerable differences between sample districts exist. In Pallisa, respondents highlighted drought in the first season as an increasing problem, and more frequent flash floods as a result of increased rainfall intensity. In Sironko and Mbale, increased rainfall intensity leading to increased ground water and water logging and landslides was reported. Comparing means across the sample locations indicates no significant differences in people's perception of climate variability ($P<0.05$). Table 2 shows the rainfall subjective index.

Table 2 : Rainfall Subjective Index

During the main growing season of 2010	Percent of response			
	Mable	**Pallisa**	**Sironko**	**Overall**
Rainfall came on time	26	10	13	16
There was enough rain at the beginning of the season	52	12	25	30
There was enough rain during the growing season	56	18	31	35
The rains stopped on time	23	7	18	16
It rained near the harvest time	2	88	4	31
The number of rainfall days changed	26	1	3	10
The frequency of heavy rains changed	30	1	1	11
The frequency of dry spells changed	7	0	1	3
The duration of the growing season changed	38	23	8	23
F-value	1.69			
P-value	0.21			
F crit (5%)	3.40			

Adaptation technologies

An inventory of farmer preferred technologies was made based on responses obtained from the survey. It was found that farmers were using one or more technologies on their farms either singly or in combination on a given plot. Overall, 71% of the respondents had employed at least one technology on farm aimed at reducing climate risks.

Technologies employed by farmers were categorised into; (1) land management, and (2) crop management technologies (Table 3). Crop management technologies are those practices aimed at ensuring proper timing of farming operations or proper mix of crops in the field to reduce the risk of crop failure (Mubiru, 2010). Land management technologies on the other hand are those practices aimed at improving the productivity of the land and include practices for fertility management and soil and water conservation (Akponikpe *et al.*, 2010).

Majority of farmers generally changed sowing dates to coincide with onset of rain or planted as and when it rained. Other crop management practices employed include; changing crop density and varieties, and

intercropping. Farmers changed crop varieties to include early maturing ones particularly maize, beans and ground nuts. In Sironko, farmers introduced non-traditional crops such as paddy rice and coco yam to cope with increased soil water and logging, while in Pallisa, farmers were moving back to local varieties of finger millet and sorghum which they perceived to be more hardy and tolerant to dry spells as opposed to improved varieties.

Cover crops, compost manure and crop rotation are the most common land management practices employed by farmers in the sampled villages. Other land management practices used by farmers include; soil bunds, terraces, mulching, water ways, grass strips, use of inorganic fertilizer and agro-forestry. Test of whether the observed differences, indicates statistically significant differences in technology adoption in the three sample locations (P≤0.05).

Table 3 : Proportion of Respondents using various Technologies by District

Technology options	Adaptation choices	Percent of respondents using technology			
		Mbale	Pallisa	Sironko	Total
Crop management	Alter sowing dates	63	100	74	78
	Change crop density	35	76	34	48
	Change crop varieties	39	28	30	32
	Intercropping	55	82	83	73
Land management	Mulching	13	30	50	30
	Compost manure	36	50	55	47
	Inorganic fertilizer	7	8	66	27
	Cover crops	11	77	58	48
	Crop rotation	6	94	29	43
	Soil bunds	48	48	19	38
	Terraces	14	16	26	19
	Water ways	4	57	14	25
	Grass strips	15	36	43	31
	Agro-forestry	16	17	41	25
F- value		4.16			
P-value		0.02			
F crit (5%)		3.24			

Heckman Selection Model - Two-Step Estimates. Despite the fact that over 90% of the farmers interviewed claimed that they had perceived variability and change in rainfall, only 71% (of total respondents) indicated to have taken action. It is argued that farmers who perceived change and responded (or did not respond) share some common characteristics, which assist in better understanding the reasons underlying their response (or failure to respond) as captured by the Heckman probit model. Tables 4 and 5 show model results indicating the probability of adopting adaptation technologies given perception of climate variability, and the marginal impacts of the various variables on adoption of technologies respectively.

Table 4: Heckman's Sample Selection Model of Whether a Farmer Fails to Respond to Climate Variability

Variables	Technology adoption (Outcome Model)		Perception of climate variability (Selection Model)	
	Coefficient	**Std. Err.**	**Coefficient**	**Std. Err.**
Gender (Male=1)	0.105*	0.063	0.266	0.301
Age	-0.001	0.002	0.002	0.012
Experience	-0.001	0.002	0.014	0.010
Education	0.009	0.018	0.046	0.099
Household size	0.025***	0.006		
Off farm income	-0.005*	0.049	0.118	0.257
Livestock	0.023	0.021		
Credit	0.057	0.046		
Extension	0.065	0.048	-0.302	0.267
Weather information			0.999***	0.269
Output market	0.012**	0.006		
Input market	-0.029***	0.008		
Farm size	-0.010	0.026		
Rainfall index	0.348**	0.143		
Mbale	-0.359***	0.767	-0.683	0.471
Sironko	-0.148*	0.085	-0.936**	0.466
Constant	0.657***	0.122	0.930	0.639
Total observations	291			
Censored	26		Uncensored	265
Rho	0.572		Wald chi2(16)	179.82
Prob > chi2	0.0000			

Statistical significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability

The results from the sample outcome model (Table 4) indicate that farmers' decisions to adopt adaptation technologies are driven by a number of factors. It is apparent that gender of the head of household, household size, access to output markets, and perception of rainfall variability and location of farmer significantly increase the probability of the farmer recording an adaptation measure. On the other hand, access to off-farm income, input markets, and location negatively affect adoption of technologies. Institutional variables such as extension on crop and livestock, and access to credit are positively correlated with technology adoption, but are not significant in explaining the observed technology adoption at farm level.

Results of the selection model indicate that only access to weather information explains the perceived change in climate. Unlike the a priori expectations, local agro-ecology negatively affected perception of climate variability, with location in Sironko negatively related to farmer perception on climate variability, as compared to Pallisa.

From the marginal impact analysis of the various factors (Table 5), there are marked differences in the ability of farmers from different agro-ecologies to respond to climate variability. The probability of responding to climate variability by farmers in Mbale and Sironko is smaller by about 15% and 6% respectively as compared to Pallisa. The probability of a farmer adopting adaptation technologies is 9% higher if they have perceived climate variability.

Male headed households have more probability of adapting to climate change which is revealed by the fact that a unit change from being headed by a female to male increases the probability of adapting to climate variability by 12%. Increasing household size, by one unit increases the probability of a farmer adopting adaptation technologies by 23%. A farmer who has perceived changes in rainfall has 9% chance of adopting new technologies than one who has not.

Table 5 : Marginal Impacts of Adaptation to Climate Variability

Variable	δy/δx†	Std. Err.	Z value	P>|z|
Gender (= Male)	0.121*	0.074	1.64	0.101
Age	-0.085	0.132	-0.64	0.521
Experience	-0.038	0.058	-0.66	0.510
Education	0.026	0.053	0.49	0.625
Household size	0.236***	0.056	4.19	0.000
Livestock	0.028	0.026	1.07	0.284
Off farm income	-0.004	0.035	-0.12	0.906
Credit	0.035	0.028	1.24	0.213
Extension	0.035	0.026	1.38	0.167
Output market	0.064**	0.030	2.14	0.032
Input market	-0.189***	0.053	-3.54	0.000
Farm size	-0.014	0.038	-0.37	0.712
Rainfall index	0.090***	0.036	2.45	0.014
Mbale	-0.152***	0.035	-4.31	0.000
Sironko	-0.068*	0.041	-1.67	0.095

† y = Linear prediction (predict) = 0.740; Statistical significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability

Discussion

Consistent with adopter perception paradigm (Adesina and Zinnah, 1993) this study shows that there is a significant association between smallholder farmers' perceptions of extreme climatic events and adoption of agricultural technologies. Decisions to adopt production risk reducing technologies generally depend on farmers' perception of the variability in the climatic condition.

Results further indicate that there is a higher probability for men to adopt technologies than women. This result is in line with the argument that male-headed households are often considered to be more likely to get information about new technologies and take risky businesses than female-headed households (Asfaw and Admassie, 2004). However, in consideration that household size also significantly affects technology adoption. This study observes that most of the technologies employed by farmers generally require labour input. It can therefore be inferred from the study that gender effect on technology adoption is generally due to the differences in labour endowment between men and women. This is in line with Pender and Gebremedhin (2006) who indicate that female-headed households use significantly less labour, because of labour constraints. As such, they are less likely to apply compost manure and less likely to use contour ploughing, which are generally labour intensive.

Unlike the a priori expectation that more experienced farmers have higher chances of adapting to climate variability, this study shows that the length of farming experience among the respondents is not a very important determinant of adoption of technologies. According to Saha *et al*. (1994), this can be attributed to the fact that farmers who have been long in the business are usually older, less educated and are more resistant to change than new entrants. Mugisha *et al*. (2012) report contrary results where they indicate that farmer's experience positively and significantly influences the rate of technology adoption.

Similarly, results on extension advice are contrary to the a priori expectation of this study. While access to extension has been linked to adoption of improved technologies by various studies (for example Atta-Krah and Francis, 1987; Maddison, 2006) and adaptation to climate change (Nhemachena and Hassan, 2007), this study shows contrary results. It is acknowledged that contact with extension allows farmers greater access to information on technology, through increased opportunities to participate in demonstrations and thus increases farmers' ability to get, process, and use technologies.

Previous studies on extension in Uganda have indicated less favourable results on the impact of extension on agricultural productivity (Benin *et al.,* 2007). More generally, lack of funds and equipment to facilitate the work of extension agents is a common complaint at the local government level (Sserunkuuma *et al.,* 2001). Kristin (2008) also cites a combination of a lack of relevant technology, failure by research and extension to understand and involve clientele in problem definition and solving, lack of incentives for extension agents, and weak linkages between extension, research, and farmers. It is therefore important to tailor extension messages to the existing farmer challenges other than general extension messages.

The probable reason for the negative relationship between adaptation and farm size could be due to the fact that adaptation is plot specific. This means that it is not the size of the farm, but the specific characteristics of the farm that dictates the need for specific adaptation methods. This finding is in line with Deressa *et al*. (2008) who found that farm size was negatively related to adaptation to climate change. Benin *et al*. (2007) also affirm that reduction in farm size is a major determinant for adoption of improved crop production practices, and improved soil fertility management.

Conclusions and recommendations

The study highlights the factors that affect farmers' perceptions and adoption of adaptation technologies. This research has shown that farmer's perception of rainfall adequacy or variation is significant in explaining farmers' decision to adopt adaptation technologies. Other factors that positively and significantly affect farmer's choice of adaptation technology are; gender of head of household, household size, and access to output markets. The key issue that relates to these variables and their effect on technology adoption is essentially labour endowment, considering that most of the technologies are labour intensive. This study finds no significant relationship between technology adoption and extension services. Yet, access to information showed positive relationship with technology adoption.

The results obtained here underscore the need for appropriate weather information to guide decision making of which adaptation technologies to adopt. In addition, household socio-economic factors and access to markets should not be ignored in the design and implementation of adaptation measures. This can be supported by building social protection mechanisms at community level, or supporting households to build economic assets if labour is to be hired. Lastly, in provision of extension services, the mode of extension service delivery, the messages and the targeting is critical if extension is to contribute to technology adoption and subsequently increased agricultural productivity.

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Drought Mitigating Technologies: An Overview of Cassava and Sweetpotato Production in Mukuyuni Division Makueni District in Semi-Arid Eastern Kenya

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Abstract

Purpose- To obtain a general overview of cassava and sweetpotato production in Mukuyuni Division Makueni County in Semi-Arid Eastern Kenya as a prelude to the establishment of a seed system for the two crops using elite KARI varieties as drought mitigating technologies.Design/methodology/ approach- Included literature review, participatory rural appraisal through structured interviews, physical observations, and focussed group discussions. Findings- The study established that there is a lot of room for commercializing cassava and sweetpotato production in Mukuyuni Division Makueni County through processing and promoting their utilization as a meal. Farmers in Mukuyuni can easily adopt drought mitigating technologies like cassava and sweetpotato. They are mainly propagated through stem cuttings or vines to produce starchy tuberous roots, which would provide the much needed carbohydrates if promoted properly. The results showed that about 90% of the farmers put between 0.125 and 0.25 acres under cassava cultivation. The number of years under cassava and sweetpotato production ranged between 1 and 20 years with only a few farmers indicating to have been growing cassava for a period above 20 years. The majority of farmers were growing local cultivars of the two crops. The main method of utilizing cassava was boiling and eating as a snack (45%). Over 77.8% of the respondents indicated the origin of their cassava and sweetpotato cultivars as other farmers. The main method of utilizing sweetpotato was boiling and eating as a snack (56.3%). 3.1% of the farmers mixed sweetpotato with beans and maize and consumed it as a stew while another 3.1% have not utilized sweetpotato at all. Only 3.1% fed sweetpotato to livestock. The rest, 28.1% sold sweetpotato in the local market. The majority of farmers, 38.9%, had attained the Primary School level of education, were farmers, and owned a cellphone. Those with a secondary level of education owned a cellphone and a postal address.

Originality/value-This is the first case study based article that focuses on the potential of using cassava and sweetpotato as drought mitigating crops in Mukuyuni a semi-arid area in Kenya.

Key Words: Cassava, sweetpotato, drought tolerant, mitigation, semi-arid areas

Introduction

Cassava and sweetpotato are drought tolerant crops, which are ideal for the arid, and semi-arid lands in provision of much needed calories (Githunguri *et al*., 2006a). A lot of work has been carried out on processing, value addition, and utilization of these crops within KARI and other institutions (Nweke *et al*., 2002; Makokha andTunje. 2000; Wambugu and Mungai, 2000; Githunguri, 1995). It is very important to present these crops to urban consumers in an attractive form at affordable prices, which are competitive to those of cereals (Nweke*et al*., 2002). Cassava and sweetpotato products processing and utilization is done mainly at the subsistence level (Kadere, 2002) and in Kenya is still limited to the household level. Past studies show that about 80% of the cassava and sweetpotato products are consumed on the farm while 20% are marketed (CBS, 1998). At the household level cassava is mainly utilized as ugali, which is prepared from cassava composite flour (Githunguri, 1995). Some development agencies, KARI, and the Home Economics branch of Ministry of Agriculture have been promoting different recipes from cassava and sweetpotato flours especially baked products such as cakes (Githunguri *et al*., 2006a). Cassava and sweetpotato production in Kenya is constrained by lack of adequate disease and pest free planting materials due to their slow multiplication rate and poor cultural practices among other factors (Githunguri

et al. 2003 and Odendo*et al*. 2001). There has been more emphasis on cultivar development than on agronomic packages and as such, there is urgent need for research programmes to start addressing agronomic requirements and rapid multiplication and distribution of clean elite planting material. The objectives of the Root and Tuber Crops Programme in Katumani are to develop cassava and sweetpotato varieties that are widely adapted to diverse agro-ecological zones. The varieties should also be high yielding, early bulking, and drought resistant/tolerant, resistant to major biotic and abiotic stresses and have good root quality (Githunguri *et al.,* 2003; Githunguri, 2004). KARI-Katumani has recognized the importance of involving farmers in their selection and breeding research programmes as suggested by Bellon (2001) and Fliert& Braun (1999). The goal of the project is to promote and distribute early maturing, drought, disease, and pest tolerant cassava and sweetpotato cultivars available at KARI Katumani in the semi-arid areas of Kenya starting with the selected project sites. The specific objective of the study was to obtain a general overview of cassava and sweetpotato production in Matiliku Division Makueni District in Semi-Arid Eastern Kenya as a prelude to the establishment of a seed system for the two crops. This will ensure the elite KARI bred high yielding cassava and sweetpotato varieties will move out and have the desired impact on food security and improved livelihoods in semi-arid eastern Kenya.

Materials and methods

Participatory rural appraisal (PRA) interviews took place at a farm in Mukuyuni located at Latitude South: 01.73256 and Longitude East: 037.42758 with an altitude of 1366 metres above sea level on 11th June 2010 involving 13 female and 7 male farmers. KARI and extension officers conducted the PRA. During the exercise, the status of cassava and sweetpotato production in Mukuyuni was established. The results of PRA were analyzed using descriptive statistics.

Results and discussion

Figure 1 shows about 90% of the farmers put between 0.125 and 0.25 acres under cassava cultivation. The rest of the farmers put in only a few stands of cassava in their farms. According to Figure 2, the number of years under cassava production ranged between 1 and 20 years with only a few farmers indicating to have been growing cassava for a period above 20 years. About 45% of the farmers have grown cassava for about 15 years while the rest had cassava-growing experience ranging between 1 and 10 years in proportions ranging between 5.6 – 11.1%. These results suggest that cassava is still being grown as a subsistence crop and a lot needs to be done if cassava is going to be commercialized in Mukuyuni.

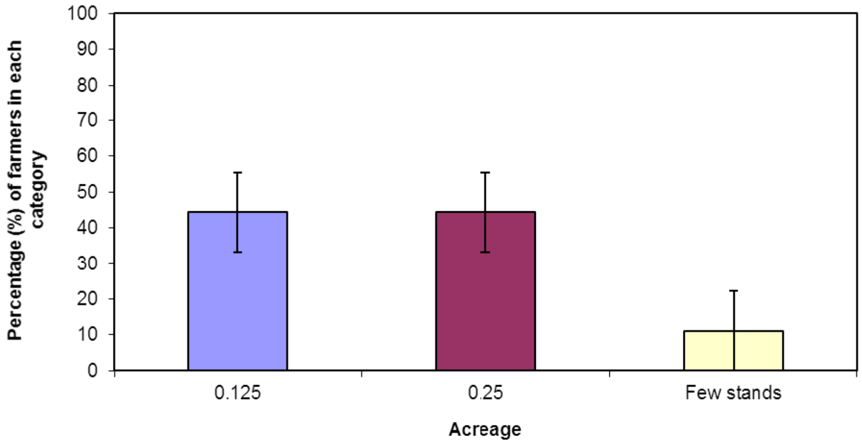

Figure 1: Proportion of acreage under cassava production in Mukuyuni Division Makueni District during 2010 long rains cropping season. Vertical bars represent the standard error between means (P = 0.05)

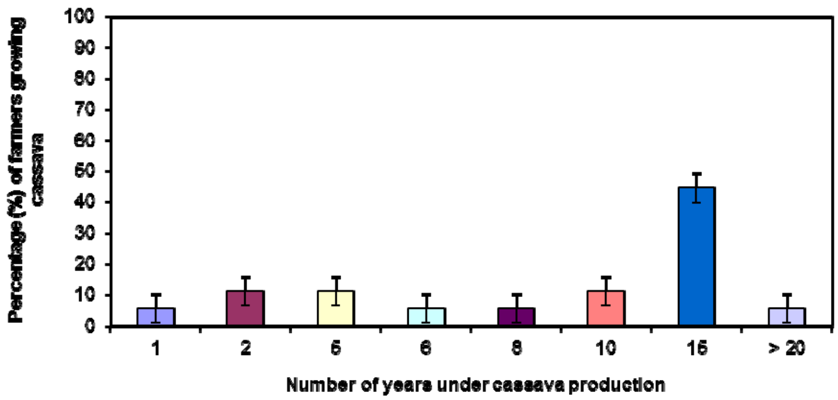

Figure 2: Number of years under cassava production and proportion of farmers growing them in Mukuyuni Division Makueni District. Vertical bars represent the standard error between means (P = 0.05)

Figure 3 shows 67% of the farmers were growing a local cultivar known as Kitwa followed by Mulava at 17%. The proportion of farmers growing the rest of the cultivars Kilava, Meu and an unknown improved cultivar ranged between 4 and 8%. This suggests that the adoption of improved cassava cultivars has been slow and as such there is need to put a lot of effort in the promotion of improved cultivars in Mukuyuni.

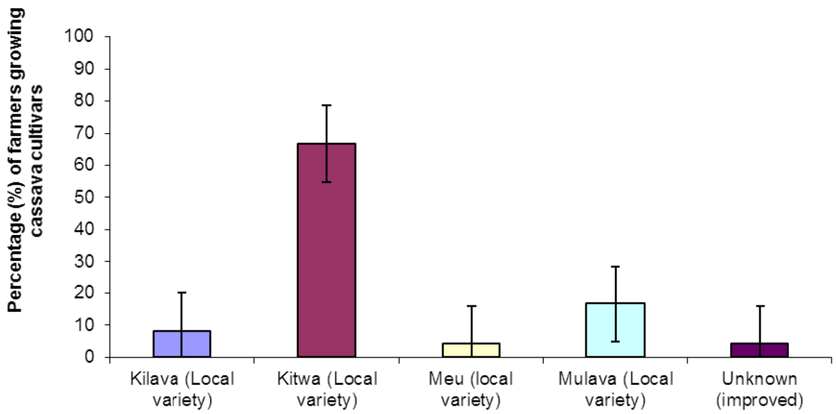

Figure 3: Types of cassava cultivars cited and proportion of farmers growing them in Mukuyuni Division Makueni District during 2010 long rains cropping season. Vertical bars represent the standard error between means (P = 0.05)

Table 1 shows that the main method of utilizing cassava was boiling and eating as a snack (45%). 12.5% of the farmers mixed cassava with beans and maize and consumed it as a stew while 10% chewed cassava raw. Very few farmers, about 7.5%, mixed cassava either with maize, millet, or sorghum to form composite flour for "ugali". Only 2.5% fed cassava to poultry. The rest, 22.5% sold cassava in the local marketing. This means that very few farmers process cassava or consume cassava as a major part of their diet. There is a lot of room for commercializing cassava and promoting its utilization as a meal.

Table 1: Method of utilization of cassava and proportion of farmers involved in Mukuyuni Division Makueni District as of 2010 long rains cropping season

Method of utilization	Percentage (%) of farmers utilizing them
Boil as a snack	45
Chew raw	10
Feed poultry	2.5
Mill into composite flour (maize and cassava) for "ugali"	2.5
Mill into composite flour (millet and cassava) for "ugali"	2.5
Mill into composite flour (millet or sorghum and cassava) for "ugali"	2.5
Mix with beans and maize	12.5
Sell in the market	**22.5**

During the PRA 77.8% of the respondents indicated the origin of their cassava cultivars as other farmers, 5.6% as KARI and a similar 5.6% as coast, while 11.1% did not know their origin. On the other hand, 80% of the respondents indicated the origin of their sweetpotato cultivars as other farmers, 10% as KARI, while 10% did not know their origin.

Figure 4 shows 36.8%, 42.1%, 10.5%, and 5.3% proportion of respondents grow sweetpotato 0.125, 0.25, 0.5, 0.75 acres, and a few stands, respectively. These results suggest that like cassava, sweetpotato is still being grown as a subsistence crop and a lot needs to be done in order to commercialize it in Mukuyuni. However, it seems the area under sweetpotato is bigger than the area under cassava.

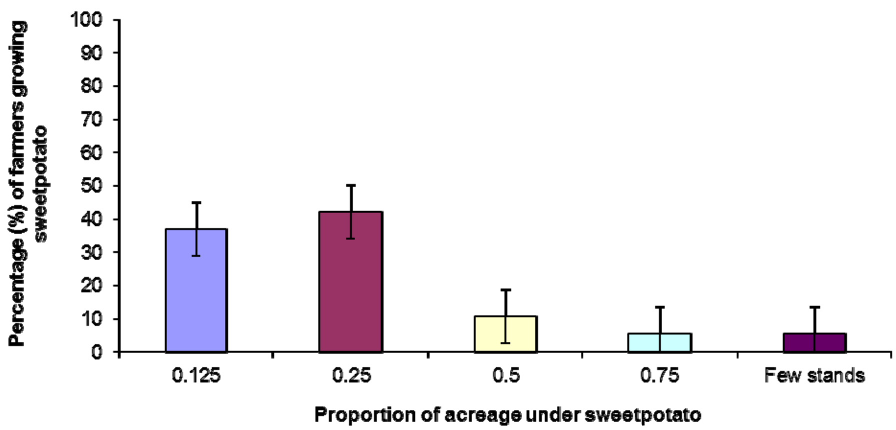

Figure 4: Proportion of acreage under sweetpotato production in Mukuyuni Division Makueni District during 2010 long rains cropping season. Vertical bars represent the standard error between means (P = 0.05**)**

According to Figure 5, the number of years under sweetpotato production ranged between 1 and 20 years with only very few farmers indicating to have been growing sweetpotato for a period above 20 years. About 42% of the farmers have grown sweetpotato for about 15 years while the rest had experience on sweetpotato production ranging between 1 and 17 years in proportions ranging between 5.3 – 21.1%. Similar to cassava, these results suggest that sweetpotato is also largely being grown as a subsistence crop and a lot of efforts needs to be taken in order to commercialize sweetpotato in Mukuyuni. Such efforts include the establishment of a sustainable vigorous cassava and sweetpotato seed system in place.

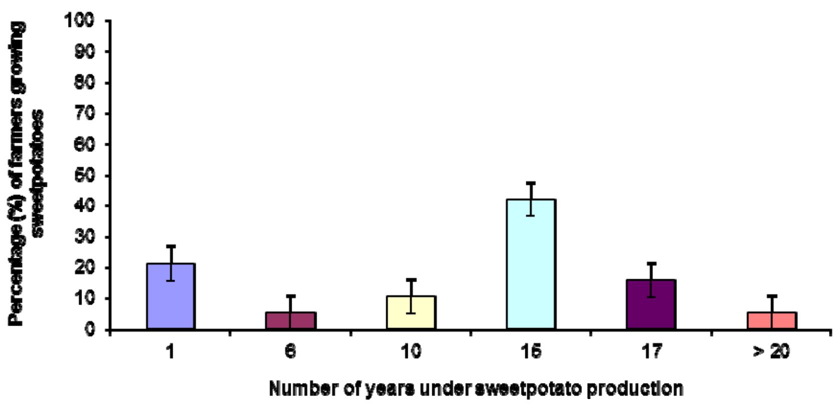

Figure 5: Number of years under sweetpotato production and proportion of farmers growing them in Mukuyuni Division Makueni District. Vertical bars represent the standard error between means (P = 0.05)

According to Figure 6, 33.3%, 4.2%, 25.0 %, 4.2%, 8.3%, 8.3%, 8.3%, and 8.3%, farmers were growing sweetpotato cultivars Kiluu (Local variety), Kitune (Local variety), local variety (unknown), Meu (Local variety), Mutune (Local variety), Mwezimoja (Local variety), Orange fleshed, and an Unknown (improved). This suggests that the adoption of improved sweetpotato cultivars has been slow and as such there is need to put a lot of effort in the promotion of improved cultivars in Mukuyuni. However, it seems the farmers were keen on sourcing more sweetpotato cultivars than cassava.

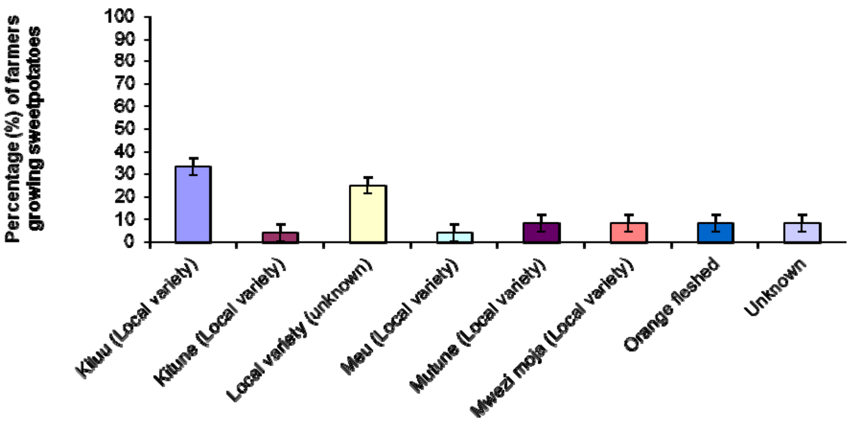

Figure 6: Types of sweetpotato cultivars cited and proportion of farmers growing them in Mukuyuni Division Makueni District during 2010 long rains cropping season. Vertical bars represent the standard error between means (P = 0.05)

Table 2 shows that the main method of utilizing sweetpotato was boiling and eating as a snack (56.3%). 3.1% of the farmers mixed sweetpotato with beans and maize and consumed it as a stew while another 3.1% have not utilized sweetpotato at all. Very few farmers (6.3%) roasted sweetpotato and ate them as a snack.. Only 3.1% fed sweetpotato to livestock. The rest, 28.1% sold sweetpotato in the local market. This means that very few farmers consume sweetpotato as a major part of their diet. There is a lot of room for commercializing sweetpotato through processing and promoting their utilization as a meal.

Table 2: Method of utilization of sweetpotato and proportion of farmers involved in Mukuyuni Division Makueni District as of 2010 long rains cropping season

Method of utilization	Percentage (%) of farmers utilizing them
Boil as a snack	56.3
Feed livestock	3.1
Have not utilized	3.1
Mix with beans and maize	3.1
Roast	6.3
Sell in the market	28.1

Table 3 shows the education level, their occupation, and main mode of communication by farmers involved in cassava and sweetpotato production in Mukuyuni. The majority of farmers, 38.9%, had attained the Primary School level of education, were farmers, and owned a cellphone. Eleven percent of the respondents had not attained Primary School level of education (Adult Education) and did not own a cellphone. A similar percentage of respondents who had either attained the Primary School level or Secondary School level of education did not own a cellphone. This suggests that there is no clearly defined relationship

between ownership of a cellphone and level of education among the respondents. However, it seems the majority of those who owned a cellphone had attained the Primary School level of education. Ownership of a cellphone is an indication of farmers who can easily adopt a new technology if promoted properly.

Table 3: Education level, occupation and main mode of communication by farmers involved in cassava and sweetpotato production in Mukuyuni Division Makueni District during 2010 long rains cropping season

Education level	Occupation	Telephone	Percentage (%) of farmers within the main categories
Adult education	Farmer	None	11.1
Primary	Church Leader/ Farmer	Cellphone	5.6
Primary	Farmer	Cellphone	38.9
Primary	Farmer	None	11.1
Primary	Mason/Farmer	Cellphone	5.6
Secondary	Farmer	Cellphone	5.6
Secondary	Farmer	None	11.1
Secondary	Mason/Farmer	Cellphone	5.6
Secondary	Nursery Teacher/ Farmer	Cellphone	5.6

Conclusions and recommendations

The farmers' cassava and sweetpotato growing experience is short. The area under sweetpotato is bigger than the area under cassava and it seems the farmers were keen on sourcing more sweetpotato cultivars than cassava. These crops are still being grown as subsistence crops and a lot needs to be done if they are going to be commercialized in Mukuyuni. Use of improved cassava and sweetpotato cultivars from research institutions was very low. The adoption of improved cassava and sweetpotato cultivars has been slow and as such there is need to put a lot of effort in the promotion of improved cultivars in Mukuyuni. Such efforts include the establishment of a sustainable vigorous cassava and sweetpotato seed system in place. In addition, very few farmers process or consume cassava and sweetpotato as a major part of their diet. There is a lot of room for commercializing these crops through processing and promoting their utilization as a meal. Farmers in Mukuyuni can easily adopt drought mitigating technologies if promoted properly.

Acknowledgement

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Situation analysis of climate change aspects in Kenya

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Abstract

Given that climate change and variability have become one of the greatest threats to food security and livelihoods, a baseline study was conducted to understand the current situation of climate change scenarios in Kenya. The study sought to determine the current status of climate change projects that have been undertaken in Kenya in the past five years between 2007 and 2012. Major climate change themes including adaptation, mitigation and capacity building and sensitive productive sectors such as agriculture, livestock, water and environment to climate change were conceptualised in which the study was based. The baseline survey targeted key informants in academic, research and policy arenas. It was observed that adaptation, mitigation and capacity building accounted for 60, 17 and 23% of the projects sampled. Agricultural sector (crops) accounted for most of climate change projects, accounting for 36% as well as 40% of all projects on adaptation. Agriculture, livestock and environment sectors accounted for 30% each of the mitigation projects. It is established that most projects undertaken in Kenya on climate change arena have been on adaptation, capacity building and mitigation. Climate change projects undertaken in Kenya were in agriculture and livestock sectors. Although considerable efforts appear to have been put in adaptation to climate change, more needs to be done, especially in agriculture and water sectors, which are important in Kenya's economy.

Key words: climate change adaptations, mitigation, capacity building, situation analysis.

Introduction

Climate change (CC) is a serious threat to agricultural productivity in regions that are already food insecure. Evidence of crop yield impact in Africa and South Asia resulting from CC is clearly witnessed in wheat, maize, sorghum and millet, and is unclear, absent or contradictory in rice, cassava and sugarcane (Knox *et al*., 2012). It is projected that by 2050 the world will have to increase agricultural production to feed a projected nine billion people against changing consumption patterns, impacts of CC and growing scarcity of water and land (Beddington, 2010). Sub-Saharan Africa (SSA) is reported as the most vulnerable region to CC and variability (Slingo *et al*., 2005). This is partly because SSA maintains the highest proportion of malnourished populations with substantial portion of its national economies dependent on agriculture (Schlenker and Lobell, 2010; Kpadonou *et al*., 2012); and most of its available water resources (85%) used for agriculture (Downing *et al*., 1997). Farming techniques in SSA have also not kept abreast with modern technology, with a majority of its land arid and semi-arid, and smallholder farming systems that have limited capacity to adapt dominating agricultural landscape (Müller *et al*., 2011). Hence development externalities associated with CC will be most felt in Africa. Some CC extremes such as seasonal droughts and floods are already undermining economies and prosperity of the SSA and its people.

In Kenya, the effects of climate change and variability (CCV) are becoming more conspicuous and real given that their impacts are already affecting ecosystems, biodiversity and people. Climate change extremes such as unpredictably more frequently occurring droughts and flooding are already undermining the economies and prosperity of Kenya and the Greater Horn of Africa. Agriculture and water resources

are among key sectors that are getting affected most by the impacts of CC scenarios. Climate change has the potential to slow down economic development of Kenya and many other countries.

Currently there is growing evidence of increased CCV in Kenya, leading to more than one drought every five years. This is causing substantial and irreversible decreases in productive sectors, particularly in livestock numbers in the arid and semi-arid lands (ASALs) of Kenya (MacMillan, 2011). The droughts and floods expose the livestock industry to serious vulnerability and myriads of problems including livestock deaths, high malnutrition rates and diseases incidences. During the 2009 drought, Kenyan pastoralists lost more than 50% of their herds; 81% and 64% of their cattle, and sheep and goats respectively (African Conservation Centre, 2012; Mutimba *et al.*, 2010).

Global circulation models predict that by year 2100, CC will increase temperatures by 40C leading to serious crop failures, reduced water and forage availability, and increased livestock mortalities and loss of livelihoods (Nanyingi *et al.*, 2012). Similarly, Knox *et al*. (2012) projected impacts of climate change on the yield of eight major crops in Africa and South Asia showing that projected mean change in yield of all crops is –8% by the 2050s in both regions. Across Africa, mean yield changes of –17% (wheat), –5% (maize), –15% (sorghum) and –10% (millet) were estimated. It is also predicted that potential cost to Africa due to CC dynamics will reach about US$10billion per year by 2030 (Pan African Climate Justice Alliance, 2009).

Hence, mainstreaming adaptation capacity in Kenya and African development policy, planning and investment processes is absolutely relevant. In spite of uncertainties surrounding CC projections, adaptation planning remains a relevant integral component of development and investments.

In order to provide practical roadmaps for future adaptation investments, programmes for adaptation actions such as the National Adaptation Programmes of Action need strengthening. One way of doing this is through conducting economic analyses of adaptation investments that are informed by credible and impartial scientific assessments of CC impacts.

Towards tackling economic analyses of adaptation options in Kenya, it became necessary to understand the current situation analysis of CC scenarios within the country. Major CC themes and sensitive productive sectors to CC were thus conceptualised in which the analysis was based. First this paper gives an introduction to climate change in general in which selected literature is described. A summary description of materials and methods is presented followed by results and discussions. Following the findings of the study, conclusions and recommendations are finally provided.

Materials and methods

A baseline survey was undertaken to determine the current status of CC projects that have been undertaken in Kenya during the past five years between 2007 and 2012. Ninety willing respondents purposively drawn from universities, government departments, national research institutions and non-governmental organizations were interviewed using a structured open-ended questionnaire. The survey targeted key informants in academic, research and policy arenas. Most respondents however came from academic institutions (universities) and a few researchers and policy planners. The collected data were coded, entered, cleaned and analysed for descriptive statics using the SPSS Version 18 software.

Results and discussion

Projects in selected CC thematic areas

Given that CC effects and impacts are being stopped and mitigated from happening and/or proceeding further, three major thematic areas/scenarios were conceptualised on what actions are being taken against CC in Kenya. The commonest actions being undertaken in Kenya were adaptation, mitigation and capacity building, which were regarded as the major CC thematic areas.

Adaptation to CC (or global warming) involves acting to adapt, cope with and/or reduce effects of global warming, an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects. Adaptation measures may include prevention, tolerance or sharing of losses, changes in land

use or activities, changes of location, and restoration. In contrast, CC mitigation is action to decrease the intensity of radiative forcing in order to reduce the effects of global warming (Marland *et al.,* 2007; IPCC, 2007; GoK, 2010). Climate change mitigation scenarios involve reductions in the concentrations of greenhouse gases, either by reducing their sources or by increasing their sinks (Molina *et al.,* 2009). In the 1990s, the UN defines mitigation as a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Mitigation include using fossil fuels more efficiently for industrial processes or electricity generation, switching to renewable energy (solar or wind power), improving insulation of buildings, and expanding forests and other 'sinks' to remove greater amounts of CO2 from the atmosphere (UNFCCC, 1997). It is important to note that adaptation and capacity building are more implementable at the micro level, while mitigation at the macro level.

Effective responses to CC combine both adaptation and mitigation strategies. There are clear complementarities in applying both mitigation and adaptation aspects to CC, although they differ in important respects. Benefits from mitigation are expected to be global and deferred, while those from adaptation projects are expected to be local and to some extent more immediate (World Bank, 2009). Important adaptation options in agricultural sector include: crop diversification, mixed crop-livestock farming systems, using different crop varieties, changing planting and harvesting dates, and mixing less productive, drought-resistant varieties and high-yield water sensitive crops (Bradshaw *et al.,* 2004).

The baseline survey indicate that CC projects implemented in Kenya during the past five years were mostly on adaptation (60%), followed by projects in capacity building (23%) and mitigation (17%).

These findings are fairly rational given that adaptation is a way of trying to tolerate and live with the CC, while capacity building is empowering people in raising awareness, training and education and providing other capacity requirements to deal with and accommodate CC scenarios. Some projects have emphasized in enhancing provision of climate information services, strengthening capacity of governments to facilitate adaptation to CC, building awareness and capacity among civil society; and to a lesser extent improving freshwater resources, pastoralism and human health (Kurukulasuriya and Rosenthal, 2003).

Projects in selected productive sectors

Kenya's productive sectors are the most sensitive ecosystems to CCV. Some of these sectors were identified as agriculture, livestock, water, tourism, health, infrastructure, natural resources (the environment), and fisheries (Kpadonou *et al.,* 2012; IPCC, 2007; IFPRI, 2007; World Bank, 2007).

By expert opinion and consensus, four most sensitive sectors to CC were identified for analysis of this research. The sectors are agriculture (crops), livestock, environment (natural resources), and water resources.

It was observed that the agriculture sector accounted for most (35.7%) of CC projects during the past five years in Kenya ;followed by livestock (27.4), the environment (19.8) and water resources sectors (17.1%).

This finding clearly indicates that agriculture and livestock (63.1%) accounted for the bulk of the CC projects in Kenya. One of the reasons underpinning this trend could be that agriculture and livestock sectors are more directly related to food security than any other sector. Further, the effects of CCV are easily and immediately reflected on the production of crops and livestock commodities.

Adaptation projects in selected productive sectors

Given that most CC projects in Kenya were implemented within the adaptation theme, it became apparent to reflect how the thematic projects were implemented and distributed in the selected productive sectors. This provided reflections on priorities areas in which investments on CC projects are made.

Adaptation projects were mostly invested in agriculture sector accounting for 39.5% of all adaptation projects implemented in Kenya during the past five years followed by projects in livestock (27.4%), the environment (17.2%) and water resources (15.9%).

Again, agriculture and livestock sectors accounted for the bulk of the adaptation projects (66.9%) implemented in Kenya.

The moderately high levels of investments in adaptation projects in agriculture and livestock are encouraging given that these two sectors are critical in their contribution to the Kenyan economy. These investment levels need to be enhanced in these sectors given their vulnerability to CCV as well as their importance to food security and economic growth.

Mitigation projects in selected productive sectors

The survey analysis shows that mitigation projects have been going on in Kenya during the past five years. The agriculture accounted for about 29.6%, livestock for 29.5% and the environment for (29.5%). In spite of the increases in frequency and severity of floods in Kenya, water resources accounted for only 11.4% of the mitigation projects.

This may explain the massive destruction of property and lose of livelihoods reported every rainy season. Notwithstanding, it is generally recognised that smallholder farmers can contribute substantially to CC mitigation, but will need incentives to adapt mitigation practices. These incentives would include the selling of carbon credits, which unfortunately are limited by low returns to farmers, high transaction costs, and the need for farmers to invest in mitigation activities long before they receive payments. Designing agricultural investments and policies to provide up-front financing and longer term rewards for mitigation practices will help reach larger numbers of farmers than specialized mitigation interventions (Wollenberg *et al.*, 2012).

It is instructive noting that potential for mitigation strategies is great and what is needed is a coordinating strategy to organise the generation and sharing of greenhouse gas data, and facilitate improved understanding of the potential for greenhouse gas emissions and removals from the CC sensitive sectors such as agriculture and forestry.

In Kenya mitigation activities have been practised on crop and soil management practices including sustainable agriculture land management, nutrient management (fertilisers), tillage and residue management, and agroforestry. Mitigation has also been practised on livestock and grazing land management that included grazing intensity – intensification and reduced herd sizes (productivity), and rangeland and pastureland management (Masiga, 2012).

Capacity building projects in selected productive sectors

Capacity building projects were mostly undertaken in the agriculture sector which accounted for 30.6% of all the projects followed by livestock (25.8%), water resources (24.2%) and the environment (19.4%). Up to 81% of all the capacity building projects were undertaken in agriculture, livestock and water resources sectors.

One example of the capacity building project going on in Kenya is the 'building adaptation capacities for CC through participatory research, training and outreach', which was initiated in 2010. This project is evaluating indigenous / traditional CC mitigating and adaptation strategies currently used by diverse Kenyan farming and pastoral communities and build capacity on CC adaptation strategies among various stakeholders (Lelo, 2011).

Conclusions and recommendations

Most projects undertaken in Kenya on CC arena have been on adaptation, capacity building and mitigation areas, while majority of the CC projects undertaken were in agriculture and livestock sectors. Three sectors on agriculture, livestock and environment received an equal share of mitigation projects, while majority of the CC capacity building projects were implemented in agriculture, livestock and water resources sectors.

Given the importance of adaptation in tolerating effects / impacts of CC, it is recommended that more adaptation work be intensified in Kenya. One area to work on is to undertake policy review to provide

enabling environment to conduct adaptation research for development. Capacity building should also be embraced to increase awareness, education and training, and tools and equipment for CC issues.

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Characterization of seasonal rainfall variability and drought probability of the semi arid areas of Mbeere region in Embu County, Kenya

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Abstract

This study examined the extent of seasonal rainfall variability, drought occurrence and the efficacy of interpolation techniques in the drier regions of eastern Kenyan. Rainfall Anomaly Index (RAI) and Coefficients-of-Variance and probability were utilized in the analyses of rainfall variability. Analyses showed 90% chance of below cropping-threshold rainfall (500 mm) exceeding 258.1 mm during short rains (SRs) in Embu for one year return-period. Rainfall variability was found to be high in seasonal amounts (e.g. CV=0.56, 0.47, 0.59) and in number of rainy-days (e.g. CV=0.88, 0.49, 0.53) in Machang'a, Kiritiri and Kindaruma respectively. Monthly rainfall variability was found to be equally high during April and November (e.g. CV=0.48, 0.49 and 0.76) with high probabilities (0.67) of droughts exceeding 15 days in Machang'a and Kindaruma. Dry-spell probabilities within growing months were high e.g. 91%, 93%, 81% and 60% in Kiambere, Kindaruma, Machang'a and Embu respectively.

Key words: dry-spell, gis, interpolation, kriging, rainfall-anomaly-index, seasonal-rainfall-variability

Introduction

Understanding spatio-temporal rainfall patterns has been directly implicated to combating extreme poverty and hunger through agricultural enhancement and natural resource management (IPPC, 2007). The amount of soil-water available to crops depends on rainfall onset, length and cessation which influence the success and /or failure of a cropping season (Ngetich *et al.*, 2014). It is thus evident that, understanding climatic parameters, rainfall in particular are prime inputs of improving the socio-economic wellbeing of smallholder farmers. This is particularly important in Sub-Saharan Africa (SSA) where agricultural productivity is principally rain-fed yet highly variable (Jury, 2002). Drier parts of Kenya's central highlands, eastern Kenya continue to experience high unpredictable rainfall patterns, persistent dry-spells/droughts coupled with high evapo-transpiration (2000-2300 mm year^{-1}) (Micheni *et al.*, 2004). Generally, the total amount of rainwater is enough; however, it has been reported to be poorly re-distributed over time (Kimani *et al.*, 2003) with 25% of the annual rain often falling within a couple of rainstorms, as a result crops suffer from water stress, often leading to complete crop failure (Meehl *et al.*, 2007). Recha *et al.*, (2012) noted that, most studies do not provide information on the much-needed character of within-season variability despite its critical influence on soil-water distribution and productivity.

There has been interest in understanding rainfall's seasonal patterns by evaluation of its variables including rainfall amount, rainy days, lengths of growing seasons and dry-spell frequencies (e.g. Mugalavai *et al.*, 2008; Ngetich *et al.*, 2014. Studies by Sivakumar (1991), Seleshi and Zanke (2004) and Tilahun (2006) noted high variations in annual and seasonal rainfall totals and rainy days in Ethiopia and Sudano-Sahelian regions. Studies on rainfall patterns in the region have been based principally on annual averages, thus missing on within-season rainfall characteristics (Barron *et al.*, 2003). However, understanding the average

amount of rain per rainy day and the mean duration between successive rain events aids in understanding long-term variability and patterns (Akponikpè *et al.,* 2008). Nonetheless, meteorological stations in the region which are sole sources of climatic data are only limited to single locations spatially. In sub-Saharan Africa, the predominant setbacks in analysing hydro-meteorological events are occasioned by either lack, inadequate or inconsistent meteorological data. The rainfall data within in the drier parts of Embu county and the neighbouring stations are scarce with missing data making their utilization quite intricate.

On the other hand, the much-needed information on inter and intra seasonal variability of rainfall in the region is still inadequate despite its critical implication on soil-water distribution, water use efficiency (WUE), nutrient use efficiency (NUE) and final crop yield. To optimize agricultural productivity in the region, there was need to quantify rainfall variability at a local and seasonal level as a first step of combating extreme effects of persistent dry-spells/droughts and crop failure. Since rainfall which is heterogeneous, in particular, is the most critical factor determining rain-fed agriculture, knowledge of its statistical properties derived from long-term observation could be utilized in developing optimal mitigation strategies in the area. To redress problems of inadequate, missing and inconsistent point data especially for un-gauged areas within the study area, this study sought to further evaluate the efficacy of geo-statistical and/or deterministic interpolation techniques in daily rainfall data reconstruction.

Materials and methods

The study area

The study was carried out in Embu County, eastern Kenya. The rainfall data were from Machang'a, Kiritiri, Kiambere and Kindaruma (herein commonly referred to as Mbeere region) and Embu (Embu) rainfall stations. This region lies in the lower midland 3, 4 and 5 (LM 3, LM 4 and LM 5), Upper midland 1, 2, 3 and 4 (UM 1, UM 2, UM 3 and UM 4), and Inner lowland 5(IL 5) (Jaetzold *et al.,* 2007) at an altitude of approximately 500 m to 1800 m.

It has an annual mean temperature of 17.4-24.5^{o} C; average annual rainfall of 700-900 mm. It has a human population of 82 km^{2} with an average farm size less than 5 ha per household. Embu represent a densely populated high potential humid area with Humic Nitosols soils and generally annual rainfall above 800 mm. Areas of the sub-humid Mbeere sub-County are emblematic of a low agricultural potential with less fertile and low soil water-holding Ferralsols, frequent droughts and annual rainfall of less than 600 mm (Jaetzold, *et al.,* 2007). However, Mbeere sub-County continues to experience population pressure occasioned by the influx of immigrants from over-populated high potential areas. These areas represent Kenya's central highlands and those of East Africa, predominant of smallholder rain-fed, non-mechanized agriculture and diminutive use of external inputs. The rainfall is bimodal with long rains from March-May and short rains from mid-October to December hence two cropping seasons per year. According to (Mugwe *et al.,* 2009), the region has experienced drastic declines in its productivity potential rendering most farmers resource poor. The prime cropping activity is maize intercropped with beans though livestock keeping is equally dominant. Mbeere sub-county represents a sub-humid climate region, with annual average rainfall of 781 mm while Embu is more humid with annual average rainfall above 1,210 mm (Table 1).

Table 1: Selected metadata of the meteorological stations used in the study

Station	Lat*	Long*	Alt*	Record_P*	Rainfall	Climate	Data
Embu	0º30'S	37⁰27'E	1409	13	1210	humid	R
Machang'a	0º46'S	37⁰39'E	1106	13	781	s-humid	R
Kiritiri	0° 41'S	37° 38'E	1153	13	934	Transitional s-humid	R
Kindaruma	0° 48'S	37° 41'E	990	13	654	s-humid	R
Kiambere	0° 42'S	37° 46'E	900	13	1041	s-humid	R`

* Lat=Latitude, Long=Longitude, Alt=Altitude, Record_P=Period of Record

This region is a strategic production region, producing about 20% of the country's maize cover. The inherently fertile Nitosols are the reasons for high-potential productivity while lower and erratic rainfall,

less fertile, shallow and sandy Ferralsols, and high drought frequency explain predominant crop failures (Jaetzold *et al.,* 2007). Daily rainfall data were sourced from both the Kenya Meteorology Department and research sites with primary recording stations within the study area. The choice of rainfall stations used depended on availability of the station, the agro-ecological zones, and the percentage of missing data, (less than 10% for a given year as required by the world meteorological organization (WMO). Much of the primary data was acquired from the ongoing recordings at Embu, Machang'a, Kiritiri, Kindaruma and Kiambere rainfall stations.

Data analyses

Daily primary and secondary rainfall time series were captured into MS Excel spread-sheet where seasonal rainfall totals for both Short Rains (SR) and Long Rains (LR) (- that is, March-April-May (MAM) and October-November-December (OND) respectively - annual average and number of rainy days were computed. In cases of high data gaps (unrecorded or missing), multiple imputations were utilized to fill in missing daily data through creation of several copies of datasets with different possible estimates. This method was preferred to single imputation and regression imputation as it appropriately adjusted the standard error for missing data yielding complete data sets for analysis (Enders, 2010). Being a season-based analysis, the cumulative impact of rainfall amount was underpinned. A rainy day was considered to be any day that received more than 0.2 mm of rainfall as reported by the WMO. Daily rainfall data were captured into the *RAINBOW software* (Raes *et al.,* 2006) for homogeneity testing based on cumulative deviations from the mean to check whether numerical values came from the same population. The cumulative deviations were then rescaled by dividing the initial and last values of the standard deviation by the sample standard deviation values (equation *i*).

Equation (*i*)

Where S_k is the rescaled Cumulative Deviation (RCD), *n* represents the period of record for *K*=1 and also when *K*=14

The maximum (*Q*) and the range (*R*) of the rescaled cumulative deviations from the mean were evaluated based on number of Nil Values, Non-Nil values, Mean and Standard deviations as well as K-S values (Equation (*ii*) and (*iii*) to test homogeneity. Low values of Q and R would indicate that data was homogeneous.

Equation (*ii*)

Equation (*iii*)

Where *Q* is maximum (max) of S_K and *R* in the range of S_K and Min is Minimum

The frequency analyses were based on lognormal probability distribution with $\log_{10}$ transformation using cumulative distribution function (CDF) for both LR and SR rainfall amounts. The Weibull method was used to estimate probabilities while the Maximum Likelihood Method (MOM) was utilized as a parameter estimation statistic. Homogeneous seasonal rainfall totals for both seasons was then subjected to trend and variability analyses based on Rainfall Anomaly Index (RAI) as described in (Tilahun, 2006).

Seasonal Variability was computed in tandem with annual averages for both positive (Equation *v*) and negative (Equation *vi*) anomalies using RAI.

Equation (*v*)

Equation (*vi*)

Where: M_{RF} is mean of the total Length of record, M_{H10} is mean of 10 highest values of rainfall of the period of record, M_{L10} is the lowest 10 values of rainfall of the period of record

The Coefficient of Variance (Co-efficient of Variation) statistics were utilized to test the level of mean variations in LR and SR seasonal rainfall, number of rainy days (RD) and Rainfall Amounts (RA) and t-test statistic to evaluate the significance of variation.

A dry day was taken as a day that received either less than 0.2 mm or no rainfall at all. A dry spell was considered as sequence of dry days bracketed by wet days on both sides (Kumar and Rao, 2005). The method for frequency analysis of dry spells was adapted from Belachew (2000) as follows: in the *Y* years of records, the number of times (*i)* that a dry spell of duration (*t)* days occurs was counted on a monthly basis. Then the number of times (*I)* that a dry spell of duration longer than or equal to *t* occurs was computed through accumulation. The consecutive dry days (1 d, 2 d, 3 d …) were prepared from historical data. The probabilities of occurrence of consecutive dry days were estimated by taking into account the number of days in a given month *n*. The total possible number of days, *N*, for that month over the analysis period was computed as, $N = n*Y$. Subsequently the probability *p* that a dry spell may be equal to or longer than *t* days was given by equation (*vii*): The probability q that a dry spell not longer than *t* does not occur at a certain day in a growing season was computed by equation (*viii*); and probability Q that a dry spell longer than *t* days will occur in a growing season was calculated by equation (*ix*) and probability *p* that a dry spell exceeding *t* days would occur within a growing season was computed by equation (*x*) as shown below:

Equation (*vii)*
Equation (*viii)*
Equation (*ix)*
Equation (*x)*

Results and discussion

Homogeneity testing

Homogeneity analyses had no NIL-values (values below threshold) but 100% Non-Nil values (above threshold) showing high homogeneity. The standard deviations (SD) of the normalized means for both LR and SR rainfall amounts were low e.g. lowest SD=0.1 (in Embu and Kiritiri during SRs), and highest (SD=0.9 in Embu and Kindaruma during LRs. Low SD values indicated the restriction of variations (rescaled cumulative deviations, RCD) around mean rainfall amounts thus high homogeneity (Table 2).

Table 2: Mean, Standard Deviation and R^2 values for the rainfall dailies from study stations for the period between 2001 and 2013

Station	Season	Trans-formation	NIL values	Mean	SD	K-S value	K-S Table value	R^2 (%)
Embu	LR	Log_{10}	0	3.2	0.9	0.2330	0.302*	94
	SR	Log_{10}	0	2.7	0.1	0.1722	0.302*	92
Machang'a	LR	Log_{10}	0	2.4	0.4	0.1479	0.302*	96
	SR	Log_{10}	0	2.6	0.2	0.19	0.302*	94
Kiritiri	LR	Log_{10}	0	2.6	0.3	0.231	0.302*	94
	SR	Log_{10}	0	2.9	0.1	0.221	0.302*	92
Kindaruma	LR	Log_{10}	0	2.2	0.9	0.165	0.302*	88
	SR	Log_{10}	0	2.2	0.3	0.066	0.302*	92
Kiambere	LR	Log_{10}	0	2.2	0.8	0.127	0.302*	90
	SR	Log_{10}	0	2.4	0.4	0.179	0.302*	96

SD= Standard Deviation; LR=Long Rains and SR=Short Rains LR=Long Rains and SR=Short Rains K-S=Kolmogorov Smirnov; (*K-S=0.302* exponential distribution applies and accepted*)

The Kolmogorov-Smirnov (K-S value) Test values, R-Square for the seasonal rainfall and the values the average rainfall *means* for rainfall months are summarized in Table 1A and 1B.

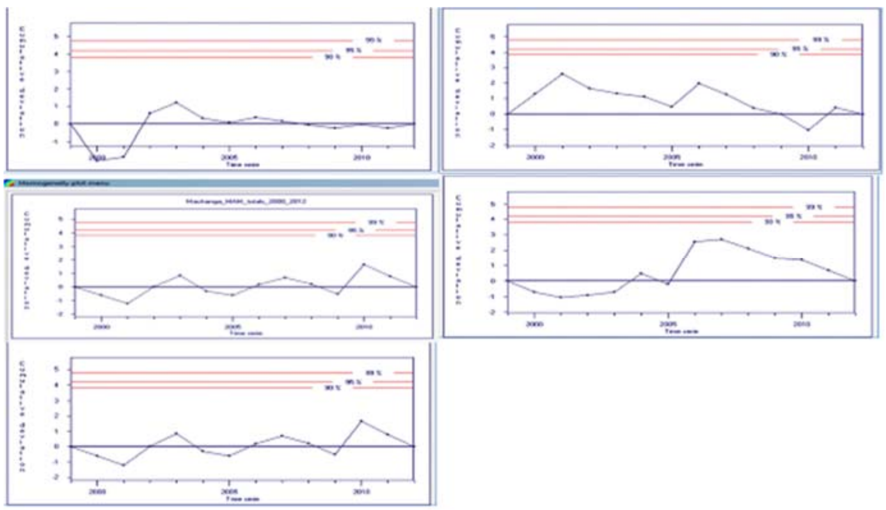

Figure 1: Rescaled cumulative deviations for Seasonal Months and studied rainfall stations for the period between 2000 and 2013

There was a normal distribution of the sampled-temporal rainfall data with high goodness-of-fit (R^2 =92% to 96%) of the selected distribution showing continuity of the data from mother primary data thus high homogeneity (Raes *et al*., 2006). Kolmogorov Smirnov values (one sided sample K-S test) showed K-S values (0.15 to 0.23) consistently lower than the K-S Table value (0.302) for n=14 at α= 0.005 probability indicating that an exponential, continuous distribution of the studied datasets was statistically acceptable, based on the empirical cumulative distribution function (ECDF) derived from the largest vertical difference between the extracted (observed k-s value) and the Table value (Botha *et al*., 2003; Mzezewa, 2010; MATLAB Central, 2013).Frequency analyses of meteorological data require that the time series be homogenous in order to gain in-depth and representative understanding of the trends over time (Raes *et al*., 2006). Often, non-homogeneity and lack of exponential distributions between datasets indicate gradual changes in the natural environment (thus trigger variability) which corresponds to changes in agricultural production (Huff and Changnon, 1973; Bayazit, 1981).

Probabilities of rainfall exceedance, return periods and amounts

Results showed that there was at least 90% chance of rainfall exceeding 141.5 mm (lowest) and 258.1 mm (highest) during LRs in Kindaruma and Embu, respectively, within a return period of about 1 year (Table 4). Nonetheless, there were observably low probabilities (10%) that rains would exceed 449.8mm and 763.0 mm during LR seasons in Machang'a and Embu, respectively for a 10-year return period (Table 4).

Table 4: Probability of rainfall exceedance and return-periods for the LRs and SRs in the study area

Exceedance (%)	Return (P)	Magnitude of Anticipated Rainfall (mm)									
		Embu		Machang'a		Kiritiri		Kindaruma		Kiambere	
		LR	SR	LR	SR	LR	SR	LR	SR	LR	SR
10	10	994.7	628.8	449.8	763	465.8	831.7	507.8	773.7	541.8	907.7
20	5	788.9	541.2	381.4	613.1	398.2	625.9	420.2	617.9	454.2	701.9
30	3.33	667.5	485.7	338.7	523.7	372.7	584.5	364.7	516.5	398.7	580.5
40	2.5	578.8	442.9	306	457.7	379.9	515.8	321.9	427.8	355.9	491.8
50	2	506.8	406.3	278.2	403.6	343.3	443.8	285.3	385.8	319.3	419.8
60	1.67	443.5	372.8	253.2	356	269.8	380.5	251.8	322.5	285.8	356.5
70	1.43	384.5	339.9	222.8	311.1	276.9	321.5	218.9	263.5	252.9	297.5
80	1.25	325.4	305.0	203.1	265.7	142	262.4	184	204.4	218	238.4
90	1.11	258.1	262.5	172.2	213.5	199.5	195.1	141.5	137.1	175.5	171.1

Exceedance (%) =Probability of exceedance (%) and Return (P) = Return period (years)

A study by Mzezewa (2010) established that seasonal rainfall amount greater than 450 mm is indicative of a successful growing season; and described it as a threshold rainfall amount. During this study, the probabilities that seasonal rainfall would exceed this threshold were quite low (at most 30% for a return period of 3.33 years). Embu, being much wetter, would probably (50%) receive above threshold rainfall amount (506.8 mm) after every 2 years (Table 4.3). Mzezewa (2010) observed 47% chance of seasonal-rainfall exceeding 580 mm but 0% (no increase) of exceeding total annual rainfall for a 5-year return period in the semi-arid Ecotope of Limpopo South Africa.

Variability and anomalies in seasonal rainfall amount

There was notable high inter-seasonal variability and temporal anomalies in rainfall between 2001 and 2013. Results showed neither station nor season with persistent near average (RAI=0) rainfall especially from stations in the sub-humid region. For instance, in Machang'a, the wettest LRs were recorded in 2010 (RAI=+4) while wettest SRs were recorded in 2001 (RAI=+4), 2006 (RAI=+3.8) and 2011 (RAI=+4). In Embu, the highest positive anomalies (+5.0) were recorded in 2002, 2005 and 2007 during LRs (Figure 4).

Stations in sub-humid areas of Mbeere sub-County had more negative anomalies in rainfall amount received than Embu. An intra-station-seasonal comparison showed that SRs in Embu were less variable but drier than LR seasons. Conversely, SRs in Mbeere were wetter than SRs in Embu but more variable in Mbeere. Unpredictability of LR seasonal rainfall patterns and farmers' reliance on SRs has been reported (Cohen, 1987; Shisanya, 1990; Hutchinson, 1996, and Recha *et al*. (2012). Shisanya (1990) repported the failure of the LRs in 1984 prompted GoK to launch a national relief fund among other responses. Akponikpè *et al*. (2008) reported similar trends of high variability (CV=57%) in temporal annual rainfall (mono-modal rainfall between February and September), in the Sahel region. This study showed that, the decade between 2000 to 2013 experienced marked increases in SRs and a decrease in LRs. Nicholson (1993) and Hulme *et al*. (2001) attributed the decrease in LRs to the desiccation (drying out) of the March-to-August rains in Sub-Saharan Africa (SSA). A study by Tilahun (2006) based on the cumulative departure index established that parts of Northern and Central Ethiopia persistently received below average rainfall for the rains received between February and August since 1970. While studying vegetation dynamics based on the normalized difference vegetation index (NDVI), Tucker and Anyamba (2005) noted persistent droughts and unpredictable rainfall patterns marked by reduction in the NVDI values during LRs for periods approaching the 21st century. On the other hand, it was apparent that SRs recorded consistent above-average trends during this study; indicating possibilities of a reliable growing season especially for the drier Machang'a region. In tandem with this observation, findings by Hansen and Indeje (2004) and

Amissah-Arthur *et al.* (2002) observed that SRs constituted the main growing season in the drier parts of SSA and Great Horne of Africa for crops such as maize, sorghum, green grams and finger millet.

Generally, high variability (often attributed to La Nina, El Nino and Sea Surface Temperatures) could occasion rainfall failures leading to declines in total seasonal rainfall in the study area. According to Shisanya (1990), La Nina events significantly contributed to the occurrence of persistent droughts and unpredictable weather patterns during LRs in Kenya. In contrast, El Nino events of 1997 and 1998 have been cited as the key inputs of the positive anomalies in SR seasonal rainfall in the ASALs of eastern Kenya (Anyamba *et al.*, 2001; Amissah- Arthur *et al.*, 2002).

Variations in rainfall amounts and number of rainy days

On average, the total amount of rainfall received in all stations was below 900 mm (sub-humid stations) and 1400 mm (humid) per annum. Yet LRs contributed 314.9 mm and 586.3 mm while SRs contributed 438.7 mm and 479.1 mm translating to a total of 754 mm and 1084 mm of seasonal rainfall in in the respective station (Table 5).

Table 5: Variability analyses: coefficient of variations in seasonal rainfall amounts and number of rainy days in the study stations for the period between 2000 and 2013

Station	Season	RA	CV_RA	RD	CV_RD
Embu	LR_MAM	586.3a	0.36	46a	0.09
	SR_OND	457.2b	0.38	40a	0.27
Machang'a	LR_MAM	314.9b	0.41	24b	0.26
	SR_OND	458.7b	0.56	53c	0.88
Kiritiri	LR_MAM	343.7b	0.39	24b	0.28
	SR_OND	486.5b	0.45	52c	0.51
Kiambere	LR_MAM	203.3c	0.29	17d	0.49
	SR_OND	285.0d	0.30	37a	0.38
Kindaruma	LR_MAM	285.5b	0.47	17d	0.43
	SR_OND	316.9b	0.41	34e	0.37

Values connected by the same superscript letters in the RA column denote no significant difference between the seasonal rainfall amount mean values; MAM=March-May-June and OND=October-November-December and; RA=Rainfall Amount in (mm), RD=Rainy Days CV-RA= Coefficient of Variation in Rainfall Amounts, CV-RD= Coefficient of Variation in Rainy Days

These account for 90% of total rainfall received annually; implying that fewrw rainy days supplied much of the total amounts of rainfall received. Evaluation of variability based on coefficient of variation (CV) in rainfall amount (RA) and number of rainy days (RD) showed that most stations received highly variable rainfall.

A CV greater than 30% in rainfall data series indicate massive variability in rainfall amounts and distributional patterns (Araya and Stroosnijder, 2011). In Machang'a, Kiritiri and Kindaruma, LR were highly variable (CV = 0.41, 0.39, and 0.47) than those in Embu (CV = 0.36). Variability was also high in the number of rainy days (CV=0.51 and 0.49 in Kiritiri and Kiambere). Long rains and SRs amounts were not significantly different from each other in most stations of Mbeere but different in Embu (Table 5). These results indicate high variability of rainfall received across all AEZs in the study area, further evidenced by massive rainfall anomalies reported earlier by this study.

Findings of Seleshi and Zanke (2004) further showed that annual and seasonal rainfall (*Kiremt* and *Belg seasons*) in Ethiopia were highly variable with CV values ranging between 0.10 and 0.50.

Monthly variations in seasonal rainfall amounts and number of rainy days

Results showed that rainfall amounts received within seasonal months (March-April-May; LRs and October-November-December; SRs) were highly variable (all with CV>0.3).

Table 6: Variability in rainfall and number of rainy days between 2000 and 2013

Parameter	Mar	April	May	Oct	Nov	Dec
Embu						
RA (mm)	110.1	300.8	175.6	175.1	250.3	71.8
CV-RA	0.61	0.48	0.54	0.66	0.43	0.97
RD	20	14	12	10	13	17
CV-RD	0.47	0.27	0.27	0.59	0.25	0.83
Machang'a						
RA (mm)	85.5	160.2	69.2	98.9	267.9	72
CV-RA	0.98	0.42	0.69	0.8	0.77	0.86
RD	8	11	5	14	29	10
CV-RD	0.61	0.22	0.61	0.35	0.23	0.34
Kiritiri						
RA (mm)	88.7	167.1	87.9	110.4	274.3	101.8
CV-RA	0.61	0.48	0.54	0.66	0.43	0.97
RD	7	14	3	12	24	16
CV-RD	0.47	0.27	0.27	0.59	0.25	0.83
Kiambere						
RA (mm)	41.8	97.8	63.8	45	147	93
CV-RA	0.88	0.46	0.59	0.83	0.67	0.81
RD	3	12	2	11	17	9
CV-RD	0.51	0.2	0.53	0.31	0.23	0.4
Kindaruma						
RA (mm)	59.5	119.5	86.5	48.6	165.6	102.6
CV-RA	0.46	0.31	0.37	0.59	0.29	0.84
RD	2	12	3	9	18	7
CV-RD	0.62	0.48	0.52	0.46	0.36	0.84

RA (mm) = Rainfall Amount in millimetres; CV-RA= Coefficient of Variation in Rainfall Amounts, RD=Number of Rainy Days; CV-RD= Coefficient of Variation in Rainy Days

Notably, coefficient of variation in Rainfall Amounts (CV-RA) were quite high during the months of March (CV-RA=0.98) and December (CV-RA=0.86) in Machang'a and CV-RA=0.61 March) (and CV-RA=0.97 (December) in Embu (Table 6). Variability in the number of rainy days (CV-RD) for each seasonal month was equally high in the two study stations. For instance, March (CV-RD=0.61 and CV-RD=0.47) and December (CV-RD=0.34 and CV-RD=83) had the highest variability in the number of rainy days in Machang'a and Embu, respectively (Table 6).

Generally, onset months (March and October) and cessation months (May and December) received highly variable rainfall amounts compared to mid-seasonal months. Notably, Machang'a, though; being more of an arid region, it generally recorded lower variability in number of rainy days during SR seasonal months compared to those recorded at Embu during the same season, evidence of reduced variability and wetting of SRs in the region. In addition, it was evident that the amount of rainfall and number of rainy days received in the past decade in most stations were more consistent (temporally) in April and November but highly unpredictable in March (onset) and December (cessation). This significantly affects the cropping

calendar in rain-fed agricultural productivity of the region. Nonetheless, lower values of variations in the number of rainy days (CV-RD) indicated that variations in rainy days were fairly consistent compared to variations in rainfall amounts received. It would also appear that most stations in Mbeere region received more rainfall during SR season with November alone accounting for about 60% of total seasonal rainfall amount received while April accounts for 51% of the LR rainfall in the case of Machang'a. Conversely, Embu received more rainfall during LRs with April accounting for about 52% of total rainfall received. These trends indicate that SR seasons would be receiving more rainfall amounts than LRs in the region, a trend acknowledged by most (67.3%) smallholder farmers in SSA Amissah-Arthur *et al.* (2002) and Barron *et al.* (2003). Trends of high variability in seasonal monthly rainfall reported by this study have also been cited by Mzezewa *et al.* (2010) who reported high coefficient of variation for seasonal (315%) and annual (50–114%) rainfall in semi-arid Ecotope, north-east of South Africa. Additionally, Sivakumar (1991) found that annual rainfall in the Sudano-Sahelian zone of West Africa was less variable (0.36) than monthly (0.54) rainfall.

Droughts and dry-spell characterization

Results showed that the probability of occurrence of dry-spells of various durations varied from month to month of the growing season. High probabilities of dry-spells were in March (0.72 and 0.55) and December (0.8 and 0.6) in average sub-humid (Machang'a, Kiritiri, Kiambere, Kindaruma) stations and humid (Embu), respectively. The probability of having a dry-spell increased with shorter periods (for instance, more chance of having a 3 than a 10 or 21 day dry-spell).

On the other hand, the probabilities that dry spells would exceed these day-durations were equally high. There was 70% chance that dry spells would exceed 15 days in average Mbeere stations and 50% in Embu (Figure 6)

Dry-spells during cropping months are quite common that often trigger reduced harvests or even complete crop failures, in the study region. Rainfall being a prime input and requirement for plant life in rain-fed agriculture, the occurrence of dry-spells has particular relevance to rain-fed agricultural productivity (Belachew, 2002; Rockstrom *et al.,* 2002). It was observed that lowest probabilities of occurrence of dry-spells of all durations were recorded in the month of April (during LRs and (November (during SRs). The occurrence of dry-spells of all durations decreased from April towards May (LR) and November towards December (SRs). Indeed, the months of April and December coincides with the peak of rainfall amounts for both SR and LR growing seasons in the region (Kosgei, 2009; Recha *et al.*, 2012). This trend is in line with works reported by several studies in SSA, including Kosgei (2009), Aghajani (2007) in Iran and Sivakumar (1992) in East Africa. High probabilities of dry-spells occurring and exceeding the same durations show the high risks and vulnerability that rain-fed smallholder farmers are predisposed to in the study area. Often, prolonged dry-spells are accompanied by poor distribution and low soil moisture for the plant growth during the growing season. General high probabilities of persistent dry-spells in SSA have been reported by Hulme *et al.* (2001), Dai *et al.* (2007) and Mzezewa (2010). This could be attributed to the persistence of intermediate warming scenarios in parts of equatorial East Africa (Hulme *et al.,* 2001; Mzezewa, 2010). Prolonged dry spells during cropping seasons directly impacts on the performance of crop production. For instance, high evaporative demand indicated by high aridity index (P>0.52) in the drier parts of Eastern of Kenya implies that rain-water is not available for crop use and cannot meet the evaporative demands (Kimani *et al*., 2005). Thus, deficit is likely to prevail throughout the rain seasons as observed in other SSA regions (Li *et al*., 2006). Run-off collection and general confinement of rain-water within the crop's rooting zone could enhance rain-water use efficiency as demonstrated by Botha *et al.* (2003).

Conclusion and recommendations

Results showed that available rainfall data series from study station are homogenous, thus records of same population. Before frequency analysis of the rainfall data is done, various transformations are essential for the data to follow particular probability distribution patters. Weibull method for estimating probabilities and method of moment (MOM) parameter estimation methods proved to be sufficient for the task, in

evaluating data series homogeneity and frequency. Decadal rainfall trends showed that both long rains (LRs) and average annual rainfall have decreased in the past 13 years in the region. Mbeere region appeared to have experienced pronounced declines in rainfall amounts especially those received during LRs. Nonetheless, rainfall amount during SRs markedly increased in most study stations, with high amount gains established in the Mbeere stations. Evidently, probabilities that seasonal rainfall amounts would exceed the threshold for cropping (500-800 mm) were quite low (10%) in all stations. The amount of rainfall received during LRs and SRs varied significantly in Embu but not in Machang'a. There was evidence of increasing rainfall variability from Embu station towards Mbeere stations to as high as CV=0.88 in Machang'a. Probabilities that the region would experience dry-spells exceeding 15 days during a cropping season were equally high, e.g. 46% in Embu and 87% in Machang'a. This replicates high chances that soil moisture could be lost by evaporation bearing in mind the high chances (81%) the same dry-spells exceeding 15 days could reoccur during the cropping season. Based on these findings, it's apparent that farmers in the lower eastern Mbeere region be encouraged to intensify cropping during SRs as compared to LRs. It's equally important that they schedule supplementary irrigation; only based on timely, regular and accurate dissemination daily monthly and seasonal forecasts by the Kenya Meteorological Department. High rainfall variability and chances of prolonged dry spells established in this study also demands that farmers ought to keenly select crop varieties and types that are more drought resistant (sorghum and millet) other than common maize cropping. For instance, probabilities of having dry spells exceeding 15 days is relatively high (63%, 80%, 91%, 93% and 57% for Machang'a, Kiritiri, Kiambere, Kindaruma and Embu, respectively) during both SR and LR seasons. In this regard, the choice of crop variety and type should be based on the degree of its tolerance to drought. These decisions can be optimized if the probability of dry spells is computed after successful (effective) planting dates. There is need for establishing further precise, timely weather forecasting mechanisms and communication systems to guide on seasonal farming. In most arid and semi-arid regions, soil moisture availability is primarily dictated by the extent and persistency of dry spells. It is thus essential to match the crop phenology with dry spell lengths based days after sowing to meet the crop water demands during the sensitive stages of crop growth. Knowledge of lengths of dry spells and the probability of their occurrence can also aid in planning for supplementary risk aversion strategies through prediction of high water demand spells.

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Green infrastructure for enhancing soil-water-plant nutrient balance and climate change adaptation on smallholder field

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Abstract

Use of vetiver as a green infrastructure can address African farmers' ecological problems through protecting farmlands on steep lands. In addition, it offers the opportunity to integrate smallholders into the green economy as it sequesters carbon, keep water and nutrient fluxes within the system, sustain high crop yield with climate change adaptation potentials. This is particularly important as more slopes are converted to agricultural lands due to increase in population density and poverty. Thus, the study investigated the optimal strip width for increases in soil productivity and farmers' preferences for space. The study planted maize and cassava in between vetiver field structures (VFS) installed on the contour at 5, 15 , 25 m apart and compared it with Farmers' Practice (FP) on a 45% slope and quantified the amount of soil displaced, water and plant nutrient losses and crop yields. Vetiver installed at 5 m surface interval spacing significantly enhanced carbon sequestration indicating potentials for GHGs mitigation and reduced N, P, Ca, Mg, Na and K losses when compared with FP. Vetiver allowed only 7% rainfall lost as against 29% on FP this demonstrates the climate change adaptation potentials of vetiver. Soil displaced under FP was 68 times higher than the soil loss tolerance limit of 12 t ha^{-1} yr^{-1} whereas under VFS at 5, 15 and 25 m it was 2½, 13 and 12 times higher. Maize grain yield were 35, 23 and 24% higher on the VFS field at 5, 15 and 25 m respectively when compared to FP. The corresponding values for cassava fresh tuber were 43, 32 and 29% higher. Unlike other technologies, vetiver grass contributes to the livelihood of the farmers by providing raw material for house thatching, handicrafts and fodder for livestock during lean seasons.

Introduction

Steep land are land with an average slope of more than 12% (Shaxson, 1999). From scientific study and recommendation, steep lands are not suitable for cultivation as it is difficult to retain soil on it once the natural vegetation is cleared. The clearing of vegetation for cultivation exacerbates soil erosion and wastage of a nations vast amount of soil capital (Oku *et al.*, 2011; 2012). Most countries have an acceptable slope for cultivation; central Africa 12%, Philippines 25%, Isreal 35%, and Ethiopia 30% (Hudson, 1981; Grimshaw and Larisa, 1995). However, cultivators of these steep lands do not observe these slope limits and it is difficult for the government of these countries to implement this policy in the face of land scarcity and population pressure. Moving farmers away from these slopes where there are no flat lands to resettle them on will mean moving millions of people and their families away from their source of livelihood. Steep land cultivation will not only continue but will expand in the future (Juo *et al.,* 1998) particularly in Africa as the population increases and its quest to meet both food and nutritional security needs also increases. This therefore means more slopes will be converted to agricultural lands not by choice but by compulsion. How much soil, water and plant nutrient does a farmer loss when the farm on steep land is not protected is not known particularly for the south south region of Nigeria as literatures are not readily available. Although the farmer and crop scientists acknowledge annual reduction in crop yield due to erosion, by what margin does crop yield decline on the farmers' field when erosion is not controlled or increased when erosion control is not well known or documented.

Most reported erosion studies are on a gentle slope (< 10%) under simulated rainfall in field and laboratory. Literatures are scanty on erosion studies on steep land particularly under natural rainfall. Lal (1990); Boonche (2001); Inthapan and Soitong (2000); Soitong 2002 call for intensification of research on

quantification of erosion on steep land. Some research prescribed soil and water conservation methods for field slope include: stone lines, earthbund, ridges across the slope (Juo *et al*., 1998; Zougmore *et al*., 2000). These structures and methods are well suited for gentle slope (< 10%) . In the past, costly engineered structures had also been employed to control erosion but with little success (World Bank 1993; Grimshaw 1993; Truong *et al*., 2008). Vetiver grass structure for soil and water conservation was proposed by the World Bank (1993); Grimshaw (1993) and Grimshaw and Larisa (1995) as a better solution. Three species of vetiver grass are known namely; *Chysopogon zizanoides*, native to tropical India, *Chysopogon nemoralis*, native to Thailand and Vietnam and *Chysopogon nigritana* from Southern and West Africa. Reports from Truong *et al*., (2008) reveals the three species of vetiver do not have the same potentials. The potentials of *Chysopogon zizanoides* are well known and documented. The use of *Chysopogon nemoralis* was discredited due to its poor potentials when compared with *Chysopogon zizanoides* (Truong *et al*., (2008). The potential of *Chysopogon nigitana* native to Africa is not well known. This is because this species have not been used outside the African continent, and within the continent study is comparatively at its infancy Babalola *et al*., (2007) Oku *et al*., (2011). Being a green field structure, where very high slope limits the performance of engineering structures and other structures as earth bunds, stoneliness, ridges etc, the vetiver structure strives, holds the soil and protect the slope for cultivation, against failure. It enhances poverty alleviation through sustainable high crop yield and the use of its prunes for other purposes as fodder for animal during the lean season, handicraft when learnt, roof thatching, mushroom production substrate, compost, mulching material, etc.

Reports from localities where steep land cultivation is common in developing nations show that the soil is getting "thinner", stony and "tired" (Hellin, 2003). Yet farmers are not convinced that soil conservation would lead to increased crop yield. Farmers in the study location plant on steep land using mounds and without any soil protection measure. The mounds traditional tillage system is known to cause excessive soil loss (Armon, 1984). The overall objective of this study was to work in the farmers' field to find optimal vetiver within the farmers' field that would reduce soil erosion, increase crop yields, soil productivity and farmers' preference for space to carry out planting and conduct all pre and post planting cultural activities.

Materials and methods

The field study was conducted on steep agricultural lands (45 %) in the central region of Cross River State (CRS), South south Nigeria. (5º 45´ - 6º 30´ N; 8º 00´ - 9º 30´ E). The population of the community is about 172,444 people who are predominantly farmers (Cross River State Tourism Guide, 2005). The rainy season starts from April, while the dry season commences from October each year. The rainfall pattern is bi-modal with peaks in June and September. The annual rainfall of the area ranges from 2000 to 2250 mm (CRADP, 1992). The soils of the experimental sites are classified as Oxic Dystropept (Inceptisol) (Cross River State of Nigeria Ministry of Agriculture & Natural Resources, 1989). The slope was determined using a Dumpy level. The primary vegetation is the tropical forest transformed into a secondary forest and grasslands. The following crops; cassava, maize and egusi-melon mixture were previously planted on the experimental sites under the traditional mound tillage system.

The experimental plots were erosion plots with vetiver field structure (VFS) planted along the contour. Vetiver field structure was planted at different surface interval spacing; 5, 15, 25 m across the slope and field without VFS constituted the Farmers' practice {(FP) (control)}. The vetiver species planted and used for the experiment was obtained in the wild within the local community and was identified in the Department of Botany, University of Calabar, Nigeria to be *Chysopogon nigritana*. Erosion plots are devices for measuring runoff and soil loss from agricultural land. They are small plots on sloping land (Biswas and Mukherjee, 2005). Each erosion plot was 150 m^2 (Hudson, 1993) measured 50 m long and 3 m wide. The plots had all the sides enclosed by barriers (earthen bunds) 30 cm high. Each plot had an end funneled neck constructed with cement blocks and ending with a trough as in Figure 1. The end trough was fitted with multi-slots (3 outlet divisors) PVC (11 cm in diameter) pipes to direct flow into the sedimentation drum The multi slot device has an odd number of openings (Biswas and Mukherjee, 2005). Only the middle one was connected to the sedimentation tank (Miller, 1994). Runoff and soil loss are first received in the trough.

From the trough, the divisor allows 1/3 of the runoff and soil loss to pass through the middle PVC pipe and is collected in the sedimentation tank while the other two are diverted into the trench. The first collecting sedimentation drum is constructed with 7 multi-slots which collect initial runoff. Each plot had two sediment collecting drums. It is constructed such that an overflow from the first drum (multi-slots) runs into the tank. When the first multi slots drum is full, 1/7 or 14.29 % of the excess pass through a slot into the second tank. Others are allowed to waste. This is to deal with runoff from an excessive rainstorm (Miller, 1994). The sedimentation tanks were installed in the ground in a trench dug at the lower end of the erosion plots. The trials were laid in a randomised complete block design (RCBD). The treatments were replicated three and there were thus a total of 12 erosion plots.

Figure 1: Experimental plot showing a cassava and maize crop mixture. Erosion plot with funnel end trough and sedimentation drums place in a trench at the foot slope

The predominant traditional tillage (mounds) and traditional simple crop mixture (cassava and maize) farming system in the study area was adopted. Mounds were made 1 m apart with a total of 150 mounds per erosion plot (10000 mounds/ha). Three cuttings of local variety were planted per mound giving a total population of 30,000 plants per hectare. Supply of unsprouted and dead stems was done within 2 to 3 weeks after planting. Maize (Oba Super II hybrid variety) was planted at the rate of 3 seeds per hole at the base of each mound. The maize seedlings were thinned to two per mound one week after emergence. Measurements were taken for maize grain and fresh cassava tuber yields. A simple non-recording rain gauge was installed at the experimental site to measure the amount of daily rainfall on the location. The amount of rainfall was obtained after each rainfall by dividing the volume of rain collected from the area of the receiver surface (funnel). The runoff and soil loss were collected in the morning after an effective (rainfall that generates runoff and soil loss) previous day's rain. An aliquot of 860 cm^3 of runoff in the sedimentation drum was collected after stirring of the suspension. This was used to compute the total sediment loss in the sedimentation drums using total volume of suspension (Hudson, 1993). Soil collected in the trough was oven dried and weighed. The addition of the oven dried weight of soil from suspension and trough gave an estimate of the total soil loss from each plot (Miller, 1994). This was done with each effective rainfall. The volume of runoff was estimated by multiplying the height of water in each drum by the cross sectional area of the drum. Runoff amount (mm) was estimated by dividing the volume by the area of the plot generating the runoff (Hudson, 1993; and Miller, 1994). Data from runoff, soil displaced, carbon and nutrient losses and crop yields were subjected to analysis of variance using Duncan Multiple Range Test (DMRT) significance ($P<0.05$).

Results

Runoff and soil displaced from cultivated steep land

The amount of runoff between the vetiver field structure (VFS) were significantly different on the steep land (Table 1). Runoff was significantly higher on the Farmers' Practice (FP) field. However, runoff on VFS

at 15 m and 25 m were not significantly different from each other. The runoff was in the decreasing order of FP > VFS 25 m > VFS 15 m >> VFS 5 m. The amount of soil displaced from FP was significantly different from the VFS fields. The FP resulted in the highest amount of soil displaced from the field. Soil displaced were 19, 4 and 5 times higher on FP when than with VFS fields at 5, 15 and 25 m respectively.

Carbon and plant nutrient loss

Table 2 shows carbon and plant nutrient losses (kg ha^{-1} yr^{-1}) in eroded sediment. Carbon and plant nutrient losses were significantly higher in FP field. Whereas it was low under the VFS intervention fields. The trend for carbon was FP > VFS 15 m > 25m > 5 m, for nitrogen it was FP > VFS 15m = 25 m > 5m. Phosphorus loss was in the order of FP > VFS 25 > 15 m > 5 m. Calcium was in the order of FP > 5 m = 15 m = 25 m. That of Magnesium was FP > VFS 5m > 25 m > 15 m. Sodium and potassium followed the same trend FP > VFS 5 m = 15m = 25 m.

Table 1: Runoff (mm) and soil displaced on 45 % slope with annual rainfall of 1200 mm

Vetiver buffer Structure (m)	Runoff (mm)	% rainfall as runoff	Soil loss (t ha^{-1} yr^{-1})
Farmers' practice	347a	29	829a
5	89c	7	41c
15	147b	12	162b
25	152b	13	151b

Mean followed by the same letter are not significantly different ($p<0.05$)

Table 2: Carbon and plant nutrient losses (kg ha^{-1} kg^{-1}) carried away in eroded sediment from cultivated steep land

	Carbon and plant nutrient in eroded sediment						
Vetiver buffer structure (m)	C	N	P	Ca	Mg	Na	K
Farmers' practice	70a	7a	63a	4a	4a	29a	32a
5	32d	3c	22c	2b	3b	14a	19a
15	48c	5b	37b	2b	2b	14a	21b
25	45b	5b	42b	2b	3b	17b	21b

Mean followed by the same letter are not significantly different ($p<0.05$)

Cassava and maize grain yield

Fresh cassava tuber and maize grain yields (Table 3) among the treatments were significantly different. The FP field produced significantly the lowest fresh tuber yield whereas fields with VFS at 5 m had the highest yield. The yield on the FP was 43 , 31 and 29% significantly lower when compared with the yields on VFS at 5, 15 and 25 m, respectively. The maize grain yield on VFS was highest, but yield under the VFS at 15 and 25 m were not significantly different.

Table 3 : Maize grain and fresh cassava tuber yield (t ha^{-1}) under Farmers' Practice and vetiver field structure

Vetiver buffer structure (m)	Maize grain	Fresh cassava tuber yield
Farmers' practice	1.31c	9.22c
5	2.0a	16.21a
15	1.67b	13.54b
25	1.73b	13.01b

Mean followed by the same letter are not significantly different ($p<0.05$)

Discussion

Vetiver field structure (VFS) used as a green infrastructure to control erosion on cultivated steep land reduced runoff but its effectiveness depends on the space between the vetiver strips. The small space between the vetiver field structure enhanced reduction in runoff velocity and subsequently a delay in runoff accumulation. This led to increased infiltration into the soil and reduced runoff. This is consistent with the reports of Casenave and Valetiin (1992), Booche (2000), Oku, *et al.,* (2011). Under the FP , VFS at 5, 15 and 25 m it was calculated that 29, 7, 12 and 13 % respectively, of the rainfall were lost as runoff from the field to the valley bottom and water course as pollutant from agricultural field. The vetiver prunes in this study were harvested and taken out of the cultivated field. Given that the vetiver prunes were harvested and used as a surface mulch, little or no rainfall would have been lost on vetiver intervention fields particularly under VFS at 5 m. The farmer would have reaped the full benefits of rainfall on the field. Mulching of the surface enables the farmer get optimal benefit of rainfall as improved infiltration and water use efficiency. This is an indication that vetiver when used as a field infrastructure in the field is a climate adaptation and mitigation green structure.

Soil displaced from the unprotected cultivated steep field was 68 times higher than the soil loss acceptable limit (12 t ha^{-1} yr^{-1}) for soils of the tropics (Roose, 1996) and about 2½, 13 and 12 times above the tolerance limit on VFS at 5, 15 and 25 m respectively. The low amount of soil displaced from VFS intervention fields is consistent with earlier studies with vetiver on some gentle slopes (Khosrowpanah, 1991; Rao *et al*., 1992; Truong 1993; Harmavan, 1996; Nakalevu *et al.,* 2000; Babalola *et al.,* 2007. This vast soil resource eroded from the farmers' cultivated field and deposited in the valley bottom and water bodies causing siltation of water bodies, thus reducing the river depth. In addition makes navigation difficult, facilitates the shrinkage of the water body with subsequent migration of fishes and other aquatic organism leading to the loss of a source of livelihood.

Vast amount of organic carbon and other essential nutrients are being lost annually through the eroded sediments. The nitrogen and phosphorous loss from the field are deposited in the valley bottom and water courses down slope leading to nutrient enrichment (euthrophication) and pollution of water sources. The vast soil organic carbon lost from the cultivate field is converted to inorganic carbon and implicated in climate change. This proves the negative contribution of smallholder farms to Green House Gases (GHGs) when fields on the slopes are cultivated without soil protected structures and soil are washed away from the field. On the other hand, the low carbon loss recorded on VFS intervention plot demonstrates the carbon sequestration potentials of vetiver when used in the field as a green infrastructure for soil and water conservation. Similar report had been reported by Agriflora Tropical (2009), the report described vetiver as a leading contender for carbon sequestration. This also shows vetiver's climate change/green house gases mitigation potentials. Maize grain and cassava tuber yield increased in vetiver intervention fields as a result of reduced runoff, increased infiltration that resulted in improved water economy and availability in the soil within the plant rooting zone. It is known that water availability increases nutrient uptake and nutrient use efficiency (Mando, 1998). The interception of runoff by the green structure and spreading out aid infiltration. This is consistent with Zougmore *et al*., (2000) who observed large increased in soil water at 40 cm depth (rooting zone of planted crop) in fields with stonelines used for soil conservation compared with FP (no stoneline) as a control in the semiarid zone.

Conclusion

From this study it can be concluded that the potentials of *Chysopogon nigitana* in soil and water conservation are comparable to that of *Chysopogon zizaionides*. Vetiver significantly reduced runoff, improve water infiltration, retained soil and plant nutrient on steep land hitherto not scientifically suitable for cultivation and increased crop yields. The use of vetiver field structure significantly reduced loss of soil organic carbon thus revealing its sequestration potentials and a green infrastructure that offers the smallholder a cheap and effective way to adapt to climate change effects as it allows the farmer get maximum benefit from every rainfall and mitigate greenhouse effects (GHGs) through carbon sequestration. In addition, retain soil, sustain high crop yields, recycle water and plant nutrient within the farmers' field while preserving the soil for future generation. It is recommended that the capacity of

smallholders be developed in the use of this green technology through field farmers' school. In addition Agricultural Extension officer's capacity in this technology be developed for the sustenance and scaling-up of the technology.

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Exploring gender dynamics on perception of climate change on farming with focus groups in Machakos and Makueni Counties, Kenya

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Abstract

This paper presents findings from 16 focus group discussions (FGDs) which took place in June 2012 at Makueni and Machakos Counties with a view to understanding farmers' perception on gender role in regard to climate change in their farming systems. A total of 192 farmers from ten villages were randomly selected to participate in the FGDs. During the discussion, men were found to have noticed increased use of manure and fertilizer for fertility replenishment where as their female colleagues from both Counties noticed increased use of hybrid seeds as a remedy for dealing with impacts of climate change and variability. The farmers suggested that policy interventions aimed at cushioning them against food insecurity and harsh climatical changes taking into account gender sensitive integration measures were necessary.

Key words: climate change and variability, gender, perception, Makueni, Machakos

Introduction

Men are regarded as family heads in Kenya and have a major role in decision making and control of domestic assets. However, women, who play a major role in the household economy through provision of labour for agriculture production as well as for domestic purposes are overshadowed thus their efforts go unnoticed. This gender based inequalities along the food production chain impede an equal attainment of food security for men and women (World Bank *et al.,* 2009). Thus the effects of climate change and variability may increase the existing inequality in the agricultural sector. In addition, climate change and variability will affect agricultural sector with smallholder farmers likely to experience adverse impacts from climate change. This may reverse the achievement gained through the Millennium Development Goals (Habtezion, 2011). This is due to the frequency and severity of both droughts and flood already experienced in the past (Ojwang', 2010). Therefore, efforts to facilitate adaptation are needed to enhance the resilience of the agricultural sector, ensure food security and reduce rural poverty (Bryan, 2011).

In response to changing weather patterns, smallholder farmers have from time memorial been adjusting their farming practices to optimize agricultural production, ensure food security and improve their livelihoods. Some of these farming practices fall under "Climate-smart agriculture". Climate smart agriculture is agriculture that sustainably increases productivity, resilience to harsh climatic conditions and enhances achievement of national food security and development goals (FAO, 2010). The study aims at assessing how men and women view changes taking place in their farming systems which are associated with climate change and variability. This is because due to the existing gender inequality, men and women do not experience climate change and variability equally (Skinner, 2011). Thus climate change may worsen the existing gender in equality (Habtezion, 2011). According to Habtezion, 2011, there is a direct relationship between gender equality, women's empowerment and climate change therefore there is need to focus on how both men and women respond to climate change (Aboud, 2011). Women are said to be more vulnerable due to the fact that they are less educated and are excluded from political and household decision making processes that affect their lives (Habtezion, 2011).

A predominantly semi-arid Ukambani occupied by the Kamba tribe was picked for this study. Generally, rural residents of Ukambani report frequent crop failures and water shortages, and food relief has become a permanent feature of rural life. According to Jaetzold and Schmidt (1983) a community leader in a semi-arid part of Kitui District, classified 51 per cent of the years from 1947 to 1979 as "bad" or "very bad" famine years. The Machakos District was a net importer of maize for 14 of the years between 1942 and 1962 for which data are available, and for eight of the years from 1974 to 1985 (Ackello- Ogutu and Mbogoh, 1991). The ever-present need for food relief has been variously attributed to overpopulation and environmental degradation, to colonization and development, or to insufficient development.

The FGDs therefore was aimed at capturing the changes occurring in their systems and the strategies aimed at meeting these challenges and the implication of these change on gender specific roles at Makueni and Machakos Counties.

Methodology

This paper presents findings from 16 focus group discussions (FGDs) which took place in Makueni and Machakos Counties between 1 and 15 June 2012 and included 192 members from the areas surrounding the Katumani and Kambi ya Mawe Kenya Agricultural Research Institute (KARI) Centers. The farmers were selected across each Location with the assistance of the provincial administration. The 192 members who participated in the FGDs were chosen from a sample of 348 randomly selected households who had participated at CALESA Project (Adapting Agriculture to Climate Change using Promising Strategies using Analogue Options in Eastern and Southern Africa) baseline survey conducted between June – September 2011. In each site, separate FGDs were conducted with women and men separately with four sets of age groups: 18-34 years, 35-44 years, 45-54 years and above 55 years. In each FGDs participants were asked to discuss agricultural practices in relationship to climate change and variability from three different perspectives: changes which have occurred, measures taken and gender role implications. This process allowed an initial open brainstorming discussion to take place followed by a consensus finding exercise where the three most important changes in agricultural practices were identified by the group.

Data analysis

The qualitative study was conducted as described by Ayayo (2004). The analysis was done using Content Analysis in which the data were broken down into themes and summarized to supplement important information with respect to the objectives of the study. Therefore, the descriptive quantitative data are being treated cautiously because the FGDs were initially not intended to be sources of quantitative data and the percentages provided should be seen as indicators of the relative importance of the issues raised by each FGDs (Davis, 2007) and to help direct further research in the quantitative research. The results are estimates based on judgements made by discussants and the author.

Results and discussions

Half of the men and women participants from Machakos County had visited different research centres. The farmers were therefore aware of the activities at KARI-Katumani with most of them indicating that the centre train farmers on crop management, conduct workshops, weather forecast as well as undertaking crop and animal research. The number of the farmers who participated in the FGDs is given in Table 1.

Table 1 : Composition of the participants in the study area

Age (years)	Machakos		Makueni	
	Men	Women	Men	women
18-34	12	12	12	12
35-44	12	12	12	12
45-54	12	12	12	12
Above 55	12	12	12	12

Changes observed in agricultural practices

The focus groups were requested to outline the changes observed over the years in their agricultural practices. The changes are listed in Tables 2 and 3 as reported by both in age and gender.

Table 2 : The most important changes in agricultural practices linked to climate parameters reported by focus group discussions

Observed changes	Frequency of inclusion	Percent groups				
		Total	Male	Female	Male	Female
			Machakos		Makueni	
Increase use of manure and fertilizer	15	81.5	75	75	100	75
Increased use pesticides	14	37.5	25	50	25	50
Increased use of hybrid seeds / changed from local to early maturing variety	11	56.25	25	100	25	100
Water management - terraces increased in their farms	10	56.25	50	75	25	75
Early preparations /planting of farms due to changing rainfall patterns	9	31.25	50	00	75	00
No longer intercrop/monocropping	6	37.5	00	25	25	25
Use of tractor	6	37.5	50	25	25	00
Grow increased crop varieties/ Growing cash crops/ diversification/grafting of fruit trees	5	75	50	00	25	00
Soil erosion control measures	2	25	00	25	00	00
Seed treatment	2	25	00	00	00	25
Adopted tree planting	1	25	00	00	00	00
Use seasonal forecasting	1	00	00	00	00	00

Table 3: Changes in agricultural practices linked to climate parameters per age group (years) in both Counties

Observed changes	Percent farmers			
	Young (18-34 years)	Middle-aged (35-44 years)	Middle aged (45-54 years)	Old (above 55 years)
Increase use of manure and fertilizer	75	100	100	50
Increased use of hybrid seeds / changed from local to early maturing variety	25	100	100	25
Water management (terraces increased in farms)	75	75	50	50
No longer intercrop/mono cropping	25	25	25	50
Use of tractor	75	25	25	25
Early preparations /planting of farms due to changing rainfall patterns	25	00	75	6.25
Soil erosion control measures	25	00	00	00
Increased use pesticides	25	50	25	25
Seed treatment	00	00	00	00
Adopted tree planting	00	00	00	00
Grow increased crop varieties/ Growing cash crops/diversification/grafting of fruit trees	00	25	25	25
Use seasonal forecasting	00	00	00	25

Farmers confirmed to have adapted different farming techniques to keep abreast with the unpredicted climatic changes in order to put food on the Table. The use of manure and fertilizer for improving soil fertility topped the list of measures taken by the farmers to cope with adverse climate changes as it was mentioned in 15 FGDs, followed by use of pesticides (14 FGDs) and increased use of hybrid (eleven FGDs). Generally, the focus groups regardless of gender and age differences identified use of manure and fertilizer to be on the increase (81.5%) due to its easy access followed by increased water management and use of hybrid seeds at 56.25% as shown in Table 2. These results attested to Odame (1997) findings that identified declining soil fertility as a major problem facing Kenya's smallholder farmers. To deal with this challenge, farmers in these two Counties had seen major changes in the increase of the use of manure and fertilizer. Makueni County has been targeted for rainwater harvesting by various organizations due to dry conditions. However a majority of famers had turned to traditional pesticides like use of ash to minimize the effects of fungal diseases on maize and blight on beans and tomatoes.

The major changes for male participants from Machakos County were increased use of manure and fertilizer (75%) with growing of cash crops, use of tractor and early land preparation tying at 50 %. This scenario is similar to studies done in the Congo climate programs where men tend to grew cash crops while women grew food for the family (Hubert, 2013). For the female participants, the major change was increased use of hybrid seeds (100%) with water management, increased use of manure and fertilizer tying at 75%. The male participant from Makueni County considered the three major changes in their agricultural practices which has occurred over the years to be increased use of manure and fertilizer (100%) and early land preparation (75%) with all other mentioned changes tying at 25%. The major changes for female participants from Makueni were use of hybrid seeds (100%), use of manure and water management both with 75%.

The men participants were in agreement that they used higher quantities of manure or different types of fertilizers with an aim of increasing yields while women are more concerned with seeds for planting. These observations are similar to those observed in Colombia where women are custodians of agro-biodiversity and ensure that seed exchanges occur at every community meeting (Aboud, 2011).

Despite biting financial constraints, men sacrificed other family expenses to address decreasing soil fertility. "These days it's a must to use manure or fertilizer if you want to get some yields and nowadays manure is not free as it was 30 years ago' confirmed a male participant form Machakos.

This concurs with observations by Herman (2010) which showed that declining soil productivity has led to decreased food security and increased poverty. It is documented t that manure improves soil structure and increases crop yields (Kihanda *et al*., 2006). Female participants had increased number of terraces or renewed them at their farms or husband's farm. Low rainfall was linked to the quest for conserving water for the female participants. This was mostly true due to improved maize varieties. Use of hybrid seeds was ranked as the major change for young farmers aged 18-34 years, while use of fertilizer was ranked high for participants aged 35-44 years, and water management for farmers aged 18-34 and 35-44 years.

"Even though I endeavour to use hybrid maize seeds, this is undermined by the presence of fake seeds in the market. There is lack of suitable seeds in the market with the Government seeds distributed one month after we have planted" Said a female participant from Makueni.

Use of pesticides featured high with fourteen of FGDs mentioning it. However, it was not featuring as one of the three major changes.

There has been increase of fungal diseases for maize, and blight in beans and tomatoes, but we use ash to control these pests and diseases' said a female a farmer from Machakos.

Farmers linked the changes occurring at their farms to changes in soil infertility, low rainfall or short and intensive rainfall, high population, high pest and disease infestation and deforestation. There was agreement across the FGDs confirmed that rains had become unreliable such that one was not sure when to plant Unpredictable weather and seasons; increased frequency and intensity of droughts, floods; warmer temperatures resulting in heat stress had all been identified as impacts of climate. All the participants concurred that the changes were bad as it worsened food insecurity. According to Awuor, (2009) some of the identified constrains while implement community projects were sudden attacks of crops by pests and diseases, and erratic weather.

The female participants from Machakos were in concurrence how farming had changed. They remembered how thirty years ago they used to plant local varieties with good yields and they could even know the exact date of planting because rains were reliable. Farmers used manure and you could get it even from neighbours since it was not being sold.

"I started using fertilizer since 2002 and the prices has since increased" a female participant complained". According to the female participants in Makueni, farmers had changed to early maturing varieties and drought resistant varieties. Thirty years ago, the farmers practised intercropping with good harvest due to reliable rainfall and incidences of pest attack were low. In those days, there was no early planting as they planted on the onset of rainfall. "I have started realizing higher yields since I started using fertiliser" said one male farmer from Machakos said.

Even though farmers had different views, they agreed that the best way to deal with changing weather patterns was through the use of hybrid seeds. To cope with short rains experienced in the region, those FGDs also appreciated the use of drought resistant crops like sorghum and cassava to ensure food sustainability. However, farmers lamented over the existence of fake hybrid seeds in the market. They also lacked professional advice on which type of seed to use. Farmers also acknowledged change of lifestyle as a contributing factor had made many farmers abandon indigenous crops that are drought resistant. Many lamented that their children did not like food stuffs from sorghum.

"During my childhood, farming was a clan issue where by everyone helped in weeding and spreading manure, nowadays I have to use a tractor to plough in order to be assured of good yields", said male farmer from Makueni.

Conclusions and recommendation

From the discussions, it was found that men and women perceived changes differently in their agricultural practices irrespective of the age. However, more quantitative analysis is being done to link it to more factors such as education, labour and employment status. Currently, most climate policies treat women as vulnerable beneficiaries and their skills and experience usually go unnoticed. Thus it's important to take into account both the women and men preferences and knowledge when formulating adaptation measures at local level. However quantitative research is being done focused on the challenges climate change and variability presents to women and men farmers. It was also clear that farmers lacked professional advice on effective farming methods like selection of hybrid seeds and pesticides to use in their farms. For this reason, extension services should be improved in these two Counties. In addition, policy makers should take into account the challenges women are facing at households level and raise awareness to enable them get involved in household decision making. Stakeholders should advocate for gender sensitive policies and process that shelter women from being affected by climate change and variability more that the men.

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Improving livelihoods in semi-arid regions of Africa through reduced vulnerability to climate variability and promotion of climate resilience

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Abstract

Climate change is expected to be one of the major threats to sustained economic growth leading to extended poverty in semi-arid regions of sub Saharan Africa (SSA). The areas of highest vulnerability are the health sector, food production, biodiversity, water resources, and rangelands. Climate change will likely create increasingly high temperatures and dry conditions across much of the globe in the next 30 years, especially along large parts of Eurasia, Africa and Australia. Many of the world's most densely populated regions will be threatened with severe drought conditions. It will likely have a profound and negative impact on livelihoods of many rural and urban communities, which could lead to changes in land use. It is estimated that the Eastern regions of Africa will experience reduced average rainfall (although some areas may experience increased average rainfall) exposing agriculture to drought stress and a rise in temperature. The situation will be worsened by the interaction of multiple stresses factors occurring at various levels, which will negatively impact agricultural productivity. Many policy makers in governments are unaware of this long-term climatic impact, often leading to land use changes, and governments have low or no adaptive strategies or capacity to make people aware of climate change and climatic impacts in the long-term. Adaptation and mitigation strategies are two general responses to manage effects of climate change and variability. Although adaptation represents the best coping option against agricultural output reduction and hence resulting in improved livelihood of small holder farmers; mitigation actions will contribute to global efforts of greenhouse gas emissions reduction, sequestration of carbon as practical measures for climate change recovery, taking advantage of the carbon storage capacity of tropical environment and improving ecosystem services of the natural resource. This paper highlights measures which can be put in place by stakeholders to improve incomes and livelihoods in semi-arid regions of Africa through reduced vulnerability to climate variability and promotion of climate resilience in development investments, enhancing biodiversity, increasing yields and lowering greenhouse gas emissions.

Background

Climate change is expected to be one of the major threats to sustained economic growth that will lead to extended poverty in sub Saharan Africa (SSA).The situation is similar to other semi-arid regions of Asia. The areas of highest vulnerability are the health sector, food production, biodiversity, water resources, and rangelands. Climate change will likely create increasingly high temperatures and dry conditions across much of the globe in the next 30 years, especially along large parts of Eurasia, Africa and Australia (Cooper *et al.,* 2013. Many of the world's most densely populated regions will be threatened with severe drought conditions. It will likely have a profound and negative impact on livelihoods of many rural and urban communities, which could lead to changes in land use. Smallholder farmers provide up to 80% of the food in developing countries, manage the majority of the farmland, and many live in some of the most vulnerable and marginal landscapes that experience unpredictable rainfall patterns. Drylands occupy 41% of the earth's land area and are home to 2 billion people. About 50 per cent of the world's livestock is supported by rangelands, and some 44 per cent of cultivated areas are in dry lands. However, more than 12 million hectares of arable land are lost to land degradation and desertification every year and the rate is rising as a result of climate change (Jeannette van de Steeg *et al.,* 2009; www.unccd.int, 2012). Land degradation affects 40 per cent of the earth's surface and damages the livelihoods of some 2 billion people living in dry lands, especially women and youth. Land degradation in dryland regions is a driver of climate

change. Yet the linkages between climate change and dryland degradation have so far scarcely featured in climate change policy debate. Desertification and land degradation are reducing the capacity to sustain ecosystems and human livelihoods. Despite this, dry lands in semi-arid regions still play a major role in global agriculture production.

Agriculture directly depends on climatic factors for crop and livestock production. Agricultural practices are also indirectly affected by landscape and environmental changes brought about by climate change. It is the SSA countries whose economies heavily depend on agriculture (cultivation of crops and livestock production) and forestry that are particularly vulnerable to climate change and variability, and will bear about 80% of the effect (Mendelsohn *et al*. 2006). Several industries and investments in SSA are agro-based. Declining agricultural output is likely to affect value chains. Though of smaller magnitude, a reduction in agricultural GDP can affect the rate of industrialization and the overall development process of many SSA countries and constrain creation of non-farm rural and urban employment opportunities through backward and forward linkages to service and manufacturing sector activities (Hanmer and Naschold, 2000, Kanwar, 2000; Kogel and Furnkranz-Prskawetz, 2000).

It is projected that several ecosystems will experience a number of climate related stresses. It is estimated that especially the Eastern regions of Africa will experience reduced average rainfall (although some areas may experience increased average rainfall) exposing agriculture to drought stress and a rise in temperature (Cooper *et al*., 2013). The situation will be worsened by the interaction of multiple stresses factors occurring at various levels. For example heat and drought stresses often occur simultaneously. Combined, these affects will negatively impact agricultural productivity. According to the Secretary General of the UN, Ban Ki-Moon, "Continued land degradation – whether from climate change, unsustainable agriculture or poor management of water resources, is a threat to food security, leading to starvation among the most acutely affected communities and robbing the world of productive land ((John Pender *et al.*, 2009)

In addition, many policy makers in governments are unaware of this long-term climatic impact, often leading to land use changes. Governments have low or no adaptive strategies or capacity to make people aware of climate change and climatic impacts in the long-term. Climate change is expected to reduce yields of major crop staples and will condemn portions of currently cultivated land into unsuitable status for cultivation across many parts of SSA. It is estimated that yields of tropical grain crops are expected to be reduced by 5 – 11 % by the year 2020 and by 11 - 46 % by 2050 (Rosenzweig and Parry, 1994; Schlenker and Lobell, 2010; Blanc, 2012), negatively impacting on the small scale farmers who solely rely on rain-fed agriculture for their livelihood (UNDP, 2008; IPCC, 2007, UNFCCC, 2007). Projected GDP losses in SSA are estimated to range between 0.2 to 2% by 2100 (Tol 2002a). National adaptation and mitigation planning is urgently needed. In addition, low agricultural productivity has increased pressure on traditional grazing lands by expanding cultivation into rangelands. This has lead to more rapid degradation of rangeland ecosystems.

If the ultimate effect of climate change and variability is not attended to, it may contribute to political instability and migration, at both intra- and regional levels. A recent survey conducted by IFPRI with the support of World Bank identified migration as one of the major adaptation strategies among the communities in semi-arid environments. (World Bank 2000; IFPRI 2010) A number of regions/sub-regions across SSA have just emerged from, or are experiencing conflicts. A new wave of ecological refugees will spark a series of conflicts among communities and complicating the development agenda of several SSA countries, if there is no action to reduce the effects of climate change now(UNFCCC undated). A good baseline study to complement earlier efforts on the possible effects of climate change in vulnerable, poor countries is therefore urgently needed, before sustainable mitigation measures can be implemented that will stabilize or stimulate economic growth in the long-term.

Adaptation and mitigation strategies are two general responses to manage effects of climate change and variability. Although adaptation represents the best coping option against agricultural output reduction and hence resulting in improved livelihood of small holder farmers; mitigation actions will contribute to global efforts of greenhouse gas emissions reduction, sequestration of carbon as practical measures for

climate change recovery, taking advantage of the carbon storage capacity of tropical environment and improving ecosystem services of the natural resource (FAO 2001;World Bank 2012).

The African Development Bank (AfDB) for example has developed their Climate Risk Management and Adaptation (CRMA) strategy which outlines key priority areas of intervention in order to manage the risks posed by climate change.

The goal as stated in the strategy document is "to ensure progress towards eradication of poverty and contribute to sustainable improvement in people's livelihoods taking into account CRMA". "Specific objectives are to:

- Reduce vulnerability within the regional member countries (RMCs) to climate variability and promote climate resilience in past and future Bank financed development investments making them more effective. Build capacity and knowledge within the RMCs to address the challenges of climate change and ensure sustainability through policy and regulatory reforms."

To achieve these objectives the AfDB considered supporting three areas of intervention namely:

- "*Climate Proofing*" investments to ensure that development efforts are protected from negative impacts of climate change, climate variability and extreme weather events.
- Support the development of *Policy, Legal and Regulatory Reforms* which creates an enabling environment for the implementation of climate risk management and adaptation interventions.
- *Knowledge Generation and Capacity Building* for local farmers, investors, extension agents, district executives or policy makers to help mainstream climate change and manage climate risks

Over time, some SSA countries are or have also developed their climate change policy plans including the National Adaptation Programme Actions and National Appropriate Mitigation Actions. Investments are needed in building up assets, implement recommended promising technologies/practices (e.g. water harvesting, storage, irrigation system, introduction of drought tolerant high yielding crops, value addition) and improving risk management capacity. As acknowledged by Stern (2006), the biggest threat climate change poses to economic growth is the use of inefficient mitigation and adaptation policies and practices (Stern, 2006). To improve the efficiency of these actions, it is important that they are based on accurate spatio-temporal impact diagnosis, and supported by a greater public understanding of these strategies and individual roles.

Unfortunately significant gaps of knowledge exist on the most appropriate interventions to use. Many actors (government, agencies and investors) are asking what options exists and which should be implemented to improve the livelihoods of the rural poor. The bottom-line costs and/or benefits of these interventions need to be known if they are to be planned and implemented and investments sources to support their development.

Therefore, there is need to therefore to continue grappling with ideas, as well as ways and means which can contribute towards improved incomes and livelihoods in semi-arid regions of Africa through reduced vulnerability to climate variability and promotion of climate resilience in development investments, enhancing biodiversity, increasing yields and lowering greenhouse gas emissions.

Key interventions

- There is need first of all to quantify vulnerability to climate change, adaptation approaches by systematic monitoring across landscapes and identify barriers to successful mainstreaming of these adaptation measures in country national plans.
- This needs to be followed by developing, promoting and adapting site specific mitigation/adaptation measures for various crop-livestock land use systems
- Thirdly, development of Policy, Legal and Regulatory frameworks in order to create an enabling environment for the implementation, promotion and scaling of climate risk management and adaptation interventions needs to be emhasised.

- Sub-saharan Africa also needs to build Capacity to mainstream climate change and manage climate risks for various land use systems

Expected outputs from the interventions

- Vulnerability to climate change, and climate change impacts quantified and mainstreamed in country national development, management and policy plans.
- Site specific adaptation and mitigation measures for various crop-livestock land use systems developed and promoted in arid and semi-arid areas
- Policy, Legal and Regulatory frameworks developed and promoted and scaled in order to create an enabling environment for the implementation of climate risk management and adaptation interventions.
- Capacity to mainstream climate change and management of climate risks for various land use systems by national scientists, agriculturalist, environmental experts and policy makers developed

Expected outcomes of the interventions:

- Implemented country development plans embrace, adopt and mainstream climate change impacts at national and regional/county levels
- Improved incomes and livelihoods in semi-arid regions through yield increases in crop-livestock production systems, reduced crop and livestock losses and reduced greenhouse gas emissions as a result of implemented adaptation and mitigation measures for climate change.
- Action plans on climate risk management and adaptation interventions implemented in project countries.
- Trained national scientists, agriculturalists, environmental experts and policy makers mainstream and implement climate change and management of climate risks for various land use systems in project countries

Expected impact

- Impact on livelihood: Improved household incomes and livelihoods, improved national GDPs
  - Ultimate beneficiaries are resource poor farmers and other members of the rural and peri-urban poor associated with the agricultural sector
  - Benefits are realized through reduced vulnerability, raised adaptive capacity and higher income
- Impact on food security
  - Benefits on rural and urban populations
- Impact on environmental health and carbon storage
  - Benefits for both local beneficiaries and a global public goods benefit

Although the notion of securing win-win-win outcomes for these dimensions is appealing (Global Donor Platform 2009; FAO 2009a), we have to recognize the possibility of trade-offs among these dimensions (Campbell, 2009; FAO, 2009b)

Proposed theory of change:

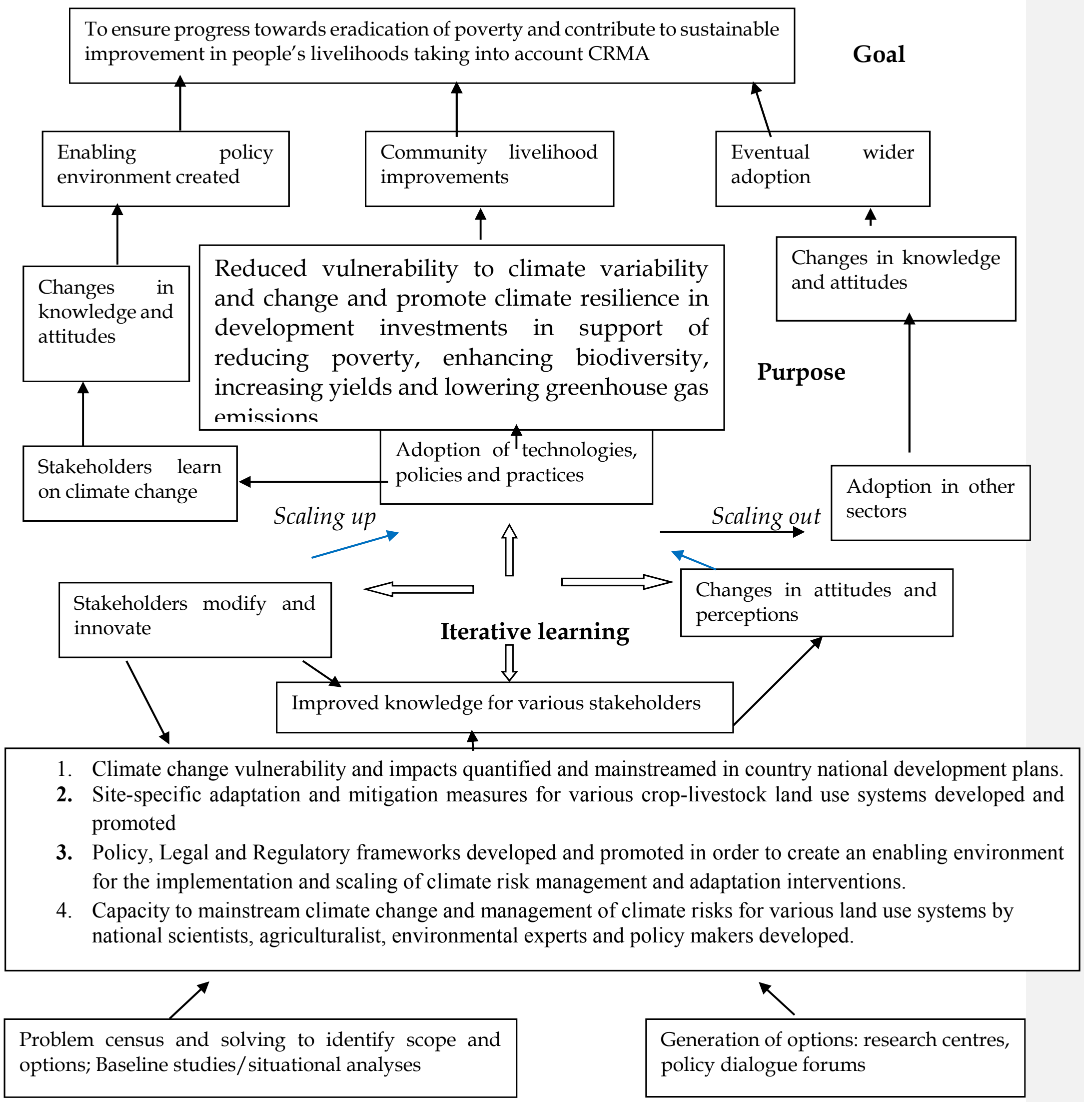
Reduced vulnerability to climate variability and change and promotion of climate resilience requires development of investments in support of reducing poverty, enhancing biodiversity, increasing yields and lowering greenhouse gas emissions. This will be achieved through the following preconditions. Firstly, the project will undertake a quantification of vulnerability to climate change, adaptation approaches and identify barriers to success mainstreaming of these adaptation measures in country national plans. This will this include identifying key metrics of vulnerability in crop-livestock systems, rangelands, agricultural systems.

Secondly, the formulated projects will need to develop, promote and scale climate change adaptation and mitigation measures for various crop-livestock, land use systems in arid and semi-arid areas. Thirdly the

formulated projects will require to undertake activities that promote development of policy, legal and regulatory frameworks in order to create an enabling environment for the implementation of climate risk management and adaptation interventions. Finally the proposed projects will need to build capacity to mainstream climate change, manage climate risks for various land use systems as well as mainstream gender along selected agricultural product value chains.

Indicators for these preconditions which will be used to assess the performance of the interventions will be an inventory of vulnerable groups, adaptation approaches, and barriers to mainstreaming these approaches in sub-Saharan Africa. A wide range of climate change adaptation and mitigation measures will need to be promoted and scaled. These will include improved land use planning, improved agricultural practices that enhance soil carbon stocks, better livestock management, use of drought tolerant crops, improved irrigation and water use efficiency, and rain water harvesting. A set of policy documents will then need to be developed for the participating countries from which action plans will be generated and implemented. Researchers, extension workers, policy makers and other relevant stakeholders will be trained and then subsequently use this knowledge and share it with other parties to achieve project overall goal. Training will include simulation modeling, greenhouse gas emission measurements, carbon stocks measurements, and participation in carbon credits market for participating countries.

Expected Impact pathway:



Partners:

Building strong partnerships will form an essential component of our consortium strategy to ensure the long-term impact of this initiative and provide the greatest opportunity for knowledge transfer. Partners will include, but are not limited to:

- CGIAR Centres
- Non-governmental and community based organizations for rural development
- National agricultural research systems
- Ministries responsible for NAPAs and NAMAs
- Regional clean development brokers
- Climate change Units
- Gender mainstreaming experts
- Private sector
- Development partners

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Characterization of climate risks in dryland crop-livestock systems of Kenya

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Abstract

The complex form of resource management and vastness of dry lands in Kenya make it very difficult to assess risks associated with climate change. In this paper, we propose the use of a framework for exploration of climate risk assessments. The qualitative risk matrix encouraged stakeholder involvement and classified climate impacts into four severity categories: minor, moderate, major and severe. The likelihood of occurrence of impacts ranges from unlikely to extremely likely. A combination of Likelihood and severity determine the risk level. The assessment followed four steps where stakeholders documented risks and their consequences in matrices. Climatic impacts with Extreme risk level were droughts and sea water intrusion while. reduced and erratic rainfall had an overall high-risk level The climat factors are of greatest concerns to inhabitants in the ASALs and should be incorporated into adaptation decisions.

Key words: climate change, risk, impact, adaptation, vulnerability, policy.

Introduction

Dry lands in Kenya cover up to 80% in area and are characterized by low and erratic precipitation, high temperatures and high rates of evapo-transpiration. Dry land include Arid and Semi Arid lands (ASALs) and support a growing population of pastoralists and agro-pastoralists. Grazing is a predominant land use especially in the Arid regions while Semi arid areas are characterized by rain-fed and irrigated agriculture, agro pastoralist, fishing, hunting and gathering. Grazing support livestock production contributing 12% of the total Gross Domestic Product (GDP). Dry lands livelihoods represent a complex form of resource management, involving a continuous ecological balance between pastures, livestock, crops and people (WISP, 2007). The environment is fragile in terms of economic and livelihood potential however, over millennia pastoral and agro-pastoralists have shown considerable capacity to cope with water scarcity, variability in rainfall and recurrent weather related shocks (IAASTD, 2009). However, there are concerns whether they will be able to adapt to future changes, l*et al*one continue to cope with already occurring variability and uncertainty (TEAR FUND 2010) as traditional coping strategies become increasingly insufficient (UNCCD/UNDP/UNEP,2009). High poverty levels (GoK, 2008), demographic growth (GoK, 2009), land degradation due to over grazing, poor soil management practices prevail in ASALs and these are exacerbated by the climatic changes occurring globally (IPCC, 2007).

Climate model scenarios for Kenya show increases in temperature of 1^{o} by 2030 and 1.5 ^{o} by 2050 for a mid-range emission scenario (CSAG and SEI, 2009). Recent studies project increased drier and drought conditions in the ASALs (Williams A. P. and Funk C., 2011). So far uncertainties exist in climatic projections. Nonetheless, climate is changing and by 2030 and beyond it will unlikely be the same as at present. Climate is closely linked with environmental resources and variability and extreme events pose risks to people's livelihoods. Risk is the potential impact of a hazard to an asset and involves a combination of an event, its likelihood and consequences. Although there is some understanding on the potential consequences of climate change for pasture and crop production, the magnitude and likelihood of these consequences is

less understood. Completing a risk assessment can identify risks, assess their significance, their likelihood of occurrence, consequences should the event occur in the future and identify climate change impacts of most importance and adaptation strategies

The main aim of this paper is to assess climate impacts and trends including their uncertainty in pastoral and agro-pastoral systems production systems in the lower Tana delta and Transmara counties in Kenya.

Materials and methods

Study sites

The study was conducted in pastoral and agro-pastoral production systems in lower tana and Transmara district, Kenya. Transmara lies between latitude 0º 50' and 1º 50' south and longitude 34º 35' and 35º 14' east with an altitude of 1500-2500 m. Topography is characterised by highlands and plateaus. Mean annual rainfall is about 1600 mm and temperatures fluctuate between 16-28 °C, the lower midland zones being hotter throughout the year.

Identification of key climatic factors and their impacts on livelihoods in the ASALs. Analysis of predominant climate trends and identification of key climatic factors was conducted by analysing climate data and gathering stakeholder and expert views in stakeholder workshops.

Rainfall data for 42 years (1968-2010) from Kenya Metereological weather stations in Kilgoris, and Galole, in tana delta were analysed .Confidence levels of climatic trends were generated and used to assess the degree of uncertainty of the climatic factor. (IPCC, 2007). The likelihood terminology and corresponding values are indicated in Table 1.

Table 1: Description of likelihood assessment of climatic factor having occurred or occurring in the future based on climatic data analysis and expert view

Likelihood Terminology	Likelihood of the occurrence/ outcome
Virtually certain	> 99% probability
Extremely likely	> 95% probability
Very likely	> 90% probability
Likely	> 66% probability
More likely than not	> 50% probability
About as likely as not	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Extremely unlikely	< 5% probability
Exceptionally unlikely	< 1% probability

Source: IPCC (2007)

Stakeholder workshops. We adopted a modified risk assessment framework (AGO, 2006; George *et al*., 2009, WBI, 2010) to assess climatic risks. A climate risk matrix was developed in a series of stakeholder workshops. During each stakeholder workshop 4 distinct steps were followed to complete the risk assessment exercise which includes: Step 1. Understanding the scope of the assessment, identify climate

change factors of interest to stakeholders and how they impact on sectors of interest and assess the level of confidence in their projections., Step 2. Evaluating the likely impacts of climate change using expert and local knowledge. Step 3.A risk assessment of the impacts to identify the threats of the impacts, the consequences and likelihood of occurrence of the impact. Step 4.completed the risk assessment of the impacts

Step 1: identification of climatic factors: Identification of key climate factors and their features that impact sectors of interest. Stakeholders were asked to identify the climatic risks that farmers face in their daily lives. The identification process facilitated awareness creation and exchange of information between communities and facilitators. The discussion centred on the indicators of climate change in each site.

Identification of variables of interest. During workshops stakeholder were guided to identify most important environmental, social and economic sectors and variables of interest to agriculture that may be impacted by the mentioned climatic change factors. The results were used to identify the variables of interest that are impacted by the climate factors and are considered critical to the functioning of the agricultural sector in the study regions.

Step 2: Impact matrices. All the identified variables were used to develop impact matrices consisting of climatic factors (left column) and the variables of interest (the top row). The workshop participants through dialogue and based on expert and local knowledge generated the likely impacts of the climatic factors and filled the matrix cells with the identified impacts.

Step 3 Risk assessment of the impact. Risk assessment of the impacts of climate change involved understanding the potential consequences and the likelihood of these consequences occurring. The association between the likelihood of the climatic factor occurring and the consequences should a climatic factor occur was translated into a risk value (George *et al.*, 2009; WBI 2010). When a factor is 'likely' to occur and have 'severe' consequences, it is classified as 'high' risk. The risk values are classified into 4 categories: low, medium, high and extreme (Figure 1).

Likelihood of occurrence				
Extremely likely	D	C	B	A
Very likely	D	C	B	B
Likely	D	C	C	B
Unlikely	D	D	D	D
	Minor	Moderate	Major	Severe
	Severity/consequence			

Figure 1: Risk matrix; Extreme risk (A), High risk value (B), moderate risk condition to give consideration for further adaptation and planning (C), Low risk value(D)

Results and discussion

Stakeholder identification of key climatic factors of interest

Stakeholder identified nine key climate variables and related aspects with potential to have a significant impact on livelihoods in the ASALS (Table 2).

Rainfall data analysis : The rainfall trend for the sites was analyzed using the meteorological data from Kenya Metereological weather stations in Kilgoris, and Galole, in tana delta. Rainfall trend is projected to decrease in Transmara with low moisture spells and possibly frequency of drought occurrence (Figure 2). Farmers confirmed these findings as they reported decreased rainfall amounts in the last 10 years and an increase in night and day time temperatures.

Table 2: Summary of climate variables and related aspects of interest to farmers in dryland regions of Kenya

	Lower Tana			Transmara	
Climate related impacts	Ijarra	Ozi	Garsen	Kirindoni	Lolgorien
1. Rainfall Reduction	•	•		•	•
Erratic rainfall				•	•
Increased rainfall intensity	•		•	•	
2. Temperature increase	•	•	•	•	•
Drought	•			•	•
Prolonged drought	•			•	
3. Floods/ sea water intrusion		•	•		
4. unpredictable wind direction	•	•	•		

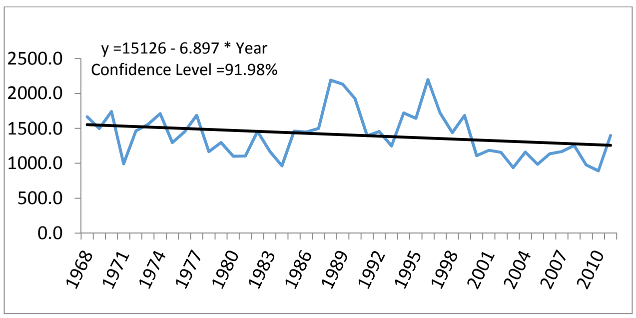

Figure 2: Kilgoris annual rainfall trends

At Galole station rainfall data for 1961-2001 (40 years) period indicates a general decline in rainfall in the area as described by the equation y = -2.123x + 503.8 (Figure 3).

Fitted equation : TotRain = 4665 - 2.123 * Year; Confidence level is 71.57%.

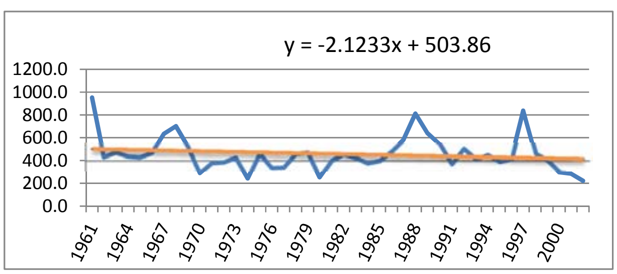

Figure 3: Time series rainfall trend for the Tana River irrigation (Galole) meteorological station

This coincides with the observations from the district departmental heads and farmers interviewed during the risk assessment exercises. Farmers lamented on the declining rainfall trends in the area characterized by shifts in seasons, erratic and relatively high intensity.

Climatic factors and sectors of interest identified by stakeholders. Increased drought frequency, sea water intrusion, temperature increase and rainfall reduction were identified as climatic factors that occur frequently in the study sites. Key sectors impacted by the recurring climatic factors included agricultural and domestic water, crop, livestock ,pasture and rice production especially in Tana delta where there is heavy reliance on flood farming and paddy rice farming.

Impact matrices. Likely impacts of the climatic factors on the sectors of interest are shown in Table 3.

Table 3: Highlights of impacts experienced in key sectors as identified by farmers

Sector/resource	Example of impacts as disused with stakeholders
Crop production	Intense precipitation can delay planting and damage crops while still in field and lead to nutrient leeching
	High temperatures and prolonged drought leads to high evaporation rates , reduced soil moisture leading to crop wilting and yield loss
	increased pests and diseases e.g. powderly mildew & mealy bugs in cashew at the coastal regions
	Decreased yields
Water	Drying up of water sources e.g. rivers, water pans and boreholes.
	Scarity of water leads to Human-livestock-wildlife water resource conflicts and water related diseases
	Decline in water quality in available water sources increase incidences of leading to water related diseases
	“Trekking” long distances to access water
Soil	Intense precipitation leads to excessive water in the cropping fields
	Heavy downpours accelerates soil erosion in sloping croplands.
Pastures	Severe drought leads to overgrazing in forests and other natural pastures areas leading to poor regeneration of native species
	Slow regenation leads to replacement with noxious “hard” weeds in pasture fields and emergence of invader species e.g. Penisetum canabatis
	Reduced pasture quantities (i.e less acreage in communal grazing lands due to shift to crop production.
	Loss of pasture quality i.e available pasture is less palatable to animals
Livestock production	Wildlife-livestock conflicts due to resource scarcity (water and pastures) leading to spread of wildlife diseases to livestock and vice versa/ Increased transmission of diseases from wildlife to livestock.
	Emergence of new disease- OSertert- local name maasai
	Livestock-wildlife conflicts results in spread of diseases
	No water for livestock
	Long distances to water points and pastures.
	Absence of family members, increased poverty levels, spread of HIV

The impact matrix shows how severe consequence will be if the climatic factor occurred. Extent of impats of the climate change factors on each of the identified production sectors of interest to farmers in the ASALs is given in Table 4.

The proportion of cells with extreme negative impacts was 12%, and 48 % had a high negative impact level. For the key variables of interest identified, consequences was high for water availability, pasture, crop and livestock production.

Table 4: Impact matrix indicating severity of consequences associated with climate impacts on selected sectors of interest for farmers in ASALs

Sector/ variable of interest	Climate impacts				
	Temperature increase	Rainfall reduction	Sporadic rainfall	Increased drought frequency	Floods (sea water intrusion)
Water availability	High	High	High	Extreme	High
Livestock production	Moderate	Moderate	Moderate	High	Moderate
Pasture availability	High	Moderate	High Risk	High	Moderate
Crop production	High	High	High	High	High
Rice production	Low	Moderate	Extreme	Moderate	Extreme

Assessment of risk level

Increased drought frequency, sea water intrusion, temperature increase and rainfall reduction were identified as climatic factors that occur frequently in the study sites. Increased drought frequency and sea water intrusion were rates as extremely likely to occur while temperature increase and rainfall reduction were rated as Very likely to occur They were viewed as having severe consequences to the livelihoods in the ASALs. The overall risk value was extreme for increased drought frequency and sea water intrusion, and high for temperature increase and rainfall reduction . These risks should be incorporated into coping decisions. The risk assessment shows an overall high impact of climate change in the ASALs. Increased drought incidences and erratic rainfall were the major causes of risks across the production systems of interest. The high potential impacts, low adaptive capacity of the farmers and frequent droughts is likely to render pasture and crop production vulnerable to climate change. Farmers are already adapting and there is need for a planned adaptation where changes are monitored and evaluated in levels of risks and suitability of adaptation strategies.

Conclusion

The risk matrix assessment methodology and provide a baseline on which to build on and complete risk assessment and further evaluate adaptation options. The tool allowed us to identify and discuss projected climate change, likely impacts, and characterized risks. Climatic factors with overall extreme risks were frequent droughts and seawater intrusion. The overall Risk value was high for water availability, pasture, crop and livestock production. These climatic factors are of greatest concerns to inhabitants in the ASALs and should be incorporated into adaptation decisions.

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In-situ soil moisture conservation: utilization and management of rainwater for crop production

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Abstract

The salient results of in-situ soil water conservation technologies that have been found suitable for increasing soil moisture in the arid and semi-arid lands of eastern Kenya are reviewed. The results. The results showed that *Zai* pits, *tumbukiza* and deep tillage when used together with soil fertility improvement can increase crop yields by 4–10 times in comparison to conventionally

Cultivated fields. Use of tied-ridging with soil fertility improvement increases crop yields by 100–300%. Sub-soiling and ripping increases crop yields by 50–100% when used with soil fertility improvement. Micro-catchment technology at 1:1 and 2:1 catchment to cultivated land ratio increase crop yields, but is not practised due to land limitation. Use of fertilisers and or manures and their combination with in-situ soil moisture conservation leads to improved water use efficiency by crops planted in the semi-arid areas. It was concluded that, in-situ rainwater conservation technologies should be part of the farming systems in the semi-arid lands.

Key words: in-situ rain water harvesting; soil fertility improvement; crop yields; semi-arid astern Kenya.

Introduction

In-situ soil moisture conservation entails capturing rainwater and retaining it in the soil for in-situ plant utilization for growth and increase in grain and biomass yield. This is achieved through rainwater harvesting on site or farm where crops or fodder are planted to benefit from soil moisture conserved and retained in and on the soil as it rains It reduces rainwater loss through runoff, thereby increasing the amount of rainwater that will be useful for crop and fodder production through increased rainwater infiltration time and hence increase in food security (Itabari and Wamuongo, 2003).

ASALs constitute 83% of Kenya's land mass and support over 25% of the human population. The problem of food security in this region is accelerated mostly due to declining land productivity, which is mainly attributed to inadequate soil moisture to support crop and fodder production. The rainwater balance in the ASALs of eastern Kenya shows that 60-70% of the rainwater is lost as runoff, leaving 25-30% for crop and fodder production (Kilewe, 1987). Many of the soils found in this region have developed hardpans at around 4 inches of soil depth, which slow rainwater infiltration, leading to rain water loss through runoff, which in turn carries away top fertile soil required for healthy crop growth. The soils are susceptible to hardpan formation due to their inherent low organic matter, causing weak soil aggregate stability. Soil aggregates are broken down to fine aggregates, which join and form a seal of impermeable layer with time. The soils become susceptible to erosion (Kilewe, 1987), losing rainwater due to decreased infiltration as the bulk density of the few inches of the top soil increases, thereby limiting infiltration. This has been observed in semi-arid Makueni District (Miriti *et al.*, 2009) where the top 0-15 cm soil was found to have higher bulk density than the soils below this depth. A special soil management technique is required for soils in the semi-arid lands because of these inherent properties.

Also, the low and erratic 100-700 mm annual rainfall in the region means crops and fodder production can only be achieved if in-situ form of rainwater harvesting is carried out to increase soil moisture amounts and retention for crop production. In-situ rainwater harvesting has the capacity to increase crop production by more than 40% (Kathuli *et al.*, 2010; Gichangi *et al.*, 2007; Itabari *et al.*, 2003) provided other crop and fodder agronomic practices are carried out. In other arid and semi-arid regions of eastern Africa, in-situ

rainwater harvesting has been found to increase rainwater productivity from 1-1.5kg/mm to 3-4.5kg/mm rain (Steiner and Rockstrom, 2003).

Crop water utilisation and efficient use of rain water is based on the principle that the loss of rain water from the moment it reaches the soil surface and ensuring that its utilisation by crops is as efficient as possible. The amount of water available for utilisation by a crop is expressed as Tcrop (mm) = P-R-D-E-Tweeds–Δs (Itabari, 1999) where T = transpiration, P = precipitation, R = runoff, D = drainage, E = evaporation from the soil surface and Δs is change in soil water stored within the rooting zone. The equation shows that, in order to have good rain water utilisation by plants, Tcrop must be optimised.

This can only happen if R, D and E are minimised through soil management. The water utilisation efficiency is calculated as WUE = crop yield/Tcrop = kg/mm rainfall. In-situ rainwater conservation reduces water lost through runoff by holding it on the soil surface thus encouraging infiltration and raising water available for crop growth and yield. This process increases water use efficiency as more rainwater that could have been lost through erosion is available for crop growth.

The objectives of this paper are: (a) to review the salient results of in-situ soil water conservation technologies that have been extensively tested and found suitable for increasing soil moisture for increased land productivity in the ASALs of eastern Kenya and particularly in areas found within Agro-Ecological Zones (AEZ) IV and V. (b) To suggest how benefits of in-situ soil water conservation technologies can be optimised for increased crop and fodder productivity.

Materials and methods

Secondary data from research conducted in the ASALs of eastern Kenya was collected from journals, conference and workshop proceedings and technical reports. The data represent the status of in-situ soil moisture conservation in the ASALs of eastern Kenya. These lands are found in agro climatic zone (ACZ) IV, V, VI and VII. Agro-climatic zone IV has mainly low to medium altitudes, ranging from 1300 to 1800 m above sea level. The mean annual temperatures here range from 18 to 21^{o} C. Agro-climatic zone V falls within 1800 to 1300 m above sea level, and the mean annual temperatures range from 21 to 24^{o}C. For agro-climatic zones VI and VII, the mean daily maximum temperature varies from 32 to 37 ^{o}C in the cooler and hotter months, respectively. The mean minimum temperature is about 22-23 ^{o}C, giving a diurnal variation of 10 to 15 ^{o}C (Sombroek *et al.*, 1982; Jaetzold and Schmidt, 1983).

The annual rainfall ranges from 500 to 800 mm, and is erratic in amount and distribution. It is bimodal in the areas along the coastal hinterland and in the areas around the eastern slopes of the central highlands, and unimodal in the areas to the West of the central highlands. In the areas where it is bimodal, it is almost evenly distributed between the 'long rains (March-May) with a peak in April, and the 'short' rains (October-December) with a peak in November. The rates of evaporation are generally high due to the high daytime temperatures. Rates of up to 8.2 mm per day have been recorded at Katumani, which lies in ACZ IV (Stewart and Hash, 1982), and over 3000 mm year^{-1} for agro-climatic zones VI and VII (Sombroek *et al.*, 1982; Jaetzold and Schmidt, 1983).

The predominant soil types are Luvisols, Acrisols and Vertisols. There are other soil types, but they are of less significant in terms of the agricultural area they occupy. Their texture ranges from sandy loam to loamy sand with a tendency to harden when dry, but are friable when wet. They are deep and well-drained in the wetter areas, but tend to be shallow in the drier areas due to the presence of petroplinthite horizons. They have low organic matter content (less than 1% C), mainly due to the poor growth of the natural and human-modified vegetation and removal of crop residues for livestock feed. They have a low water-holding capacity, are generally medium to slightly acidic (pH5.0 to 6.5) in the surface horizons, poor structural development, are highly erodible and prone to surface sealing and capping through the energies of high-intensity rainfall and solar radiation (Muchena, 1975).

Results

Some of past researched technologies on in-situ rainwater conservation technologies include the tied and open-ridges, *zai* pits, semi-circular hoops, stone bunds, negarims, contour bunds, terraces, trapezoidal bunds, micro-catchments (Itabari *et al*., 2004), deep tillage and sub-soiling/ripping (Kathuli *et al.,* 2010; Miriti *et al.,* 2009; Steiner and Rockstrom, 2003). These technologies allow rain water retention for a prolonged duration on the soil surface for increased infiltration, retention and better rain water use efficiency (Steiner and Rockstrom, 2003; Itabari, 1999). The following is a description of each of these in-situ rain water conservation and utilisation with highlights on successes and constraints.

Fanya juu terraces

Fanya juu terraces are constructed by heaping soil up-slope to make an embankment which forms a runoff barrier leaving a trench used for retaining or collecting runoff. The canal is 0.6 m deep and 0.6 m wide. The soil embankment is about 0.7 m from the surface. Runoff from external catchments is led into the canals for retention to allow more time for water to infiltrate into soil. Crops such as bananas, paw paws and citrus can be grown in the ditches. This technique is recommended for areas with slopes greater than 5%.

Contour bunds

Small earth, stone or trash lines embankments are constructed along a contour line to form an embankment .The embankments trap rain water flowing down the slope and retain it behind the bunds. The area behind the bunds can be levelled to ensure homogeneous infiltration. The spacing of the contour bunds depends on slope and soil type. Land on steep slopes will require closer contour bunds. Catchment to cultivated area ratio should be 2:1. A successful sorghum crop has been achieved with 270 mm rainfall using this technology (Itabari and Wamuongo, 2003).

Semi-circular bunds (hoops)

These are semi-circular earth embankments with tips of the bunds on the contour. Water is collected within the hoop from the area above it and confined to the depth defined by the height of the bund and position of the tips. Excess water is discharged around the tips.

Negarims

These are small V-shaped embankments with the apex at the lowest point. Water is collected from the V-shaped basin and stored in the soil profile at the apex. This technique is good for the establishment of trees and shrubs. Catchment area ranges from 16 m^2 in AEZ IV to 1000 m^2 in AEZ V. The soil embankment is 15–20 cm for water collection, while the apex basin is 40 cm deep for water storage.

Tied ridges

These are made to increase surface storage and to allow more time for rainwater to infiltrate the soil. Oxen made furrows are manually tied at 3-5m intervals. The lower furrow is tied starting from the point between the above tied furrows such that tieing is not perpendicular to prevent possible erosion in the farm. The cross- ties are usually lower so that if they fill, the overflow is along the furrow but not down the slope. This technology is recommended for land with slope greater than 2% for the furrows to retain rainwater that would be lost as runoff if the structures were not in place. Effect of tied and open ridging technology of rainwater harvesting on mean maize grain yields across various sites in semi-arid eastern Kenya is shown in Tables 1–3.

Data from Gichangi *et al*.'s (2007) study on maize grain yields across various sites in semi-arid of eastern Kenya (Table 1) show that tied-ridging with manure, manure and fertiliser application can increased crop yields from 100 to 359%. Similar results were obtained in Mwala during the short rains of 2007 although the maize Total Dry Matter (TDM) yields were not significantly different from conventionally cultivated fields (Table 2).

Table 1: Effect of tied ridge rainwater harvesting on mean maize grain yields (kg/ha) across varius sites (Kiomo, Masii, Mavuria and Kwa Vonza) in semi-arid eastern Kenya (1997-2003)

Treatments	Average grain yield (kg/ha)		%yield increase + water harvesting	% increase-water harvesting
	+water harvesting	-water harvesting		
0 t /ha FYM	655.0	483.0		
10t/ha FYM	1319.4	788.0	101.4	63.1
20t/ha FYM	1866.9	1284.0	185.0	165.8
20kg N/ha	1466.9	1167.0	123.8	141.6
20kg N, 20kg p_2O_5	2035.0	1603.0	256.5	231.9
10t FYM, 20kg N	2536.8	1784.0	287.3	269.4
10t FYM, 20kg N,20 kg P_2O_5	3007.0	2155	359.1	346.2
$Lsd_{0.05}$=407.6				

Source: Gichangi *et al.,* (2007)

Table 2: Effect of tied ridging on TDM yield (KG/HA) of maize in Mwala (AEZ 4), Yatta and Kitui (AEZ 5) during the short rains 2007

District	farmers	Tied ridging	Open furrows
Mwala	P.Kyululi	1414	1393
	A.Musyoka	3814	3384
Yatta	T.Muthama	308	254
	M. Ndolo	193	125
Kitui	M.Mwava	204	157
Mean yields		1186.6	1062.6

Source: Kathuli and Itabari (2012)

Table 3: Effect of tied ridging and fertilizer on grain yield and water-use efficiency (WUE) of Sorghum at Masinga during the short and long rains 1995

Treatments	Grain yield ($kgha^{-1}$)	ET	WUE($kgha^{-1}mm^{-1}$)
Short rains			
Flat cultivated-fertilizer	190b	299.0	0.64
Flat cultivated + fertilizer	380B	299.2	1.27
tied ridging -fertilizer	360B	297.8	1.21
tied ridging + fertilizer	820a	300.5	2.73
long rains			
Flat cultivated-fertilizer	80c	276.09	0.29
Flat cultivated + fertilizer	350abc	276.86	1.26
tied ridging -fertilizer	310bc	275.53	1.13
tied ridging + fertilizer	1030a	276.97	3.75

Note: Values in the same column followed by the same letter are no significantly different at P=0.05 level; Source: Itabari (1999)

Tied-ridging with fertiliser use significantly (p = 0.05) out-yielded plots with Conventional cultivation during the 1995 short rains (Table 3).

Trapezoidal bunds

These are bunds with trapezoidal-shaped earth embankments. Tips of embankments are placed on the contour. The embankment top is level and higher than the ground level at the tips. Water flowing down-

slope is trapped and retained behind the bund up to the level of the tips and any excess overflows around the tips into other bunds in the system or natural drainage course. The size of enclosure depends on slope and may vary from 0.1-1.0 ha. Embankment base width varies from 2.6-5.8 m. ratio of catchment to cultivated area varies from 1:1-5:1 depending on rainfall regime, soil properties and crop water requirements. This technology can increase crop yields by 30-90% in semi-arid lands of eastern Kenya (Itabari and Wamuongo, 2003).

Zai pits

This involves digging small planting pits 30cm in diameter and 15-20cm deep. Manure or compost is placed at the bottom of the pit and mixed with soil prior to planting. During digging, the soil is thrown down-slope to form a small embankment. The pits are made at a spacing on 1m row to row and pit to pit can be 30cm. the pits should not be perpendicular to each other to avoid possible erosion in case of a heavy rainfall. These are useful for establishing vegetables. Some results obtained from zai pits are shown in Table 4.

Table 4: Effect of tillage and fertilizer on grain yield and water-use efficiency (WUE) of Sorghum at Masinga during the short and long rains 1995

Treatments	Grain yield (kgha^{-1})	ET	WUE(kgha^{-1}mm$^{-1)}$
Short rains			
Flat cultivated-fertilizer	190b	299.0	0.64
Flat cultivated + fertilizer	380B	299.2	1.27
Zai pitting-fertilizer	850a	297.9	2.85
Zai pitting + fertilizer	1010a	298.8	3.38
long rains			
Flat cultivated-fertilizer	80c	276.09	0.29
Flat cultivated + fertilizer	350abc	276.86	1.26
Zai pitting-fertilizer	900ab	275.10	3.27
Zai pitting+fertilizer	780ab	275.99	2.83

Values in the same column followed by the same letter are no significantly different at P≤0.05 level: Source: Itabari (1999)

Sub soiling and ripping

This involves use of a sub-soiler and ripper which are animal drawn. The sub-soiler is made of round steel metal with a sharp end with an attachment to oxen plough. It is adjustable and penetrates the soil to a depth of 6inches breaking soil hardpan normally formed at 4inches due to continuous cultivation at this depth. The ripper opens the narrow furrow left by the sub-soiler to 8cm wide ready for planting. The seeds are placed at the bottom of the furrow and covered slightly. The furrow traps rainwater and holds it for some time as it infiltrated the soil. Sub-soiling or ripping has been found to increase crop production by 40-60% in the semi-arid lands (Steiner and Rockstrom, 2003; Mwangi *et al*., 2005). In absence of in-situ rainwater harvesting, these lands lose 60-75% of rain water through surface runoff due to their land topographic features and inherent soil properties (Kilewe, 1987). Combination of this in-situ rainwater harvesting technologies and integrated soil fertility improvement technologies has led to increased crop yields (Mwangi *et.al*. 2005, Kathuli *et.al* 2010). Similar results were obtained by use of sub-soiling or ripping in-situ water harvesting technologies with sorghum, sorghum-cowpea intercrop and sorghum rotation with and without manure application which resulted in increased sorghum yields where manure was applied in Makueni County (Kitinya *et al*., 2011). Some of the data obtained from on-farm trials is shown in Table 5 and 6 below.

Table 5: Sub-soiled/ripped and conventionally tilled farms during the short rains 2007 and the long rains 2009 in Mwala

			Total dry matter yield (kg/ha)		%yield increase
			Treatments		
Farmers name	District	season	Sub-soiling/ripping	Conventional tillage	
A Muli	Mwala	SR 2007	239	102	134
Tabitha	Kitui	SR 2007	50	25	100
Kalumu	Kitui	SR 2007	350	167	109
Mean			213	98	117
Alize Musyoka	Mwala	LR 2009	189.8	222.2	
B Muoki	Mwala	LR 2009	766	570.0	34
M Kiingu	Mwala	LR 2009	283	438	
A Muli	Mwala	LR 2009	590	189	212
Mean			457.2	355	29
Lsd (5% level)			392.3	392.3	
CV%			47.4	47.4	
s.e.d			123.3	123.3	
%mean yield increase by subsoiling/ripping			29%		
Sig. test (P≤0.05)			none	none	

Table 6: Effect of integrated soil fertility and tillage methods on maize grain yields (kg/ha) in Mwala AEZ- 4 and Yatta AEZ-5 during the short rains in 2009 and Kitui AEZ-5 during the 2007 short rains

Site		Treatments		%Yield change
Kyasioni (AEZ-5) Yatta	Soil fertility Management	Sub-soiling/ripping	Conventional tillage	
	5t/ha FYM	1530	1630	-6%
	5t/ha FYM +20kg N/ha	1710	1080	58%
	(20kg N +20kg P_2O_5)/ha	3710	933	298%
	5t/ha FYM +(10kg N+10kg P_2O_5)/ha	2210	1340	65%
	Mean	2290	1246	84%
Kyawango (AEZ-4) Mwala	5t/ha FYM	2430	1680	45%
	5t/ha FYM +20kg N/ha	2950	1810	63%
	(20kg N +20kg P_2O_5)/ha	2220	2020	10%
	5t/ha FYM +(10kg N+10kg P_2O_5)/ha	3370	2450	38%
	Mean	2743	1990	38%
Kauwi (AEZ-5) Kitui	5t/ha FYM	50	25	100%
	5t/ha FYM	350	167	109%
	Mean	200	96	108%

Source: Kathuli *et al.*, (2010)

Tumbukiza

These are planting pits, 60 cm wide, 60 cm deep. They are modification of Zai pits. The top 0-20cm soil is mixed with manure or compost prior to planting. 5-7 maize seeds can be planted per pit. They are spaced 100 cm row to row and 75cm pit to pit and can also be used to establish fodder crops.

Deep tillage

This works as subsoiling and ripping. Once soils are deep ploughed, rainwater infiltration is increased. Rainwater storage by the soil is also increased and yield can increase 3 times in comparison to adjacent land tilled conventionally (Itabari 1999). Field data on effect of deep tillage on sorghum yield from dry land Katiorin is shown in Table 7 below.

Table 7: Sorghum and cowpea grain yields (kg/ha) from a runoff harvesting trial at Katiorin (1981) with different tillage treatments

Treatments	Sorghum (kg/ha)		Cowpea (kg/ha)
	First harvest	Ratoon harvest	
Impounded plot, deep tillage	420	595	70
Impounded plot, zero tillage	120	N/A	N/A
3 m contour ridges hoop, zero tillage	410	900	130
control plot deep tillage	60	325	20

Source: Imbira (1989)

Deep tillage increased sorghum yield by 3.5 times as compared to a farm with the same Management but with a lower depth of tillage. Both plots had rainwater harvesting with one plot being deep-tilled.

Micro catchments

This involves capturing runoff from one part of the farm and collecting it in adjacent part of the farm which should be in the lower part of the farm. Rainwater in the upper part of the farm runs off into the farm below. The soil in the lower farm is cultivated to increase water infiltration. The ratio of the catchment to cultivated area usually varies from 1:1 to 5:1 depending on the rainfall regime, soil properties and crop water requirements. Yield increases of 30-90% has been obtained using this technology in the semi-arid Baringo sub-County (Imbira, 1989) (Table 8).

Table 8: Yield of sorghum from trial plots using on-farm external catchment systems during the 1982-1983 short rains

plot	year	Catchment: cultivated area ratio	Experimental plot yield (kg/ha)	Control plot yield (kg/ha)	%yield increase
Katiori	1982	2:1	775	135	474%
Marigat	1983	1:1	540	10	5300%

Source: Imbira (1989)

Discussion

The technologies reviewed here allow rain water retention for a prolonged duration on the soil surface for increased infiltration and retention and better rain water use efficiency (Steiner and Rockstrom, 2003; Itabari, 1999). In the absence of these technologies, the farms would be losing about 70% of rainwater to runoff and leaving only 25–30% for crop or fodder production (Kilewe, 1987).

Fanya juu terraces are constructed on land with slope ranging from 2 to 22% (Itabari *et al*., 2011). These structures form a runoff barrier, which collects runoff rainwater and eroded soil. The water collected spreads back in the terrace and is retained for a longer time allowing infiltration and raising soil moisture for fodder and crop production. The effects of fanya juu terrace indicate that the trapped rain water would have been lost in the absence of these structures thus limiting crop productivity. The in-situ conserved rain water will increase crop and fodder productivity in ASALs where water is the most limiting crop and fodder production constraint (Itabari *et al*., 2011). However, these structures require periodic maintenance to increase the embankment height as more soil is removed from upper side of the terrace and deposited

in the lower side to form a bench terrace. There are reports of increased crop productivity in those farms where terraces are periodically maintained (Itabari *et al.,* 2011).

The contour bund embankments trap rain water flowing down the slope and retain it behind the bunds. The area behind the bunds can be levelled to ensure homogeneous infiltration. This technology concentrates rain water in a smaller area for cultivation of early maturing crops. The technology has led to a satisfactory sorghum crop with rainfall of 270 mm using a catchment to cultivated area ratio of 2:1. However, adoption of this technology is not wide spread (Itabari and Wamuongo, 2003) due to land scarcity.

Semi-circular bunds (hoops) are common in ASALs of Turkana and Baringo Counties. The bunds are used to capture rainwater that would be lost as runoff in the absence of these structures due to land topography. The rainwater is retained in the structures allowing longer infiltration time. They are used to rehabilitate degraded lands (Kitheka *et al*., 1995) in ASALs of Kenya. Restoration of productivity is achieved within three seasons. The bunds are used for the reseeding of grass, fodder, shrubs and can be used to grow early maturing crops like cowpea and green grams. Adoption of the technique has been hampered by labour involved in construction of the structures.

Negarims are suitable in establishment of trees or tree crops (Itabari *et al*., 2011). Under very low rainfall, the runoff is concentrated into a planting pit thus increasing soil moisture for tree crop establishment and growth (Kathuli and Mweki, 2012). These structures improve fruit tree establishment by 60% leading to increased yields and farm income. The structures are recommended in areas with 300-700 mm annual rainfall and with 1–5% slope (Critchley *et al*., 1991).

The effect of tied-ridging with and without fertiliser use on sorghum grain yield and water use efficiency in semi-arid lands of Masinga in eastern Kenya during the 1995 short and long rains (Table 3) shows that tied-ridging plus fertiliser significantly ($p = 0.05$) increased sorghum grain yield in both seasons. Rain water use efficiency was similarly enhanced by combination of tied-ridging and fertiliser use. Evapotranspiration (ET) remained fairly constant within the seasons. Tied-ridging has been shown to increase the total dry matter of maize by less than 1% in very poor seasons (Table 2) (Kathuli and Itabari, 2012), while in good rainfall seasons, sorghum yields increased by 3–5% across short rains and long rains (Table 3) (Imbira, 1989), and maize yields increased by 101–359% due to tied-ridging with integrated soil fertility management (Table 1) (Gichangi *et al.,* 2007). Tied-ridging allows rain water to be conserved in-situ as it infiltrates the soil. The prolonged time it is retained on furrows allows increased infiltration and hence increased soil water which is used by crops. The water use efficiency of crops is increased with addition of manures and fertilisers (Tables 1, 3 and 4).

Similarly, *zai* pitting significantly ($p \leq 0.05$) increased sorghum grain yields and improved sorghum water use efficiency in Masinga, Machakos County during the 1995 short rains (Table 4). Sorghum yields increased four times with fertiliser and two times without fertiliser use on *zai* pits (Tables 3 and 4). *Zai* pitting without fertiliser application significantly ($p = 0.05$) increased sorghum grain yields by ten times over the plot without *zai* pitting and with no fertiliser during the same period (Tables 3 and 4). This is attributed to limited rainfall with the same fertiliser during the short rains. *Zai* pits can increase crop yields by a bigger margin with soil fertility improvement. This is because rainwater is concentrated into a smaller area increasing soil water per unit soil volume thus providing adequate soil moisture that favours crop growth and yield increase. Sub-soiling and ripping can increase crop yields in semi-arid eastern Kenya (AEZ 4 and 5). A yield increase of 117% of maize total dry matter from 98 kg/ha to 213 kg/ha in

conventional and sub-soiled/ripped tillage treatments, respectively, was recorded in short rains 2007, while 29% yield increase from 355 kg/ha to 457 kg/ha of total maize dry matter was recorded in long rains 2009 (Tables 5 and 6). Use of this technology with integrated soil fertility improvement increased maize grain yield from a mean of 84-108% (Table 6) because of soil moisture retention and conservation. Fertiliser nutrients applied become available over longer duration of crop growth due to availability of minimum soil water, which is required for crop nutrient uptake either by mass flow or diffusion (Tisdale *et al*., 1985).

The constraints arising from this technology are excess covering of planted seeds with soil. Seeds should be covered lightly depending on size. The cost of sub-soiler and ripper are also prohibitive but this has been solved with a modified mould board plough which is fitted with a shear modification and mould board modification for in-situ hardpan breaking and making planting furrow similar to that is made by the sub-soiler and ripper. The cost of modification is about US$7.5 and can be fabricated by farmers using locally available materials.

Planting pits (*tumbukiza*) resulted in increased maize yields in Mwala district and Mukuyuni division in Machakos district (KASAL) project (2007–2011). A farmer reported a yield of 4–90 kg bags of maize from pits made in 0.25 acres of land in Mukuyuni, while another one reported yield of four bags of 90 kg maize from 0.25 acres due to pitting and manure use in Makutano community development association in Katangi Machakos County. Similar observations were made in KASAL project in Mwala district-Mbiuni division, Kwa Lumbu village. In the short rains of 2009, a high yielding maize crop was observed planted in planting pits in Kako division of Makueni district. It seemed that pitting increased the yield of the crop as the soils were of low fertility and highly eroded over time. Tumbukiza concentrates rainwater in a smaller area thus raising soil water content per unit volume of soil. This raises the water level in the soil which favours crop nutrient uptake (Tisdale *et al*., 1985), growth and eventually increased yields. Overall *tumbukiza* can increase crop yields due to rainwater harvesting and conservation. The crop yield increases is enhanced by use of fertiliser and manure for soil fertility improvement.

Deep tillage assists the soil to conserve water for crop growth. Deep tillage increases soil porosity and air spaces which are filled with rain water raising the soil water holding capacity (Hillel, 1980). The soil that is not deep tilled would not exhibit such level of porosity and air spaces for rain water holding and hence the difference in sorghum and cowpea yield performance from dry land Katiorin planted during the 1981 short and long rains in those two contrasting managed soils (Table 7). This technology is recommended to farmers for increased crop production in ASALs due to increased soil water holding capacity. Kenya, reported that runoff harvesting using a catchment to cultivated area ratio (C: CA) of 1:1 increased yields of most dry land crops by 30–90%. Itabari *et al*. (2004), working with green grams in the same region, reported that a C: CA of 1:2 increased net benefits by 17% where no furrows were made in the cropped area and by 40% where connected furrows were made in the cropped area during the long rains of 2002, which had a total of 310 mm of poorly distributed rainfall. The technique has also been shown to substantially increase crop yields in Kitui district (Critchley, 1989) and in Baringo County (Table 8), where its effectiveness was shown to increase with increasing catchment to cultivated area ratio. In another runoff on study in Baringo county, Kinyali *et al*. (2000) reported that runoff harvesting increased soil water regime by 66% and the subsequent

yield from the runoff treatment was 19 bags per acre, whereas the rain fed treatment produced no yield. Manure in combination with semi-circular bunds water harvesting technology resulted in increased grass biomass yields (0.5–3 t/ha) and better ground cover (Munyao *et al*., 2011). The yields obtained through use of this technology are very high (400%). Yield increase from catchment to cultivated area ratio of 1:1–2:1 (Table 8) is very encouraging for this technology. It is advisable for small-scale farmers to use this technology. The technology would however be constrained by lack of land for capturing the rain water. Land next to homestead always has a good crop due to runoff harvesting from the homestead.

Micro-catchments (runoff-run on) technique involves spreading runoff from part of land on to an adjacent cultivated land without using any structures. The soil in the cultivated area is loosened to increase infiltration. The ratio of the catchment to cultivated area usually varies from 1:1 to 5:1 depending on the rainfall regime, soil properties and crop water requirement. Gibberd (1995), working in semi-arid Eastern.

Way forward and recommendations

The in-situ soil moisture conservation technologies that have been tested and found suitable for ASALs are *fanya juu* terracing, tied and open ridges, deep tillage, sub-soiling and ripping, planting pits, semi-circular bunds, negarims and micro-catchments. Tied ridging with manure and fertiliser application can increase

crop yields by 100–359% and improve water use efficiency from 0.29 to 3.75 kg/ha/mm. Contour bunds with catchment to cultivated area ratio of 2:1 can increase sorghum yields by 30–90% with rainfall as low as 270 mm. Trapezoidal bunds and micro-catchments with 1:1–5:1 catchment to cultivated area ratio also can increase sorghum yield by 30–90% in ASALs.

Zai pits can increase sorghum grain yields by 3.5–4.3 times without and with use of fertilisers, respectively, with an increase in water use efficiency from 0.64 to 3.38 kg/ha/mm. Sub-soiling and ripping increase maize TDM yield by 29–117% in very low rainfall seasons and grain yields between 38% and 108% in good rainfall seasons.

The effects are more evident in AEZ 5 with application of 5 t/ha FYM + (10 kg N + 10 kg P2O5/ha). Deep tillage can increase sorghum yield by 3.5 times. Negarims can improve tree crop establishment by 60%. *Fanya juu* terraces can trap rain water and allow it more infiltration time thus increasing soil moisture and crop and fodder productivity. Generally, there are many technologies for in-situ rain water harvesting and their impact is enhanced by combining these technologies with integrated soil fertility improvement. The in-situ rainwater harvesting technologies have potential to increase crops and fodder productivity and are viable for farmer adoption. It is recommended that these technologies be participatory verified by scientists and farmers for a wider promotion and adoption in ASALs for increased crop and fodder productivity.

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Critical analysis of tillage practices with fertility levels in maize and populations in beans as adaptation measures to climate change to enhance food security at Kabete

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Abstract

Trials were carried out in 2012/2013 short and 2013 long seasons at Kabete site representing a warm and wet environment in Kenya to determine, the appropriateness of combining fertilizer levels for maize and population levels with tied ridges for beans, as adaptation measures under changing climate. The maize experiment consisted of three fertilizer levels of 0, 20 and 40 kg/ha N while the bean experiment had three spacings of 12, 15 and 20 cm in a split plot design. The experiments were replicated thrice and consisted of conventional tillage and tied ridges as main plots representing the two soil water management practices while the three soil fertility levels (in maize N0, N20 and N40) or spacing options (12, 15 and 20cm) were sub plots in a Completely Randomized Block Design. The ridges were tied at intervals of 1 m and spaced at recommended crop spacings (i.e. 75cm for maize and 45cm for beans) and the crop planted on the slope of the ridge in 6 by 5 m plots. Basal phosphate ($P_20_{5)}$ fertilizer in the form of Triple Superphosphate was applied at planting time at the rate of 40kg/ha. Nitrogen in the form of Calcium Ammonium Nitrate was applied at 20 Kg/ha in the 20 and 40 N treatments at planting and further 20kg/ha N top dressed in the 40 treatment level. Harvesting was done at physiological maturity of grain which was air dried. Statistical analysis was done of the treatments and comparisons done of the adaptation advantages of the treatments. Tied ridging increased maize yields at the medium fertilizer level of 20 (+5.22%) but were negative under both zero (-15.56%) and 40 kg/ha application of fertilizers (-5.42%). In the short season, increased bean spacing from 12 to 20 decreased yields under normal (-13.6%) and tied ridges (-37.3%) but remained higher at populations of 12 and 15. In the long season increasing bean population from spacing of 12 cm to 20 had no advantage and under tied ridging compared to normal tillage. Tied ridging as a climate change adaptive measure should not be instituted as a blanket recommendation across rainfall regimes, crops, fertilization levels or plant populations and is more advantageous in drier seasons.

Introduction

It is now acknowledged that climate change would impact negatively on agricultural production through reduction of crop yields especially under subsistence farming in developing countries where impacts on food security can be devastating (Bochiolo *et al,* 2013). Climate change already adversely impacts on 175.4 million ha of rain-fed agriculture accounting for some 440.8 MT of production in sub Saharan Africa alone (Calzadilla, *et al*, 2008; Ewbank, 2012). It is also reported that there will be an increment of global temperatures but it is not so clear whether or not rainfall will decrease or increase or in which areas. Various scenarios have been developed to attempt to understand the impacts of these climate change possibilities (Lobell and Burke, 2008; Onyango *et al*, 2012). Experience has also shown that these possible impacts can be dealt with by integrating a wide range of adaptation strategies especially into national development planning (Parry *et al*, 2007; Deressa *et al*, 2008). Some positive adaptation measures reported include seed choices and planting dates for the likely changes in climatic conditions to which significant increases in yields have been attributed (Campbell *et al*, 2009). Given that small-scale farmers globally use 60 per cent of the world's land to produce half the world's food (Ewbank, 2012), introducing adaptive capacity to prevent eminent hunger and reduce poverty in the face of impeding climate change is pertinent (Van Ardenne-van *et al*, 2002).

In Kenya effectiveness of tillage practices to improve rainfall water utilization is significantly influenced by soil and climatic conditions Sijali and Kamoni (2005). Tied ridges can yield more maize crop dry matter (1.18 Mg/ha) than flat tillage (1.04Mg/ha) when seasonal rainfall is 222mm but dry matter under tied ridges (0.69Mg/ha) was 28% less than flat tillage when the rainfall was 144mm (Sijali and Kamoni, 2005). It is hence important to test these practices under a variation of soil and climatic conditions to determine their relative advantages across various conditions. In-situ soil moisture conservation entails capturing rainwater and retaining it in the soil for in-situ plant utilization for growth and increase in grain and biomass yield. Gichangi *et al* (2007) proposed that whatever in-situ rainwater conservation technologies are used, manure should be an integral part of the technology for increased soil moisture conservation and utilization by crops for increased crop production and food security in eastern Kenya. Kathuli *et al*, (2010) reported that tied ridging when used with fertilizer, manure or their combination has potential to increase crop yields by up to 100-300%. These increments have been explained to arise from use of fertilizers and or manures with in-situ soil moisture conservation through improved water use efficiency by crops planted in this semi-arid region of eastern Kenya (Itabari *et al*, 2004; Gichangi *et al*, 2007). Manure has also been shown to increase soil moisture profile irrespective of whether it is used with in-situ soil moisture conservation technology or otherwise (Gichangi *et al*, 2007). This analysis attempts to outline salient adaptation strategies of maize under fertilizers and bean populations at Kabete Kenya.

Materials and methods

Area of study

Experiments were carried out at Kabete Campus Field station which represents a warm and wet agro-ecological zone (UM3) and lies between 36^{O} 44, E 01^{O} 15 S co-ordinates at an altitude of 985 meters above mean sea level. The site lies on a humic nitisol receiving about 970 mm of rainfall, has a mean annual temperature of 18.2^{o} C and a bimodal pattern of rainfall with two cropping seasons per year.

Experimental layout

The first experiment was laid in a split-split plot design layout consisting of two soil water management practices and (W0= Normal tillage and W1= tied ridges) as main plots, three plant fertilizer levels (0= No fertiliser, 20=20 kg N/ha and 40=40 kg N/ha) and as the sub-plots. Maize *(Zea mays)* variety DK8031 was used as the test crop. The second experiment had also the two soil and water management practices (W0= Normal tillage and W1= tied ridges) as main plots, three plant densities (1=12cm, 2=15cm and 3=20cm) as the sub plots with beans *(Phaseolus vulgaris)* (KK8 variety) as the test crop. The treatments in both experiments were in 6 x 5 m plots and were replicated three times. The results presented below are of grain yield attributes from 1st season (2012 long rains) and 2nd season (2012/2013 short rains).

Results and discussion

Fertility and ridging responses in maize

In the short rainy season (i.e 2012/2013) tied ridges had +8.18% and +5.68% increments in maize yields under zero and 20kg/ha N applications but reduced yields by +9.06% under 40kg/ha applications at Kabete. See Figure 1. Generally however, the fertilizer levels also progressively increased maize yields from zero application to 40 kg/ha. Comparing the two tillage practices tied ridging had higher yields at the medium fertilizer levels of 20 (+5.22%) but were negative under both zero (-15.56%) and 40 kg/ha application of fertilizers (-5.42%). The highest positive change in maize yields occurred with 20 kg/ha N application. See Figure 1.

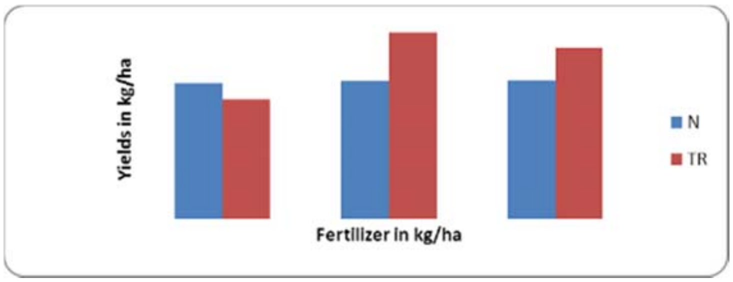

Figure 1: Maize responses in second season 2012/2013

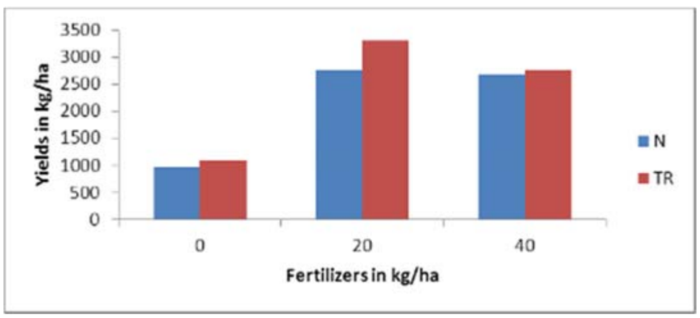

Figure 2 : Maize responses in the first season 2013

During the first season 2013 maize yields progressively increased (i.e. 1.9%) with increasing fertilizers rates under normal tillage. See Figure 2. Under tied ridging however increasing fertilizer levels from 0 to 20 raised the maize yields by 55% but when the fertilizer levels were further raised to 40 the yields decreased by 6.5%. The best yields under tied ridges were therefore obtained with 20 kg/ha application of fertilizers.

Normal tillage had relatively lower yields even with the 40 kg/ha fertilizer levels and was relatively advantageous to tied ridging when no fertilizers were applied. There is therefore no need to invest in labour constructing tied ridges if no fertilizers are to be applied as evident in both seasons. It is also unnecessary to increase fertilizer levels to 40kg/ha especially with tied ridging which would yield even less than a lower application. Increment in yields under tied ridges can be explained to be arising from increased plant available moisture content as was also reported by Miriti *et al.,* (2012). Kathuli *et al* (2010) has also reported general increments in yields of maize in semi arid areas of Kenya.

Population and ridging responses in beans

In the short rains (i.e. 2012-2013) increasing bean populations from a spacing of 12 to 20 decreased their yields progressively both under normal (-13.6%) and tied ridges (-37.3%) although yields under tied ridges were higher at populations of 12 and 15. See Figure 3. Tied ridging was therefore only slightly advantageous under populations of 12 and 15 but was actually disadvantageous at populations of 20.

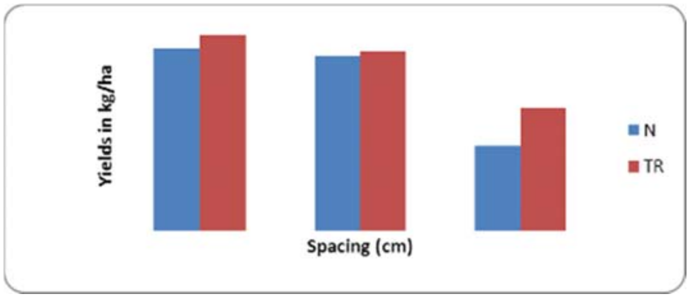

Figure 3: Bean responses in second season 2012/2013

During the 2013 long rains normal tillage consistently yielded better (21.5%) than tied ridges under all the three plant populations. See Figure 4. Under tied ridging however increasing the population from spacing of 12 to 15 increased the yields by 20.5% before dropping by 18.1% when the spacing was increased to 20. Increasing the population from spacing of 12 cm to 20 clearly had no advantage and under normal tillage and even appeared to be reducing the yields.

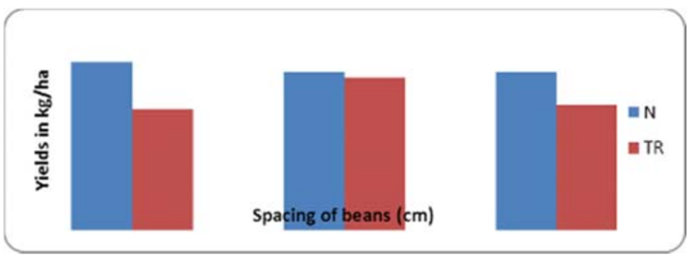

Figure 4: Beans responses at Kabete first season 2013

Since the March-June rainfall has consistently higher rainfall there appears that there would be no advantage in conserving extra moisture for beans at Kabete. However under the drier season (e.g. November-December short rains) a clear advantage is observed under tied ridging.

Conclusions

- The tied ridging as a climate change adaptation measure should only be instituted with caution and is dependent on crop and rainfall regime.
- Under maize tied ridges should be instituted with medium (20kg/ha) fertilizer applications otherwise further increments in fertilizer rates alone would appropriately improve yields especially in the drier seasons without institution of tied ridges
- Bean yields would be enhanced under lower populations if tied ridges are instituted in the drier seasons but decreasing the population (i.e. spacing of 20) has no advantage. With adequate rainfall (i.e. in the long season) it would be unnecessary to institute tied ridges with any bean population

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Experimenting with smallholder communities for climate change adaptation in East Africa

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Abstract

Climate change has recently emerged as the most significant threat to sustainability of human livelihood and the environment at a global scale.In this paper we present findings of a study on the potentials of integrated soil fertility management (ISFM) options to enhance farmers' coping and adaptation strategies to climate change and variability in diversified cereal-root crops and banana based farming systems in the Lake Victoria ecoregion of East Africa. The study was conducted through a survey of 480 households from 6 villages in Bukoba and MissenyiDistricts, Tanzania,- and 2 villages in Tororo district, Uganda.Drawing on the findings of the survey, we developed strategies for communities to test some of the potential ISFM. Through Participatory Action Research (PAR) approaches, criteria for establishment and implementation of 15 learning Centres (LC) to promote co-learning and accelerated exchange of technical information among farmers (and with service providers), while testing different ISFM options for increased crop productivity were developed.Tested options include use of mineral and organic fertilisers, improved maize varieties for tolerance to pest and diseases, Soil moisture conservation and exploitation of biological nitrogen fixation (BNF) through rhizobial inoculums on soybean. Drawing on the results obtained from the learning centres, farmers entered another cycle of participatory evaluation and reflection in order to develop adaptation strategy for agriculture against the major identified climaticfactors/ impacts. The study revealed high awareness among farmers about climate change and variability, about 80%, 91% and 83% of survey households in Bukoba, Missenyi and Tororo districts, respectively. Our results show that farmers in East Africa explain climate change and variability from its impacts and efforts to communicate the science of climate changes to them has remain rudimentary and fraughtwith what are perceived to be contradictory and unreliable messages. The study also shows absence of social institutions and arrangements that enhances collective/ participatory decision making process. Experimentation with farmers revealed that use of best-bet ISFM technologies including fertilisers (mineral and organic), improved crop varieties (high yielding and drought and pest tolerant/ resistant) can more than double crop yields (compared to what is obtained now). We conclude that with a wake of climate change and variability, it is probably the time we should resume popularisation of ISFM, along with the efforts to create awareness on climate change and variability.

Key words: climate change and variability, participatory action research, farmer co-learning

Introduction

Climate change has recently emerged as the most significant threat to sustainability of human livelihood and the environment at a global scale. The Intergovernmental Panel on Climate Change (IPCC) states in its Fourth Assessment Report, the vulnerability of African Agriculture and all who depend on it for food security and livelihood (IPCC, 2007). Climate change models for East Africa predict increasing rainfall in humid areas, lower rainfall and extended drought periods in dry areas, which will further exacerbate risks in the region as a result of declining productivity of crops and livestock (UNEP, 2008). A study on anticipated impacts of climate change in East Africa (Orindi and Murray, 2005), identified seven but interlinked scenarios: i) decreased rainfall, increased temperature and evaporation in dry areas, ii) frequent

drought spells leading to severe water shortage, iii) change of planting dates of annual crops, iv) increased fungal outbreaks and insect infestations due to temperature and humidity changes, v) decline in crop yields, increased risk of food shortage and famine, and vi) reduction in ecosystem integrity, resilience and decline in biodiversity, and vii) increased potential of malaria transmission and burden on the countries' health care systems.

The negative impacts of climate change mentioned above are not just future threats but the present challenges to subsistence communities in Africa. Recent severe droughts in 1983/1984, 1991/1992, 1995/1996, 1999/2001, followed by El Niño related floods of 1997/1998, then successive droughts in 2004, 2006 and 2010/2011, demonstrated how vulnerable local communities in East Africa can be to variations in climate. These extreme weather events, respectively, reduced maize production by 20%, 17 % and 7% in Kenya, Uganda and Tanzania (Nyanga, 2006). It is also alleged that, these consecutive droughts caused a loss of 70% of livestock in drought prone areas of East Africa (Tearfund, 2010).

Rampant poverty and food insecurity among African smallholder farmers are associated with low agricultural productivity, which in turn, is linked to poor and declining soil fertility (Sanchez *et al*. 1997). Raising fuel and fertiliser prices, high rates of rural poverty, underdeveloped farm input and output markets, and a declining human capacity for soil and natural resource research remain constraint to investment in soil fertility (InterAcademy Council, 2004; Sanginga and Woomer, 2009). Climate change and variability aggravates the situation because its negative impacts also reduce agricultural production. Smallholder farmers have no alternative but to adapt their livelihood systems to changing climatic conditions. Fortunately, several practical options for adaptation exist. They include, but not limited to those embedded in the Integrated Soil Fertility Management (ISFM) paradigm, commonly defined by the Tropical Soil Fertility and Biology research area of the International Centre for Tropical Agriculture (TSBF-CIAT) and The Soil Fertility Consortium of Southern Africa (SOFECSA) as the *application of soil fertility management practices, and the knowledge to adopt these to the local conditions, which maximize fertiliser and organic resources use efficiency and crop productivity. These practices necessarily include appropriate fertiliser and organic input management in combination with the utilisation of improved germplasm.* The key challenge is for researchers, development practitioners and policy makers to help smallholder farmers to identify and use these practical adaptation options, especially by developing their skills in testing and identification of technologies required, and on how to derive benefit from their use.

Against this back ground, this chapter gives an overview of the findings of a study on the potentials of integrated soil fertility management (ISFM) options to enhance farmers' coping and adaptation strategies to climate change and variability, through enhanced crop and livestock production in diversified cereal-root crops and banana based farming systems as managed by farmers in the Lake Victoria ecoregion of East Africa. The chapter demonstrates how participatory evaluation of alternative combinations of ISFM technologies and different crop types/varieties at field-based learning centres enabled communities to access information and knowledge, enhancing their decision-making in selecting cropping and ISFM options that particularly suited their circumstances. The chapter emphasizes the need to recognise and incorporate the views of local people in the science of climate change and to build their capacity to recognise and apply potential options for effective participation in adaptation activities.

The study area

The study was carried out in three administrative district, namely,Bukoba and Missenyi (located in Kagera region, northwest Tanzania), and Tororo (located in eastern Uganda). The districts have been impacted by the changing climate and have climatic and farming systems typical of those found the Lake Victoria Ecoregion of East Africa and. The Lake Victoria ecoregion is a trans-boundary natural ecosystem located between latitudes 2^{o} N and 3^{o} S, and between longitudes 29^{o} and 35^{o} E, and defined by a conglomeration of basins of Lakes Victoria, Edward, George and Kyoga, shared by Republic of Rwanda, Kenya, Tanzania and Uganda.

Bukoba and Missenyi districts a found on the boarder of Tanzania and Uganda (Figure 1).The altitude range from 1,250 m on the lowlands to above 1,450 m asl, in the highlands. The natural environment has a

complex mix of natural landscapes interspaced with human settlements, ranging from heavily populated (650 person km^{-2}) banana-coffee agro-ecosystems in the lake littoral zone (covering 80% of Bukoba district's land) to the sparsely populated (250 person km^{-2})but heavily grazed semi-arid savannah in the hinterland (covering 70% of the Missenyi district's land). The farming system is comprised of three distinct but closely linked land use types; i) the homegardens (*kibanja*), where a mix of crops line bananas (Musa spp.), coffee (*Coffeacanephora*), beans (*Phaseolus vulgaris*), maize (*Zea mays*), taro (*Colocasiaesculenta*), cassava (*Manihotesculenta*) and various fruit trees are grown; ii) annual cropping field (*kikamba*) for growing maize, cassava, sweet potatoes (*Ipomeabatatas*), yams (*Dioscorea spp*.) and occasionally taro and iii) grasslands (*rweya*) which serve as communal grazing land, source of mulch and thatch grass and area for shifting cultivation(Baijukya, 2004). The characteristics of the district are summarised in Table 1.

Tororo district is found in eastern in the Sothern and Eastern Lake Kyoga Basin Agro-Ecological Zone. The altitude in the district is 1,050 m asland receives on average 1,238 mm of rain per annum, which occur in a bimodal pattern (Wortmann and Eledu, 1999). The soils are mainly loam on the ridges and upper slopes and sandy loam on the lower slopes. The soils have low organic matter and low nutrient supply. The district has extensive wetlands,which are increasingly encroached by agricultural activities. The population density is moderate with 129 person km^{-2}. The major food crops are finger millet, sorghum, cassava, sweet potato, grain legumes, maize and rice production is important in low-lying areas. Cotton is a major cash crop, with the main economic activities being crop and livestock production. The major characteristics of the districts are summarised in Table 1.

Agricultural systems in the study districts are characteristic of east and central Africa, notably the sparsely populated dry land agro-pastoral system based on heavily grazed savannah grasslands, and the highly populated intensive banana-coffee agro-ecosystems found in the highlands. Farming is done on inherently poor soils (Baijukya and SteenhuijesnPiters, 1998; Wortmann and Eledu, 1999) with the majority of households very poor (characterised by low food consumption, inadequacy in basic education, use of rudimentary tools, poor housing, small land area, little disposable income, use of unimproved crop varieties, and with strong reliance on indigenous knowledge) (FAO, 2008).

As in most parts of study area, increasing human pressures on landis causing the intensification of land use and the adoption of unsustainable practices, exemplified by overstocking and overgrazing, continuous cropping with reductions in fallow and rotations, reduced crop diversity in response to markets, encroachment of subsistence cropping into more fragile drier areas, over-exploitation of forests and woodland for timber, fuel wood, charcoal and brick making (NEMA, 2008; Mwiturubani, 2010). These changes in land use and land cover, particularly the decrease of forests, have altered rainfall run-off and run-off infiltration process, hence crop production. Nevertheless, the existing local knowledge does not encompass how to cope under such changed circumstances, nor in response to insidious, unprecedented environmental changes and variations due to climate change.

Table 1: Main Characteristics of study districts

Characteristic	District		
	Bukoba	Tororo	Missenyi
Geological materials *[1]*[2]	Sandstone, shales and gneissic formations to intrusive basic rocks and volcanic materials	Shales and quartzite to alluvial and colluvial materials in the wetlands	Granite, alluvial and colluvial materials in the wetlands
Soils	Ferralsols, Acrisols and Andosols	Luvisols, Gleysols and Planosols	Acrisols, Vertisols
Land form	Hilly to gently undulating uplands, long stony slopes to the shores of Lake Victoria	Mixtures of wide and narrow colluvial valleys and flat low level countryside	Hilly to undulating and flat low level plains
Rainfall mm yr^{-1}	1500-2000 (bi-modal)	750-1000 (bi-modal)	800-1200 (bi-modal)
Farming system and major crops	Mixed agro-forestry, crops; (intercropping of perennial banana and coffee with and annuals dominated by cassava, sweet potato, maize and beans) and livestock	Livestock based (largely transhumant), annual cropping dominated by cassava, maize, beans and sweet potato	Mixed crop (perennial banana-annual cropping of maize, sorghum, rice and integrated to various extents with legumes, tubers) and livestock
Human population (person km^{-2} of cultivate/inhabited land)	430-750	Less than 250	280
Average land holdings	0.5 ha	1.5	3 ha
Major economic activities	Predominantly agriculture, in additional to fishing and related trade activities	Mixed livestock and crop farming and related trade activities	Mixed crop farming and livestock keeping
Adult literacy rate (% age 15+) *(School attendance: primary + secondary)	72%	68%	76%,
Poverty % rural population below national poverty line ($1/day) (average annual)*[2]	$370 (2008)	$310 (2008)	$460 (2008)
Poverty, % population <$1/day consumption	52% *(2008)	60% (2008)	52% (2008)
% Undernourished *[3]	31%	34%	27%

Source: *[1] Baijukya and de Steenhuijsen Piters (1988); *[2]Wortmann and Eledu (1999), *[3]WHO (2008)

Materials and methods

Diagnosing farmers' perception, adaptation strategy and vulnerability to climate change and variability

The first step in this study was to establish and document how local communities interpret the broad subject of climate change and variability, examine the impacts, vulnerability and adaptation strategies. To do so, we conducted a survey of 480 households; 160 households from villages Maruku, Kyema and Butahyaibega (in Bukoba District), 120 households from villages Nsunga, Kassambya and Byamutemba (in Missenyi district) and 200 households from sub counties Kisoko and Usukulu in Tororo district.Rather than confronting farmers with a pre-determined menu of so-called climate change factors, we asked them to describe their experiences on changes of weather patterns, the associated impacts and what they are doing to minimize/ eliminate the impacts. Complementary research methods including group discussions, participatory appraisal and key informant interviews were used such that we could gather more information on spatial vulnerability to climate change and variability. Care was taken to ensure that women's perspectives of climate change and variability are captured by making sure that at least one third of survey households were female headed. Questionnaire contained specific questions regarding household demography and physical assets, farming activities, farmer perceptions of climate change, vulnerability and climate risk management. Overall, more than 1,200 people were interviewed; 700 in Tanzania and 500 in Uganda. For researchers to observe and document the state of the farms, crops and farming practices, transect walks were performed in different directions of the villages/subcounties. This not only gave broader perspective community vulnerability, but also, allowed analysis of divergence in views and implications of these differences for management of climate changes and variability in the region.

Conceptualisation of change and prioritisation of adaptation strategies

Drawing on the findings of the survey above, we developed strategies for communities to test some of the potential ISFM options. This was done using Participatory Action Research (PAR), a process of progressive problem solving, with iterative cycles of learning and doing (German *et al*. 2008). It is important to note,however, that the PAR approaches used in this study varied depending on the experiences of research teams in different countries. In Bukoba and Missenyi districts, workshops were organised with participation of community members, community leaders, extension agencies, civic organisation and NGO working in the respective communitiesto give them feedback on the findings of the survey. The workshops were used as an initial step in creating the much needed awareness on climate change and variability issues, enabled discussion among participants on point cause of vulnerability, the most affected households, and actions necessary to enhance adaptation. In Tororo, the PAR process involved formation of working groups (crops, soils and environment, socio-economics, livestock and resource mapping) to understand the livelihood assets, prevailing situation (constraints and opportunities), coping mechanisms and visioning whether the proposed options were relevant to contribute towards farmers' attaining their vision. The RIVER and BUS codes were used in the visioning process where a community vision highlights the ideal situation that would reflect their aspirations, values, life goals and purpose that is where individual households and the entire community want to be after a specified period of time. The vision creates a sense of how soil fertility management technologies will contribute towards achieving the community vision. In all cases, PAR process started with plenary sessions, followed by group discussions and finally group presentation to the plenary where participants made their contribution and their desired changes on prioritised issues.

Experimentation and co-learning with farmers around ISFM learning centres

The PAR process led to the development of criteria for establishment and implementation of 15 learning Centres (LC). These were Maruku, Kyema, Butahyaibega and Bulinda (Bukoba District); Nsunga, Kassambya and Byamutemba (Missenyi district) and Osukuru and Kisokoin Tororo district (each with 3 learning centres). The main objective was to promote co-learning and accelerated exchange of technical information among farmers (and with service providers), while testing different ISFM options for increased crop productivity. The entry points were Farmer Field Schools (FFS), established farmer groups and CBOs

as such groups were thought effective to work with and for easier and wider dissemination.Functioning farmer groups and FFS were selected to run and manage the learning centres and to fine tune the best-bet Integrated Soil Fertility Management Technologies (ISFM). Most soils at the learning centres were poor in total nitrogen and phosphorus as indicate in Table 2.

Table 2: Some physico-chemical characteristics of top soils (0-30 cm) at the learning centre sites

District	Learning centre	pH (H_2O)	OC (g kg^{-1})	Total N (g kg^{-1})	Total P (mg kg^{-1})	Textural class
Bukoba	Maruku	4.7	13.4	0.4	13.6	Sandy clay loam
	Bulinda	5.4	14.3	0.9	10.1	Sandy clay loam
	Butahyaibega	5.6	21.7	1.1	22.6	Sandy clay loam
Missenyi	Nsunga	5.6	24.9	0.8	10.8	Sandy clay loam
	Byamutemba	5.5	16.7	1.2	7.9	Clay loam
	Kassambya	6.3	33.1	1.4	8.0	Sandy loam
Tororo	Kisoko	-	-	-	-	-
	Usukuru	-	-	-	-	-

Results and discussion

Farmers' perception of climate change and variability

There was high awareness among farmers about climate change and variability. About 80%, 91% and 83% of survey households in Bukoba, Missenyi and Tororo districts, respectively, stated they were aware of climate. Out of these, 60% of respondent cited short rain seasons, poor rainfall distribution or both and 28% of respondent mentioned increased incidence of storms floods, meaning that farmers were more prone to droughts than floods. This runs parallel to the meteorological information collected from stations nearby the study districts which shows an overall decreasing amount of rainfall (Nyanga, 2006). There were however, diverse views about cause of climate change and variability among farmes. In Bukoba district, where human activities has intensified and brought about conflicts on natural resources, 68% of respondents attributed the changes to human forces with the rest attributing it to natural powers. On the other hand, 68 % and 58% of respondent in Missenyi and Tororo districts, respectively, attributed the experienced changes to natural power. Some farmers also expressed strong opinions pointing the increasing human population, human development, weak institutional capacity and poor governance as causal factors of changes.

The perceived impacts of climate change and variability varied among communities, largely reflecting the overriding constraints to agricultural productivity in the respective districts (Table 4). In Bukoba district where prolonged rains create conducive environments for occurrence of crop pests and diseases and accelerate leaching of nutrients from the soils, increased crop pests and diseases were the frequently (73% and 67% of respondents) mentioned impacts. On the other hand, Missenyi and Tororo districts which are more prone to droughts and have large numbers of livestock, crop failure and shortage of pastures were frequently mentioned.The observed disparities among communities and community members on understanding of cause and impacts of changes have significant implications for adaptation. The local understanding of climate change emphasise not only the visible impacts but also the wider social conditions in which the impacts manifests. They may also be indicative of community or individual surrender to the problem.

Table 3: ISFM treatments tested in learning centres by communities in Bukoba and Missenyi districts of Tanzania and Tororo district of Uganda

District	ISFM option tested	Crop
Bukoba	Fertility management with farmer practice (apply ash after burning plant and weed residues in the field); Mineral fertiliser calcium ammonium nitrate (at recommended economical rate of 50 kg/ha); Farm yard manure at moderate rate of 4t/ha; Farm yard manure plus mineral fertiliser (combination of ii and iii above)	Improved and local maize varieties
Missenyi	Planting maize seeds on flat cultivation; Flat cultivation with mulch; Normal ridges; Tie ridges; All treatments with basal application of cattle manure at moderate application rate of 4 t/ha	Improved and local maize varieties
Tororo	Fertility management with Farmer practice (no fertiliser application) 30 kg N/ ha; 30 kg N/ha plus 10 kg P/ ha; 4.0 t/ ha kraal manure; 15 kg N/ ha plus 5 kg P/ ha plus 2.0 t kraal manure/ha; 30 kg N/ha plus 4.0 t kraal manure/ ha	Maize and sorghum
	Fertility management with Farmer practice; 4.0 t / ha manure; Rhizobia inoculation; 10 kg P /ha[1]; Rhizobia inoculation plus 10 kg P /ha	Soybean

Table 4: Perceived impacts of climate change and variability by smallholder farming communities in Bukoba and Missenyi districts, Tanzania and Tororo district, Uganda (N = number of respondent)

Perceived impact	District		
	Bukoba (N =160)	Missenyi (N=120)	Tororo (N=200)
	% of respondents		
Increased frequency and intensity of droughts	28	75	66
Decline in household asset level	5	16	35
Increased incidence of crop pests and diseases	73	44	54
Increased incidences of livestock diseases	32	68	52
Increased incidence of human diseases	33	42	18
Decline in soil fertility	67	12	38
Increased shortage of pasture	3	65	54
Shortage of water for domestic and livestock use	-	34	-
Economic loss	16	39	32
Increased bush fires	-	23	-

Discussions with elder respondents in Bukoba district revealed that the problem of declining soil fertility has become persistent and some diseases are increasing becoming destructive and cannot be controlled without God's will.Studies byBrownlie, (2006) and Rugalema *et al*. (2009) also reported increased incidences and severity of Malaria and Tuberculosi, livestock diseases- Foot and Mouth Disease and Contagious Bovine Pleuropneumonia, and crop diseases -Banana fusarium wilt, Banana Xanthomonous wilt, Cassava Mosaic and Coffee Wilt in areas around the Tanzania-Uganda border.Yields of bananas and coffee have been reported to fall from 18 t/ ha and 6 t/ha in the 1960's to lessthan 4 t /ha and 1t/ha in 2000, largely due to above mentioned diseases (Walker *et al*. 1984; Moses *et al*. 2007; Rugalema *et al*. 2009), confirming prolonged struggle of farmers with the diseases.

Farmers' adaptation/ copping strategies to the changing climate

IPCC(2001) defined adaptation to climate change and variability as the adjustment of a system to moderate the impacts of climate change, to take advantage of new opportunities, and to cope with the

consequences.Along with this definition smallholder farmers in the study district could be perceived as efficient, experienced and fundamentally adaptive. Adaptation measures used include planting of locally selected short duration/ early maturing crops, planting of drought tolerant crops (e.g. cassava, millet, sorghum and sweet potatoes), preparing gardens early, planting whenever it rains (i.e. staggered planting), extending farming in wetlands, adoption of water loving crops e.g. rice, mulching fields with grass to conserve moisture and storing food from past harvests. Social networks also exist to address food insecurity and typically involve selling of labour, the sale of livestock and other household assets, gift in kind or loan from friends or family, for relief food from Government, collection of wild plants to eat, and cutting down trees for timber, charcoal and bricks making to raise capital.

However, most adaptation strategies as currently used by farmers are unlikely to provide expected impacts because of associated limitations. Examples of some of the limitations include; unavailability of improved seeds of short duration/drought tolerant crops, unavailability and high prices of mineral fertilisers, poor soils give low crop yields limiting the amount of food farmers can store for use during periods of shortage, fields can only be prepared at the onset of the rains which are difficult to predict, money for buying food is not readily available due to numerous demands of households, farmers have little crops to sell, available marketsare not remunerative to build capital for investment in agriculture, wetlands are communal grazing areas hence cultivation of crops in themcause conflicts especially when animals destroys crops.Off-farm employment are locally available but with low pay and strong completion. Some of the coping strategies can also adversely affect adaptation strategies as people become unable to repay debts, and cutting down trees degrades the environment further. This unhealthy situation continues to persist in many communities in Africa because of lack of appropriate local institutions that enhances collective decision making process and arrangements that discourages marginalisation of vulnerable populations.

Performance of tested ISFM options and crop types at learning centres

In Bukoba district, combined application of farmyard manure and mineral fertilizer gave the best yields in each case, out-performing both sole manure and sole fertilizer treatments by about 38-80% (Table 5). Across the cropping seasons and different learning centres, the improved variety consistently gave 2-5 times more maize grain than the local variety. Sole manure and sole fertilizer treatments did not differ significantly. Farmers were able to learn that they could get better returns to fertility management if they use improved varieties instead of recycling local seeds. The local variety yielded 0.7- 2.9 t ha^{-1} under the different ISFM treatments, while the improved variety, (STUKA), yielded between 1.0 - 5.0 t ha^{-1} (Figure 2).

Under low rainfall conditions, in Missenyi, use of mulch on flat land gave the highest maize yield followed by use of ridges (Table 6). Both these treatments more than doubled yields achieved under farmers' current practice, with the improved variety giving more yield. During participatory evaluation exercises, farmers acknowledged that improved crop varieties were more tolerant to soil moisture stress as well as diseases. The short rain season of 2008 was regarded by many farmers in Kagera region as a drought season, but the improved variety SITUKA gave considerable yield as opposed to almost zero yields from the local varieties.

There was a significant increase ($P<0.05$) of up to 100% in sorghum grain yield in response to the application of inorganic fertilizers and manure when compared with the farmer practice (control) at all learning centres in Tororo(Table 7). The highest sorghum yield increases were achieved with combinations of organic and mineral fertilizer. The significant increase ($P<0.05$) in sorghum grain yield in response to application of P as compared to N alone indicates that P is a limiting factor for these low fertility soils. The debate that ensued during farmer field days was related to whether the increase in productivity of sorghum by such a magnitude would be attractive enough for farmers to prioritize the crop which was competing with maize, a crop that responds more favourably to fertilisers during favourable rainfall seasons.

Maize-based Learning Centres yielded up to 4 t ha^{-1} of maize grain following application of combinations of manure, nitrogen and phosphorus fertilizer (Table 8). However, maize yields in relatively poor seasons (2008B and 2009A) during the course of the study were < 2 t ha^{-1}, comparable to sorghum yields during the same seasons. This seems to suggest why farmers continued to take the risk of growing maize, but notwithstanding the multiple benefits of sorghum such as better storability and low external nutrient

demands. Farmers agreed that sorghum would ensure some yield during bad seasons, and therefore resolved to strategically grow both crops to ensure food availability when below-normal rainfall seasons fail to sustain high maize production.

The yields of soyabean doubled with a combination of rhizobial inoculation and P fertiliser application (Table 9). The rotational benefits realized by farmers in terms of yield increases for both sorghum and maize encouraged farmers to experiment with the various options in their own fields. Networking with other organizations through Africa 2000 Network enabled wide dissemination of the project findings in a short time. Following the PAR planning workshops held during 2009, the community leadership mobilized farmers to double the production of sorghum through use of ISFM, as well as increasing the planted area. However, this gave rise to an urgent need for animal traction, to enable timely planting and increased returns to labour investment. This therefore constituted part of the re-planning cycle for 2010, an activity that extended beyond the lifespan of the project.

Throughout the learning centres, alternative ISFM options more than doubled the yield of test crops compared to farmer' practices. The success of technologies and practices reported above, have also been reported in numerous farms and farming systems in sub-Saharan Africa (Waddington, 2002; Sanginga and Woomer, 2009), justifying investment in soil fertility management to enhance farmers adapt to effects of climate change and variability. Although manure gave good response, there is insufficient quantity to apply at the low rate 4 t /ha to area under crops. Therefore use inorganic fertilizers and exploitation of biological nitrogen fixation systems through increased use of legumes in the farming system will have to be enhanced for increased crop and soil productivity to meet the farmers' goal of food security and improved livelihood.

Development of an adaptation strategy for agriculture

Drawing on the results obtained from the learning centres, farmers entered another cycle of participatory evaluation and reflection in order to develop adaptation strategy for agriculture against the major identified climaticfactors/ impacts. However, pointing on the tested ISFM adaptation options, farmers mentioned a range of factors which would limit their wider application (Figure 3). Lack of basic seeds of improved crop varieties, inadequate knowledge by community members on the application on application lack of money to support were most often cited by farmers in all participating communities. Other constraints include limited availability of labour, which was more pressing farmers in Bukoba and Missenyi and shortage of agricultural land, a factor more important in with significant impact to farmers in Bukoba district.

One of the method improved seed available is to multiply them locally through trained farmer groups known as "Community Seed Production Groups (CSPGs). This strategy was employed in Bukoba and Missenyi districts through a joint collaboration of Maruku Agricultural Research Institute (MARI) who supplied basic seeds, the agriculture offices of the respective districts who provided supervision to the groups and the National Seed Certifying Institute (TOSCI) who provide technical backstopping to the communities for enhanced seed quality. This activity is now fully facilitated by the district councils (with more than 7 functional CSPG), where by the end of 2010, a total of 24t of improved maize varieties STUKA and STAHA had been produced byparticipating farmers. The challenge however, is the availability of basic seeds of other superior crop varieties and high cost of crop inspection in the field given the remoteness of study districts.

To improve the availability of quality manure, members of learning centres in Bukoba were mobilised to practice zero grazing of goats followed by trainings on animal husbandry, and manure management. In Tororo, many farmers have adopted composting but are constrained by the shortage of composting material and usually end they produce composts with poor quality. To improve the quality farmers were trained on how to better mix manure and plant residues and fortify the mix with phosphorus fertilisers which will result into grater nutrient solubility and retention. Farmers in Missenyi district considered mulching and important option to improve production of crops and were facilitated to further learn about of *in-situ* production of mulch using short fallow herbaceous legume Mucuna (*Mucunapruriens*). At all

learning centres, these initiatives have generated interest from community, development partners and they continue to be funded under different projects in Tanzania (including the Lake Zone Agricultural Research Fund, the District Agricultural Development fund and the Soil Health research Project funded by the Alliance of Green Revolution in Africa AGRA) and Uganda (largely the NGO under Africa 2000 Network).

Conclusions and recommendations

The present study was undertaken to test and demonstrate to smallholder farmers the potential of integrated soil fertility management (ISFM) options to enhance their coping and adaptation strategies that support enhanced crop and livestock production and overall livelihood benefits in the face of increasing climate variability and change. Of particular interest was to understand how the local knowledge and empirical science can be combined to assist farmers to adapt to climate change and variability. Our results show that farmers in East Africa explain climate change and variability from its impacts and efforts to communicate the science of climate changes to them has remain rudimentary and fraughtwith what are perceived to be contradictory and unreliable messages.Farmers continue to adapt to the impacts, as they have always had to adapt to changing environmental circumstances. However, the adaptation strategies used consists of uncoordinated actions both at household, community and district levels and do not take cognizance of the trends imposed by the declining/ poor soil fertility. This is because of the fact that communities and individual householdspursue a wide range of crops that vary both within the farm, across farms and agro-ecological zones, possess different vulnerabilities and they tend to be impacted differently thus require a wide range of adaptation options. The study also shows absence of social institutions and arrangements that enhances collective/ participatory decision making process.

Experimentation with farmers revealed that use of best-bet ISFM technologies including fertilisers (mineral and organic), improved crop varieties (high yielding and drought and pest tolerant/ resistant) can more than double crop yields (compared to what is obtained now). This additional yield may be used to improve households' food security, improve and stabilise income, reduce further environmental degradation to encounter climate change and eventually relieve smallholder farmers from pressure of climate change and variability. Our results complement other successive stories of ISFM in pockets of different farming systems in sub-Saharan Africa(e.g. Waddington, 2002; Sanginga and Woomer, 2009). With a wake of climate change and variability, it is probably the time we should resume popularisation of ISFM, along with the efforts to create awareness on climate change and variability. In this process, PAR as used in this study would be instrumental because the practices are easily testable by farmers and should facilitate adoption. Along with this local and national government should create enabling environment for farmers to adopt ISFM including:

- Make available and promote the use of seeds of improved crop varieties.
- Support communities to establish appropriate social institutions and arrangement that discourage marginalisation of vulnerable population and enhance collective decision making
- Create polices that facilitate availability of specific ISFM products including appropriate mineral fertilisers, pesticides and inoculants
- Improve markets for farm produces by linking different actors in the agriculture production value chain
- Build capacity of local scientists and extension workers on conducting adaptive research on adaptation to climate change. They should be able to diagnose with farmers and take their traditional practices and their limited capacity to investment into account when devising recommendations
- Build capacity of local institutions to generate and to provide reliable seasonal climate forecasts to farmers

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Adoption of water resource conservation under fluctuating rainfall regimes in Ngaciuma/Kinyaritha watershed, Meru County, Kenya

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Abstract

Availability of water in quantity and quality affects economic growth. The aim of this study was to assess water resource conservation under fluctuating inter-annual rainfall regimes in Imenti North District, Kenya. Unsustainable use of water resources has drastically affected the volumetric flows of Ngaciuma/Kinyaritha River rendering some of its tributaries seasonal. This has adversely affected accessibility to adequate water for both domestic and agricultural use. A study was carried out to understand the adoption levels of water conservation practices in Imenti North. The influence of water resource accessibility on adoption of water conservation (WC) practices and constraints were assessed. Primary and secondary data were utilized. Descriptive statistics was used to analyse socioeconomic parameters. Regression, correlation and spearman's t-test were used to compare the relationship between variables. Tree planting, roof catchment and bench terraces were the major WC practices in use. Multiple regression analysis revealed that lack of technical knowhow could explain 83.5% variations of adoption level of WC practices. One sample t-test comparing the means of WC practices among respondents' was significant at $P<0.01$. Spearman's rank test revealed a decreasing trend during the long rains (March-May) for the period 1986-2008 at $P<0.05$. The disparity between the levels of adoption among water users coupled with the decreasing seasonal rainfall calls for urgent and better management of water resources in the study area.

Key words: Rainfall, unsustainable water resource use, water conservation practices.

Introduction

Critical discussions and negotiations on water resources have been on the international agenda and have elevated water resource to a greater global awareness. Water is a scarce resource, yet an essential component for human survival. This scarcity is linked to climate change; demand that exceeds available water resources and most importantly unsustainable use of the resource (Molle, 2000). Many parts of the world, markedly the Middle East and the sub Saharan Africa are experiencing intense competition over limited inland water resources. This situation is serious in shared drainage basins where it has heightened political conflicts (McCartney, 2000). The situation in Kenya is not any better. Kenya receives less than 647/m3 of fresh water per capita per year, making it one of the most water scarce countries in Africa and the world (WRI, 1994). Competition over water between agricultural, industrial, domestic and municipal needs has worsened, stretching the recovery of hydrological systems (Orie, 1995). Kenya experiences high rainfall variability, low investment in water resources development and poor protection of the existing water resources resulting in extensive degradation (Were *et al.,* 2006).

A basic water management challenge is to find ways to satisfy human needs while coping with climatic changes and protecting the water resource from long-term degradation. With regard to water resource management, the use of participatory approach is one of the principles of the Dublin convention (Cosgrove and Rijsberman, 2000). The concept partly reflects the observation that people who inhabit an environment over time are often the ones most able to make decisions about its sustainable use. However, the vast majority of people have become passive observers, and a few people are taking decisions for everyone else. That is one of the prime reasons why the water resources are being destroyed (McLvor, 2000). The real revolution in water resources management will therefore come when all stakeholders, where possible, have

the power to manage their own water resources. Efforts should be made to maximize productive water use. This could be by finding and stopping wasteful leaks, enhancing focused irrigation techniques, using less water-intensive industrial processes, implementing wastewater recycling, and overall conservation of water catchment areas (Mitchell *et al.,* 2004).

Most of the people living in the rural areas tend to overexploit their immediate environments. According to Gikonyo (2004) indiscriminate cutting of trees has impacted negatively on precipitation and river systems in the Tana Catchment which houses Ngaciuma/Kinyaritha watershed, the study area. Some tributaries in the watershed have become seasonal due to increased land use changes and direct over-abstraction (WRMA, 2008). The sub-catchment also experiences temporal variations in water demand that creates a negative balance between demand and supply during the dry season (DAAD, 2008). This study addresses the following key

questions: How has been the trend in rainfall for the period 1986-2008 in the study area? What is the level of adoption of water conservation practices in the study area? Which are the constraints faced? Does accessibility and participation in local Water Resource Users Associations (WRUAs) affect adoption of water conservation practices?

Materials and methods

Study area

Ngaciuma/Kinyaritha watershed is located within Meru municipality geographically bound by latitudes 37.5° E and 37.75° E and 0.04°N and 0.15° N. The watershed covers an area of 167 km2 in Imenti North District, Kenya. Climatic conditions range from humid to semi-humid with Agro-ecological zones UM1=Coffee-Tea Zone, UM2= Main coffee Zone and UM3= Marginal coffee zones (Jaetzold *et al.,* 2007). Rainfall is bimodal with mean annual rainfall range of 1100-1600 mm and annual temperatures range of 10-30oC. Altitude ranges from 1120- 2600 m. Geology of the catchment comprises pyrocrasts (Plate1) and the major soils are nitisols (Plate2) which are poorly consolidated hence susceptible to erosion, mass movement and high seepage where water is conveyed in open channels.

Plate 1: Nitisols

Plate 2: pyrocrasts

Data collection

Data was negated from primary and secondary sources. Primary sources included administering of questionnaires, focus group discussions, key informant interviews and non-participatory observations. The fieldwork was conducted between the months of June and October 2011. Secondary data included rainfall data acquired from Kenya Meteorological Department in Nairobi and Water Resource Management Authority in Imenti North sub-regional office. Before the main study, a reconnaissance survey was carried out to pre-test the research instruments and work out modalities of identifying respondents in the study area.

Data analysis

Descriptive statistics were used to analyse socioeconomic parameters. To measure the adoption level of water conservation practices, a weighting system was used that assigned values to each conservation practice based on its importance as perceived by the respondents relative to all other conservation practices. The weighted importance score for each practice was multiplied by reported answers of implementation from respondents. Finally, respondents were categorized as "low", "fairly low", "fairly high" and "high" adopters based on the collective 'adoption score'. Score ranges for low, fairly low, fairly high and high adoption categories were determined by mean and standard deviation, as follows (equation 1):

Min<A<Mean-St.d: A= Low

Mean-St.d <B<Mean: B = Fairly Low…………………………………………………………1

Mean <C<Mean+St.d: C= Fairly High

Mean+St.d <D<Max: D = High

Trends in rainfall were analyzed using the Ms Excel software to generate graphs. Spearman Rank Correlation test was used to test the null hypothesis of no significant variations in trends of rainfall and stream flow for the period 1986 - 2008 in Ngaciuma/Kinyaritha watershed. Rainfall data was ordered and ranked from the lowest to highest. The differences between the rankings were computed and squared. The latter were summed up to yield $\sum\partial i2$. The Spearman Rank Correlation (rs) was computed using equation 2.

$$rs = 1 - 6\sum_{i=1}^{N}\partial i2 / N(N2-1) \qquad (2)$$

Where, ∂i=ki-I, ki is the rank of the series xi and N the total number of observations. The approximate significance of rs2 for N>8 and df =N-2 was calculated by computing:

$$t = rs\,\{df/(1-rs2)\}0.5 \qquad (3)$$

Coefficient of variation was computed to compare variability of each water conservation methods adopted among the respondents. Correlation analysis was used to measure the association between dependent and independent variables. Stepwise multiple linear regression model was used to explain variations in adoption level of WC practices among respondents. Eleven independent variables: Age, Education level, Household size, participation in WRUA conservation activities, Farm size, level of information sources and channels, economic motivation, stewardship motivation, level of awareness on sustainable WC practices, attitude towards conservation practices and level of technical knowhow were fitted in model. Backward elimination approach which involved starting with all independent variables and testing them one by one for statistical significance, deleting any that was not significant was used to fit the regression model.

Results and discussion

Household characteristics for each zone are given in Table 1. Majority of the respondents' were farmers at 83.7%. Due to unreliability of rainfall, rain fed agriculture is no more reliable and thus majority of the farmers are practicing irrigated agriculture. Despite the perception that the study area is well watered, lack of adequate water supplies was the major hindrance to the expansion of irrigation and livestock keeping having up to 75% of mentions (Table 2). This is an indicator that Ngakinya/Kinyaritha watershed is faced with inadequate water supplies against the perception that the watershed is well watered.

Table 1: Summary characteristics of selected households according to Zones

Household Characteristics	Description	Locations			
		Upper Zone	Middle Zone	Lower Zone	Average (%)
Sex (%)	Male	66	82	80	76
	Female	34	18	20	24
Education (%) level of respondents	Primary	50	48.6	54	50.9
	Secondary	26.7	20	25	23.9
	Tertiary	13.3	22.9	10	15.4
	None	10	8.5	11	9.8
Age (%)	18-36	33.3	28	21	27.4
	37-54	50	56.7	66.4	57.7
	>54	17.7	15.3	12.6	15.2
Occupation of household heads	Farmer	90	78	83	83.7
	Civil servants	6.7	12	8	8.9
	Business persons	3.3	10	9	7.4

Table 2: Major constraints limiting expansion of irrigation agriculture

Constraint	Number of times Mentioned	Percentage of Mentions
Land size	60	50
Water accessibility	48	40
Lack of adequate water	90	75
Market problems	6	5
Cost of farm inputs	30	25

Note the percentages do not add to 100% because the respondents answered to more than one constraint.

Analysis of rainfall trends for the period 1986-2008 Analysis of rainfall for the period 1986 - 2008 shows an inter-annual fluctuation in rainfall and declining rainfall trends both linearly and in five year moving averages (Figure 2).

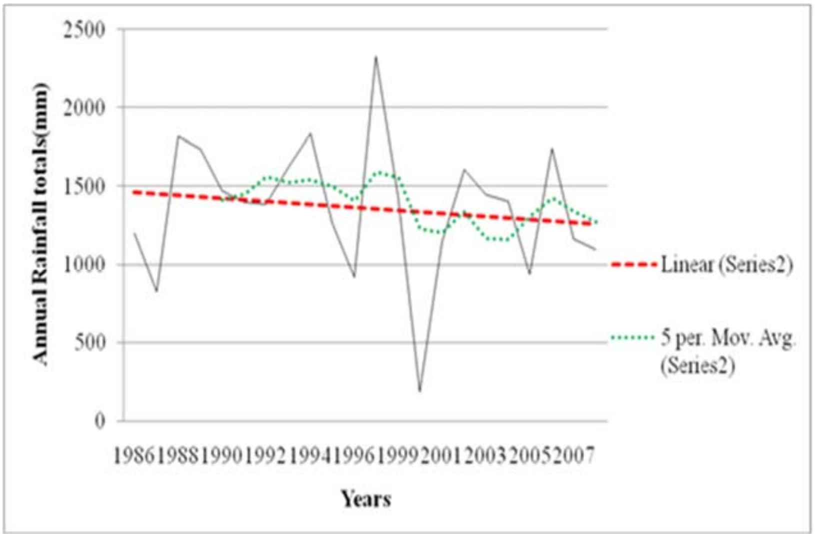

Figure 2: Inter-annual fluctuations in rainfall for the period 1986-2008

The Spearman test showed a significant decreasing trends for the long rains (March-May) for the period 1986- 2008 at a statistically significant level of $p<0.05$ (Table 3). This indicates reduction in water resources as rainfall is the major source of water for rivers and ground water replenishment. This would therefore imply inadequate water supply for both domestic and agricultural uses.

Table 3: Spearman' test for annual, long (Mar-May) and short (Oct-Dec) rainfall

	Period	1986-2008	1986-1995	1996-2008
	Df	20	8	10
Annual rainfall	rs	-0.22179	0.29697	-0.2940
	T	-0.9500	0.0857	-0.5620
Long rains(Mar-May)	rs	-0.4048	0.0303	-0.2940
	T	-1.9563a	0.0857	0.46905
Short rains(Oct-Dec)	rs	0.03500	0.1636	0
	T	0.1566	0.46905	0

a Trends statistically significant at $p<0.05$.

Analysis of perceived indicators of sustainable water conservation practices Tree-planting; Rainwater harvesting by use of roof catchments; Bench terraces and Mulching are top of the list in terms of prioritization by the respondents (Table 4). Drip irrigation according to respondents required a lot of expertise and finances to put up the systems hence the least water conservation method in Ngaciuma/Kinyaritha watershed.

Table 4: Prioritized indicators of sustainable water conservation practices

Conservation method	Mean	Standard deviation (Std)	Coefficient of Variation (CV)	Priority
Tree planting	0.670	0.140	0.209	1
Rainwater harvesting	0.767	0.161	0.210	2
Bench terracing	0.667	0.300	0.450	3
Mulching	0.500	0.225	0.450	4
Vegetative strips	0.750	0.338	0.451	5
Infiltration ditches	0.308	0.302	0.980	6
Waste water reuse	0.322	0.395	1.227	7
Fanya juu	0.256	0.376	1.469	8
Water metering	0.287	0.422	1.470	9
Drip irrigation	0.156	0.293	1.878	10

Analysis of adoption level of WC practices and the constraints Table 5 shows the levels of adoption of water conservation practices. It could be inferred from the Table that majority of respondents fell into either fairly low or high ranking.

Table 5: Adoption level of water conservation practices by respondents

Group	Scale	Frequency	%of frequency
Group1 (low)	3.817	21	17.5
Group2 (Fairly low)	3.818-5.280	48	40.0
Group3 (Fairly high)	5.281-6.743	21	17.5
Group4 (High)	7.9	30	25.0
Total		N=120	100
Max:7.9,	Min: 1.4,	Mean: 5.28,	Std:1.463

The community faces constraints despite the efforts to participate in water conservation practices (Table 6). However, an important finding from this study was that some of the listed adoption constraints decreased with increase in the number of water conservation practices adopted. Similar findings have been observed elsewhere by others (Tenge *et al*. 2004). Lack of capital was a major constraint. Wealth is linked to power and property rights over natural resources affecting peoples' option for adopting technology (Knox and Meinzen, 1999). Those who posses a higher quantity and quality of endowment will place a higher future on medium and longterm benefits produced by investment in water conservation technologies. Majority of the farmers enjoyed security of tenure having title deeds for their land, thus land tenure was not a major constraint.

Table 6: Observed constraints in relation to the number of WC practices adopted

			Scores by number of WC practices adopted a (%)			
Adoption constraints	Frequency	Overall score (%)	1(n=8)	2(n=15)	3(n=62)	4(n=35)
Lack of capital	100	83.3	41.65	24.99	8.33	8.33
Lack of technical	72	60.0	28.80	19.8	9.00	2.40
Land tenure insecurity	9	7.5	6.4	1.1	0.00	0.00
Small farm size	90	75.0	22.5	7.5	15.0	30.0
Benefit not known	8	6.7	6.03	0.67	0.00	0.00

a Types and numbers of adopted WC measures may have included the following measures either singly or in combination: Fanya juu; bench terraces; grass strips; mulching; tree planting rain water harvesting; waste water reuse(Kitchen gardens) and water metering

Correlation analysis of adoption level of WC Practices and Selective Variables

Table 7 shows there is a positive association between adoption of WC practices and information sources as well as communication channels at P<0.01. The positive association implies that as the level of information and communication channels increase, the adoption of WC practices increases and vice versa among farmers' in Ngaciuma/Kinyaritha watershed. Similarly economic motivation/income level was positively associated P<0.01 with adoption. Sinder and King (1990) in their study on water conservation technologies adoption found that economic factors promote actual adoption by farmers. There was a positive and significant correlation (P<0.01) between the level of awareness about the effects of water conservation practices and level of adoption. A similar finding was reported by Mahboubi, 2005 in their study on factors affecting adoption behaviour of water conservation technologies in Gol watershed in Iran. Similarly the level of knowledge is positively and significantly (P<0.01) correlated with the WC practices adopted.

Table 7: Correlation between adoption level of WC practices and selective variables

Variables	Coefficient of variation
Age	-0.033
Education level	-0.013
Household size	-0.013
Participation in WRUA conservation activities	0.126
Farm size	0.353**
Level of information sources and channels	0.460**
Level of economic motivation(Income level)	0.334**
Level of stewardship motivation	0.331*
Level of awareness on sustainable WC practices	0.136
Level of technical know- how	0.918**

* (P<0.05) and ** (P<0.01)

Regression analysis explaining variations in adoption level of WC Practices In order to explain variations in adoption level of WC practices, stepwise linear regression analysis was used. The results show that the level of technical know-how could explain 83.5% of variations in adoption level of water conservation activities among respondents (Table 8).

Table 8: Regression analysis computing variations in adoption level of WC practices

Description	Label	Water conservation practice	
		B	T
Constant		2.158	7.084**
Level of knowledge (Technical know-how)	∂	0.693	18.255*
F=333.237**	R2=0.835	R2adj=0.832	* (P<0.05) and ** (P<0.01).

* (P<0.05) and ** (P<0.01)

According to the results presented in Table 8, the following model could be used to explain respondents' adoption level of water conservation practices in the study area:

Y= 0.695∂+ 2.157. Where Y=Dependent variable representing respondents adoption level of water conservation practices and ∂ is the level of technical know-how of the respondent.

Conclusion and recommendations

Accelerated water resource degradation is among major constraints to agricultural production. The result of analysis of rainfall indicates reduction in water resources as rainfall is the major source of water for rivers and ground water replenishment. Since adoption of many recommended water conservation measures is still minimal in many areas, paying attention to the factors which determine adoption is a priority. Looking at the factors expected to influence adoption of water conservation practices, participation in Water Resources User Association (WRUA), information sources and channels, economic motivation, level of awareness and level of technical knowhow appear important factors due to their positive and significant correlation with independent variable adoption. These factors interact with each other logically to influence adoption. Additionally the research provides evidence showing that the level of technical knowledge received notable support regarding water conservation practices in the regression model. The findings provided a basis for the following recommendation. It is generally true that access to information sources and communication channels with relevant content may increase awareness about the effects and consequences of water conservation practices among farmers while providing them with required technical knowledge. By understanding the economic and environmental effects of water conservation practices, effective uptake of WC technologies may occur. Thus, provision of required information via various information sources and communication channels in order to raise farmers' awareness is suggested. Community awareness on the conservation measures should be promoted through the use of mass media. The solution is to better target extension services and improve the methods of information delivery. Whereas lack of technical knowhow is cited as a hindrance to adoption, the farmers should be made to know the practices and how best to integrate or incorporate these practices in their agricultural activities for better living as well as protect the environment.

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Optimum crop enterprise combination in sugarcane based farming systems: A case of sugarcane and maize in busedde sub-county, Jinja District, Uganda

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Abstract

The present study titled" Optimum crop enterprise combination in sugarcane based farming system: a case of sugarcane and maize in the vicinity of Kakira sugar estate specifically Busedde sub-county, in Jinja District", it was undertaken to find a way how sugar cane and maize enterprises can be combined using the available limited resources in order to maximize profits and solve the problem of food security, as well as ensuring sustainable land management. Simple random sampling was used in selecting sample farmers, were by three parishes were selected, and two villages from each parish were considered for detailed study. From each village, 10 small scale sugarcane famers were selected randomly and all together 60 famers were considered in the study. The required data was collected using check lists and personal interviews .Linear programming was used in developing optimum plans for maximization of profits.

Findings of the study indicated that 83.3% of the people in the study area depend on maize as the main source of food. Also the farmers should use 25% for maize and 74% for sugarcane of the total land utilized for agriculture. In addition sugarcane contributed an average net return of 13,360,354 Uganda shs, and maize 526,960 Uganda shs per hectare to farmer's income with in a period of five years .The net present value analysis indicated that sugarcane growing Project is a profitable enterprise however its not advisable to carry it out as a single project because the out comes can not cater for all requirements for the house hold.

In conclusion in order to solve food security issues in the area the small scale sugarcane out grower should produce 1units of sugarcane and 1 unit for maize, for a period of five years using 1.8 ha of land for sugarcane and 0.6 ha for maize and full utilization of the available labor and seeds, of the total resources available , in order to maximize profits that can enable them to avail their families with enough food for a period of five years in the sub county of Busedde in the vicinity of Kakira sugar estate.

Introduction

Background

Africa's socio economic development is mainly agrarian and about 70 percent of the labor force and 80 percent of its poor people are directly or indirectly engaged in agriculture, live in rural area and depend on agriculture for livelihood (New partnership for African development-NEPAD, 2004).

According to the state of environmental report (2010), agricultural sector in Uganda is composed of crop and animal production, forestry and fisheries and the associated trade and processing industries. Agriculture continues to dominate the Ugandan economy albeit at a continually a declining level. Agricultural production contributed approximately 15.1 of the total GDP in 2009 down from 15.7 percent of GDP in 2007/2008. At current market prices, agriculture contributed 22.5 percent of GDP in 2010 compared to 23.7 percent in 2008/09and 21.2 percent in 2007/08. The sectors share of exports and employment however remained at 90 and 80 percent respectively in 2009.The sector also constitute about 40 percent of manufacturing sector through food processing. The sector supports 24.6 million people of the estimated total Ugandan population of 30.7 million people. In addition agriculture is important in simulating economic growth through the supply of raw materials to agro industries, supporting the development of food security system, income enhancement and employment. (Kitutu *et al* ,2010).

Agriculture is the most important sector of the economy, employing over 80% of the work force (Uganda economy profile, 2012).Over 70% of the population of Uganda is engaged in agriculture, most of the farmers cultivate <5.0 Ha of land (Misango, 2008).

The agricultural system in the Busoga region is majorly occupied by the sugar cane farming system which is practiced in most of the areas of Jinja district and Mayuge district. A good % of the farmers in South Busoga region do grow sugarcane while others are picking up (Misango, 2008).

Crop combination and food security issue.

Crop combination analysis technique was evolved by weaver to delimit agricultural regions which, he argued, are not regions of simple monoculture as suggested by the names Corn Belt, or spring wheat belt, but are areas of combinations of crops. (http://www.answers.com/topic/crop-combination-analysis)

In the region sugar cane is being grown with other crop, such as maize, banana, coffee, sweet potatoes and cassava, and about 15 years ago, Busoga region was well known for its production of a wide variety of food crops especially maize, sweet potatoes and fruits like oranges. The people also used to intercrop their farms with Coffee and cotton that served as cash crops (http://www.sunrise.ug/news/national-news/4386-plan-to-limit-sugarcane-growing-in-busoga.html)

The increased growth of sugar cane in the region especially in the sub county of Busede has contributed to the increased food insecurity in the region, and best combinations to give the farmer desired result is a decision they often take by trial and error method, therefore the outcome of this study is to provide answers to which enterprise combinations between sugar cane and maize would be the most profitable venture in order to solve the problem of food insecurity in the region.

In agriculture, as in any other business, the efficiency is achieved by an optimum utilization of resources. Resources include land, labor, capital, irrigation facilities etc. Optimum allocation of land and other resources is defined as what crops to undertake, how much land to allocate to each crop activity and what method and combination of inputs to use for each crop so that the farm returns are maximum (Varalakshmi, 2007)

This study attempts to analyze the possibilities and prospects of increasing the net farm income and reducing the increasing food insecurity problem by rational resource allocation through optimum crop enterprise combination for the case of sugar cane and maize in the vicinity of kakira sugar estate.

Problem statement.

The sugar industry in Uganda provides employment to the population, an estimate of 20,000people provide work force on the estates alone and it provides livelihood for many more in jarggery estates and those involve the out growers (Mukiibi, 2001).

The increasing number of farmers in the vicinity of Kakira sugar estate is concentrating on sugar cone growing were by most of the land in this area is used for sugar cane growing, which is grown in isolation which is done in the disguise of it being profitable as the different reports indicate it that is according to Mukiibi ,(2001). This has lead to the increasing food crisis in the areas of Eastern Uganda because sugar cane growing is not a sustainable farming system since its associated with monoculture which reduces the productivity of the soil for planting of other crops like maize ,cassava, banana, beans and sweet potatoes for the purpose of food security.

There is an ever increasing concern about the ever-worsening food crisis and the capability of agriculture to satisfy the food requirements of a fast-growing population with in the vicinity of Kakira sugar estate; this has been majorly due to the increased expansion of sugar cane growing by the farmers in this area.

The above problem is because it’s not known by the farmers how best they can combine the sugarcane growing with other food crops such as Maize using the available resources in order to reduce the problem of food security with in the vicinity of Kakira sugar estate. This research provides critical information about the relationship between food security and profitability, by determining the best combination of sugarcane growing and maize in a sugar cane based farming system in the vicinity of Kakira Sugar Estate.

Significance of the study

This study is important to different stakeholder that is through use of its findings. It provides critical information about the contribution of sugar cane and maize to farmer's income in the vicinity of Kakira sugar estate and also how best maize as the main food crop within the area can be optimally combined with sugarcane growing. This optimal combination improves the farmer's well being in terms of food security and income and also to benefit the company of Kakira Sugar Estate and the sub county plus the country as a whole in decision making and Land use planning for sustainable food security and climate change adaptation in Africa

Objectives of the study

General objective

To determine the optimal crop enterprise combination in a sugar cane based agricultural system in the vicinity of kakira sugar estate specifically Bussede sub county. (For the case of maize and sugarcane)

Specific objectives of the study.

a). To identify the main food crop and its contribution to farmer's income in the vicinity of Kakira sugar estate

b). To find out the contribution of sugar cane growing to farmer's income in a sugar cane based farming system.

c). To determine the optimal crop enterprise combination in the vicinity of Kakira sugar estate.

d). To identify recommendations about the best crop combination in a sugar cane based farming system in busedde sub county, Jinja district

Objective questions.

a). What is the major food crop in the vicinity of Kakira sugar estate?

b). How much land is used for sugar cane growing in the vicinity of Kakira sugar estate?

c). How much land is used for the main food crop in the vicinity of Kakira sugar cane estate?

d). What is the contribution of sugar cane growing to farmer's incomes?

e). What are the returns of both sugar cane and the main food crop?

f). What and how much requirements are needed for sugar cane growing?

g). What and how much requirements are needed for the main food crop?

Methodology and materials used

Description of the study area.

The research was carried out in the sub county of Busedde, the sub county is made up of five parishes which include Bugobya, Kisasi, Nalinaibi, Itakaibolu and Nabiambala .The study covered three parishes of the sub county that is Kisasi, Bugobya and Nalinaibi ,and the study area is located in Jinja district (Eastern part of Uganda) and it is with in the vicinity of Kakira sugar estate. The estate is located in jinja District, approximately 10 miles(16km) east down town Jinja on the highway to Iganga .The coordinates of the town :00 30 00N , 33 16 48E(Latitude :0.5000; Longitude:33.2800) , and occupies a land area of about 37 square kilometres. The agricultural system in the study area is majorly sugar cane based farming system.

Stake holder assessment

Table 1: Stakeholders' analysis

	Stakeholders			
Interest, influence, type and adoptation	Government(NEMA)	Kakira sugar estate (KSWL)	Farmers (out growers)	Sub county (CBOs and NGOs)
Interest	1	1	1	2
Influence	2	1	3	1
Type	Secondary	Primary	Primary	Primary
Adoptation capacity	1	2	3	2

1-high ,2-medium, and 3-low

Research design

The study was conducted using a combination of approaches to obtain primary and

Secondary data as follows:

Check lists and key informant interviews targeting relevant farmers and leaders of farmers and other farmers in Busedde Sub County.

Document reviews of publications and reports of key actors in the agricultural sector. These included reports from the district and other agricultural research reports and books from Kakira sugar estates library and public libraries. This helped to obtain the secondary data

Case Studies were taken from particular out growers of Kakira sugar estates in different parishes of Busedde Sub County.

Sampling design

Selection of the area

Busedde Sub County was selected purposively for the present study as it is one of the sub counties with most of the out growers of sugarcane in the vicinity of Kakira sugar estate, and it's claimed to have had rampant effect of food insecurity from the findings.

Selection of parishes and villages

Among the six parishes in Busedde sub county three parishes are going to be selected and from each parish two villages were selected for a detailed study. The selected parishes were Nalinaibi, Bugobya and Kisasi and the villages were Kakuba, Kisasi, Bugobya, Kiko, Nalinaibi and Nabitambala.

Selection of farmers

The list of farmers or out growers from the selected villages was obtained from the list of farmers at Kakira sugar estate. The study concentrated on small scale farmers, and ten famers were selected randomly from each village and all together 60 respondents were considered in the study.

Data collection method

Representative farm households were selected using simple random sampling from the list of small scale sugar cane out growers of Kakira sugar estate in parishes of Bugobya, Kisasi and Nalinaibi in Busedde Sub County from the factory library.

Information on household characteristics, farm size, and management, input costs, farm gate prices and yield was solicited using a check list which included the questions about the farm and interviews were individuals are asked a series of questions with the hope that they will supply use full information to the decision maker. (Shannon 1993).

Also in addition the observation method of data collection was also used and it involves the use of eyes to observe different aspects during the study, and in this study it was used to observe the main food crop in the study area that is in terms of its area coverage in comparison to other food crops.

Data processing and analysis tools

Tabular analysis

This involved the computation or the calculation of the means, percentages and other measures, and this was used to determine the social economic characteristics of the respondents with in the vicinity of the study for example the level of education ,period of in the field of agriculture and others.

Average gross returns and average net returns

It involves the calculation of the average gross profit and average net profits of different enterprises and its and under this, profit returns of each crop were calculated by multiplying the average price of that crop with the average out put per hectare to obtain the gross returns. The average net return was calculated through subtraction of the average expenditure from theaverage gross returns of the enterprises. The average gross return and the average net returns were used to indicate the contribution of the different enterprises to famer's income, and also were used in the model linear programming model.

That is, $Max\pi = average\ price \times average\ yield$ .For average gross return

Average Net returns =Gross returns–Expenditure.

According to Hans Ruthenberg (1976) Net return (NR) is the most appropriate measure if the purpose is an accounting evaluation of past or future projected performance. It is obtained as:

NR = TGR - TC

Where TGR, total gross return of the enterprise, is the sum of all outputs times their prices, real or imputed, and TC is total enterprise cost, again real or imputed.

Net present value analysis.

It is defined as the sum of the present values (PVs) of the individual cash flows of the same entity. NPV is an indicator of how much value an investment or project adds to the firm, and when the NPV is greater than 0 then the investment would add value to the firm, when it is less than 0 the investment would subtract value from the firm and when it is 0 the investment would neither gain nor lose value for the firm (http://en.wikipedia.org/wiki/Net_present_)

The net present value in this study was used to determine the profitability of the sugar cane enterprise as it take along period of time and to also find out whether it adds value to the farms of the house holds, it was calculated using a discount rate of 15% for each period and the average net returns from the different life cycles of sugar cane project that is the plant, raton 1 raton 2, and raton 3. It is given by the formula below,

$$\boldsymbol{NPV = \sum_{i=0}^{n} present\ values/(1 + rate) \wedge i}$$

Were i is the time period of the project..

Linear programming analysis.

It is a mathematical technique used in computer modelling (simulation) to find the best possible solution in allocating limited resources (energy, machines, material, money, personnel, space, time and others) to achieve maximum profits or minimise costs. (http://www.businessdictionary.com/definition/linear-programming.html).

Linear programming (LP) was used to determine the optimal crop combination in a sugarcane based agriculture based farming system, and the maximum profits obtained is going to be compared with the calculated requirement for food security in monetary terms to determine the level of food security in the

area .It was also used to determine the way how the resources available in the region can be combined in order to maximize profits through use of the optimal decisions that was obtained by linear programming.

Mathematical specification of the linear programming model

Max (Z) = W1X1 + W2X2+ …+ WjXn………………………………….. (1)

Subject to.

B1X1+B2X2+………+ BiXn < M0 …………………………. (2)

Xn ≥0 for j = 1…n …………………………………………… (3)

Where

(Z) = objective function.

Wj = per unit cash return of jth activity .were j =1, 2, 3…………

Xn = enterprises .were n =1, 2, 3………

M0= level of resources available

Bi = amount of i th resource consumed by each activity per hectare.

Equation (1) is the objective function.

Equation (2) is the constraint inequality.

Equation (3) is the non negativity inequality.

The objective function

The objective function for the model in this study was to maximize the annual net returns on the farm (from maize and sugar cane crop enterprises) subject to the resource constraints specified in the model. The total average net returns were calculated by deducting variable expenses from total average gross returns.The various items of variable costs were cost of seeds, human labor (weeding, ploughing, planting, harvesting), transport costs, and land rent. In this model the value of objective function (the optimum solution) which was to be maximized included the sum of the year's average total net returns.

The maximized average net returns was compared to the monetary value of yearly house hold food requirement calculated for the case of Mayuge by Isabirye (2005) in order to asses the level of food security in the area.

Resource constraints in the model.

In this model the resources which seemed to be so important to the farmers and they were in limited supply were considered that is the type of constraints included in the model were physical resource constraints, and among these included labor constraint inters of the average number of workers used on the farm in the different activities, seeds constraint in terms of kilograms used, land constraint in terms of acres and the non negativity production constraint.

Degree of utilization of the constraints at the maximum profits.

The degree of utilization of the resources indicated the percentage of the resources used when the firm has maximized the average net returns with in a given period of time and this was used in determining the percentage of the resources which should be used of the available resources scarce resources to the small scale farmer in a period of five years in order to maximize profits.

This formula was used $bi = (d/g)100$

Were bi is the percentage value of the resource utilization, d is the average amount of the resources utilized and b is the average total amount of the resource available in the period of five years.

Assumptions based on in the study

It was assumed that the famer entirely depends on agriculture for his or her living were by it's the only source of income to the famer and the net returns gained by the farmer are used to purchase food in the home.

A period of stable economic condition was also assumed over a period of five years.

It was also assumed that sugar cane project takes approximately five year consisting of the plant and three ratons, and for the case of maize there are two seasons with in a period of one year that is 10 seasons in five years with a stable bimodal type of rain fall.

All the assumptions of linear programming were considered that is, linearity, divisibility, limitedness, non negativity, additivity and fixed proportionality.

It was also assumed that the physical condition of the soil favors the growth of crops for a period of five years.

Results and discussion

Socio-economic characteristics of the sample farmers.

Family size.

For the case of the family size the study considered the number of people at home of an individual irrespective of the gender disparities, and in the family of a small scale individual it was found out that they consist of an average number of 6-8 people as indicated in Table 3.1 below.

Line of employment.

In the study most of the sample farmers are employed in agriculture that is 80 percent of the sample farmers depend on agriculture as the source of income as indicated in the Table 3.1 below and a few of the people are employed in other economic activities such as Boda boda riding, teaching and trade . This indicated that the dominant activity in the vicinity of Kakira sugar estates especially in the sub county of Busede depend on agriculture as the major source of income and this is in line with the view that, Most of the Uganda population live in rural areas and directly depend on agriculture and related activities for their livelihood (Uganda Bureau of statistics, 2002). Also that agriculture is the most important sector of the economy, employing over 80% of the work force. (Uganda economy profile 2012), and in addition also from the findings of Misango (2008) 70% of the people in Busoga region solely engaged in agriculture as their business, growing sugarcane as their major cash crop.

Gender

From the analysis most of the sample famers in the study area were male that is 85 percent of the respondents were males as indicated in Table 3.1 below and this indicated that most of the people who own the farms in the study area males .

Period in the agriculture sector

The period spent in agriculture was indicated by the amount of years spent in the agriculture sector and this was handled in different categories as indicated in Table 3.1 below, and from the analysis it was found out that most of the sample famer fall into the category of 10-19 years that is 40 percent of the respondents were with in that category. Their period in agriculture account for their being small scale farmers.

Level of education

Most of the sample farmers in the study area reached at least the secondary level of education that is 58.3 percent of the famers fall in the category of the secondary level of education as indicated in the Table 4.1 below.

Level of fertilizer use.

From the findings of the study most of the sample respondents do not apply fertilizers, were by nearly zero percent of the respondent were using fertilizers and 100 percent of the respondents were no using fertilizer

and this accounts for their low yield as indicated in the Table 1 below. And from the findings of the study the farmers claim that "the fertilizers are very expensive yet they have no enough capital and so they decide to abandon them" (per-Sekibungo).

Table 1: Socio-economic characteristics of the sample farmers

Parameter number	Parameter	Unit	Average values
A	Family size	No .people(average)	6-8
B	Employment opportunity	No /Percentages	
0	Agriculture		48 (80)
1	Other fields		12 (20)
C	Gender		
0	Male		51(85
1	Female		9 (15)
D	Period in agriculture		
1	0-9		19(31.7)
2	10-19		24(40)
3	20-29		5(8.3)
4	30-39		6(10)
5	40-49		3(5)
6	50+		3(5)
E	Education level		
1	Non		7(11.7)
2	Primary		11(18.3)
3	Secondary		35(58.3)
4	Tertiary		11(11.7)
F	Use of fertilizers		
1	Use		0(0)
2	No use		100(60)

Note, the values in the parenthesis indicate the percentage to the total. (Source- primary data)

Main food crop in the study area.

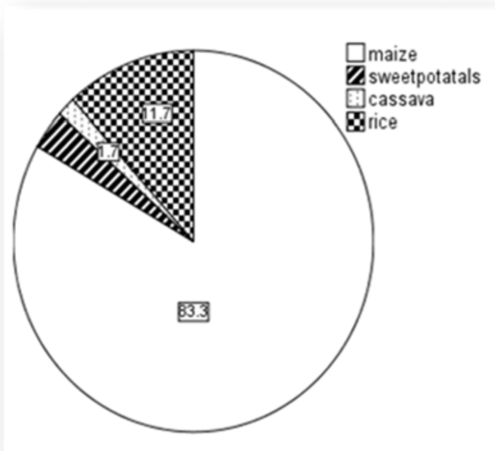

Figure 1: Food crops in the study area

From the Figure 3.1 above, a number of food crops were and most of the respondents depend on maize (Zea mays L) as the main food crop in the that is 83.3 percent of the people in the study area depend on maize for their survival and this indicates that maize is a very important crop in the area and Uganda as a whole and this is in line with the view that Maize (Zea mays L) is one of the world's important cereal crops (Ambrose *et al* 2008)

In East Africa, the crop is a major staple food for a large proportion of the population, in addition to being an important animal feed. Also Maize is gradually becoming a very important cereal in Uganda in terms of area under cultivation, production and human consumption. In an average year, maize acreage accounts for about 10 percent of the total area under annual crops and maize consumption accounts for about 12 percent of cereals consumption (An overview of maize in Uganda, Ambrose Agona, Jane Nabawanuka H. Muyinza) http//www.egfar.org/.../A-2-008-001-

A18_Maize_in_Uganda.

Contribution of sugar cane and the main food crop (maize) to farmer's income.

The contribution to farmers income is this research was based on the net returns got from the two enterprises that is sugar cane and maize and this was analyzed using a budget as shown in the Table below 2 below.

Table 2: Analysis of the average cost and average returns for maize and sugar cane for a period of five years

Crop enterprises	Sugar cane plant	sugarcane roton 1	sugarcane raton2	sugarcane raton3	Maize for 5 years
Average costs (shillings /ha)					
Labor					
Plunghing	309671.605				809,666.67
Planting	250617.284				486,629.65
Weeding	362551.440				505,145
Harvesting	475884.774	475884.774	475884.774	475884.774	374,074.07
sub total cost	1398725.10	475884.774	475884.774	475884.774	2, 175,515.38
seeds (tones	1750570.37				209,396.45
Transport	1269639.24	1269639.24	1269639.24	1269639.24	No transport costs
land rent	1668313.58				3, 288,065.84
trash alinment	1431000	145800	145800	145800	
Average total expenditure	7, 485,873.4	1, 891,324.01	1, 891,324.0	1, 891,324.0	5, 672,977.67
Average yield/ha	98.8(t)	93.8(t)	93.13(t)	93.13 (t)	11,111(kgs)
Average price	70,000	70000	70000	70000	558(per kg)
Average gross returns/ha(shs)	6, 916,000	6, 566,000	6, 519,100	6, 519,100	6, 199,938
ANR/ha(shs)	-569873.4	4, 674,675.99	4627775.99	4627775.99	526,960.33
ANR/ha(shs) for 5 years	13, 360,355				526,960

Contribution of the main food crop (maize) to farmer's income.

As per this study maize growing was one of the major contributors to the farmers income and on average the area used for cultivation of maize was 1.51667 acres (0.6138 hectares) of the overall land available to a small scale famer and this contributes much to the lively hood of the farmers in form of both providing food and providing income for other family needs and this is in agreement with the view that, Maize is Uganda's most important and highly cultivated crop. It is the number one source of income for most farmers in Eastern, Northern and Northwestern Uganda and is a key staple food crop. (http://programs.lwr.org/site/c.asKTJbNPIlI2F/b.8022175/k.23FF/Improving_Livelihoods_of_Farmers_Through_Enhanced_Participation_in_the_Maize_Value_Chain.htm)

Contribution of maize basing on the average net returns.

From Table 2 the average yield of maize by a small scale famer in the study area was 900kgs per acre (11,111 kgs per hectare) for a period of five years with an average price of 558 shillings per kilogram and this yielded an average net returns of 526,960 Uganda shillings per hectare with in the five years, which is the contribution to farmers income basing on the assumption that was used in the study that the average net returns per acre of maize indicates the contribution of maize to farmers income. The farmers in the study majorly depend on local seed varieties and also it was found out that the do not apply fertilizers and this account for the low returns from the maize as also noted that , despite the importance of Maize production that is accorded in Uganda, farmers continue to face a number of challenges. Maize farmers lack access to quality inputs and the technical knowledge needed to improve farm production.

(http://programs.lwr.org/site/c.asKTJbNPIlI2F/b.8022175/k.23FF/Improving_Livelihoods_of_Farmers_Through_Enhanced_Participation_in_the_Maize_Value_Chain.htm)

According to (http//www.egfar.org/.../A-2-008-001-A18_Maize_in_Uganda) was found out that most of the maize that is got is used for home consumption that it is used as food and the remaining potion is sold in order to get other home requirement such as cloths and school fees for the children. But this is contrary to the view that about one percent of the total maize produced in Uganda is consumed by the household on the farm and the rest of the crop is sold. This means that maize is now produced mainly for sale.

Contribution of sugar cane to famer's income.

From the result of the findings sugar cane is the main cash crop in the study area and sugar cane cultivation occupies about 4.416667 acres (1.7874 hectares) on average of the total land area owned by the small scale famers in the study area as indicated in Table 3.4 below and from this sugar cane is the main source of income in the study area, and this is in line with the argument that the cultivation of sugarcane provides a livelihood for millions of farmers and estate workers around the world. (http://solidaridadnetwork.org/sugarcane)

This is similar to what was found out by Singh *et al* (2008) that in western Uttar Pradesh region major income source of farmers in the area has been found sugarcane (58 per cent), followed by livestock and cereal crops.

Contribution of sugar cane based on the average net returns.

From the findings of the study basing on the formula defined for calculating the net returns a small scale farmer in the study area maximizes an average net return of 13,360,354. Uganda shillings per hectare for a period of five years as indicated in the Table 2 above.

Comparing the net returns of maize and sugar cane as indicated in Table.2, this indicates that sugar cane is a profitable business compared to maize and from this study it was found out that the people in the area majorly depends on income from sugar cane growing though it is associated with a lot of problems and from this study it was found out that sugar cane growing leads to problems such as soil erosion, reduction of soil fertility , climate change in general and food insecurity because most of the land is used for sugar cane growing and less is used for growing food crops such as maize.

However, assuming an individual only grows sugar cane as the only source of income, then the average net returns got from sugar cane growing is not enough for a family of six people to survive for all the requirements in the home. That is as indicated in the food required for the period of five years is 12,750,000 Uganda shillings, it means that the remaining balance is 610,355 Uganda shillings from the average returns per hectare, which when divided by the number of days with in the five years the money available for use by a famer a day is 339 Uganda shillings a day.

The above indicates that the growing of sugar cane with out caring out any other employment opportunity or with out growing any other food crop in order to reduce on the money spent on food , sugar cane growing as a single project by an individual or by a farmer is not profitable.

There for it is not advisable to only grow sugar cane with out growing other food crops with in the study area.

Contribution of sugar cane basing on the net present value

Table 3: Net present value of sugar cane

Data (bank discount rate)	Description
15%	periodic discount rate
-569873.4	Return for plant of sugar cane
4, 674,675.99	Return from raton1
4627775.99	returns from raton2
4627775.99	returns from raton3
Formula	Description of the results
NPV of the above values	8, 727,968.34

The positivity of the net present value indicates that the investment in the sugar cane project is finantially atttractive.And from the above findings it was found out that sugar cane enterprise contributes to a large extent to farmer's income in the vicinity of Kakira sugar estate specifically in Busedde Sub County.

Optimal resource combination.

Under this the interest was to find out the optimal solutions that maximizes net returns and also to find out how the sugar cane and maize crop enterprises can be combined using the available resources in a period of five years.

Before examining the details of determining the optimal combination of sugar cane and maize crop enterprises, the farm resource base and crop requirements were assessed. It was calculated that the mean farm size in the study area was about 2.6305ha and this was the land constraint. The total average labor supply on each farm for a period of five years was 195. This was the farm's labor constraint disregarding the possibility of using labor from the house holds. On average the amount of seeds supply on the farm for a period of five years measured in kilo grams was7029.58335kgs. The data in Table 3.4 summarizes the resource levels and requirements as well as returns for sugar cane and maize in the study area.

Table 4: Mean Farm Resource Levels and Requirements for sugar cane and maize in Study area for a period of five years

Resources considered	Average Resource Level available	Resources Required/ha	
		Sugar cane	Maize
Average Land (ha)	2.6305	1.78731	0.613773
Average Labour (number of people)/ha	195	140	55
Average Seed (kgs)/ha	7029.58335	7000	29.58335
ANR(shs)		13, 360,354.57	526,960.33

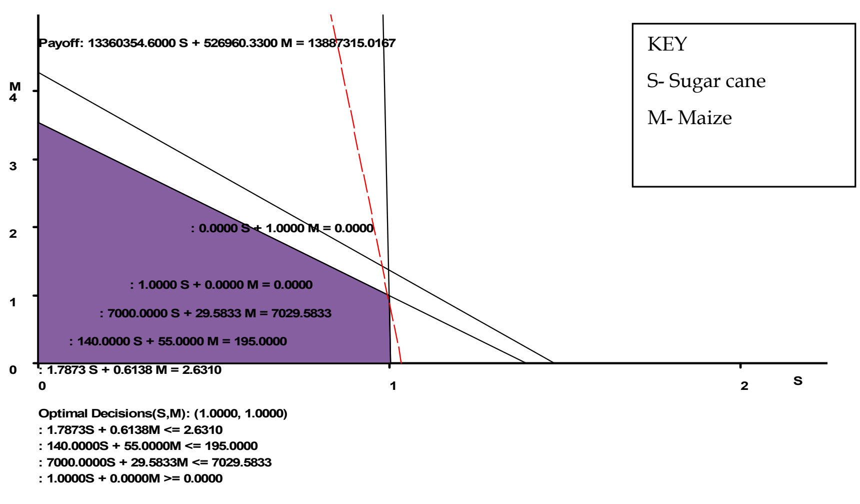

Figure 2: Illustration of optimal combination of maize and sugar cane crop enterprises

In the Figure above the shaded region is the feasible area and crop combinations outside this area are now unattainable by the farmer that is it's the region were by any combination of the resources can yield the famer profits.

In this analysis, the highest corner point that the profit line passes through is (1, 1) which is the optimal solution for the study. That is, if the smallholder farmer grew maize and sugar cane as mono crops or as different crop enterprises for a period of five years with 10 seasons of maize growing and four seasons of sugar cane that is plant, raton 1, raton 2 and raton 3 with in a period of five years, the optimal combination would be the optimal combination would be production of 1 units of sugar cane and 1 units maize for a period of five years using 1.8 ha of land for sugarcane and 0.6 ha for maize and full utilization of the available labor and seeds ,of the total resources available.

The above optimal solutions yield the farmer maximum profits of 13, 887,315 Uganda shillings in a period of five years as indicated by the pay off equation in the Figure 2 above, this plan of allocation helps in increasing the gross margin and the yield got from the two enterprises

That is there is a difference in the net average net returns received in the existing resource allocation patterns and the average net returns in the optimal resource allocation pattern and this is similar to the conclusion made by Igwe *et al*, (2013), that resource allocation patterns in the optimum plan were remarkably different from that in the existing plan.

Thus optimal crop enterprise combination will in turn help in improvement of the live hood of the small scale farmers in the study area were by maximum net returns will be generated by the farmers if it is put into practice, and the generated income can be used to acquire the basic needs of the farmers. This is in agreement with the view that it is recommended that the optimal combination of enterprises be integrated in developing a prototype for the zone. (Igwe *et al*., 2013)

Degree of utilization of each constraint at the maximum profits.

Table 5: Degree of utilization of each constraint for both maize and sugarcane for a period of five years

Constraint	Average resources utilized/ha	Average resources available/ha	Average % utilization/ha
Land (ha)	2.4011	2.6310	91.3
Labor /ha	195	195	100
Seeds /ha	7029.5833	7029.5833	100

From Table 5 above, for maximization of the average net returns indicated in Figure 3.2 above, 91.3% of the available land should be utilized for both sugar cane and maize enterprises and on the average amount of labor available per ha 100% of the available labor per ha has to be utilized in the production of both maize and sugar cane in the study area, in addition also 100% of the available seeds per ha should be utilized in order to attain the maximum average net profits and the combination of the three leads to the maximum average net returns to the farmer per hectare in a period of five years.

Table 6: Degree of utilization of each constraint for maize and sugar cane respectively

Constraint	Average resources utilized	Average resources utilized for maize	Average resources utilized for sugarcane	Average % utilization for maize	Average % utilization for sugarcane
Land (ha)	2.4011	0.613773	1.78731	25.6	74.4
Labor/ha	195	55	140	28.2	71.8
Seeds /ha	7029.5833	29.58335	7000	0.4	99.6

From the Table 6 above, 25% of the average total land utilized has to be allocated for maize and 74% of the average total land utilize has to be directed to sugar cane growing in order to attain the maximum average net returns .Also in addition 28.2% of the average total labor utilized should be directed to maize production and 71.8%of the labor has to be directed to sugarcane growing if the farmer is to attain the maximum net returns with in a period of five years further more most of the average utilized seeds have to be directed to sugarcane that is 99.6% of the utilized seeds are directed to sugar cane only 0.4% of the seeds is directed to maize production per hectare and this indicates that the seeds required by maize per hectare are less that the required seeds for sugar cane for profit maximization.

Optimal combination and food security.

Under this the intention was to asses the influence of optimal crop enterprise combination on the level of food requirements in the study area assuming the maximum returns were to be used for purchasing of food for a period of five years.

With reference to the findings of Moses 2005 that in Mayuyge a family of six people require 391 $ to purchase maize meal (1700 kg) to last one year which in this case implied that 1700kg are enough to ensure food security a home for a year, this implies that for a period of 5 years a family of six people requires 1700kg×5 which gives an equivalent of 8500kg.

Using the current unit price of maize meal in the study area that is 1500 Uganda shillings the food requirement in a period of five years costs 12,750,000 Uganda shillings on assumption that the average family size of the small scale famer is six people.

Comparing the required money to purchase food for a period of five years that is 12,750,000 Uganda shillings with the maximum average net returns in the optimal combination of maize and sugar cane enterprises using the available limited resources for a small scale farmer for a period of five years that is 13,887,315 Uganda shillings as indicated in the Figure 3.2 above ,its enough to purchase the food required for the house hold in the study area and also remain with a balance of 1,137,315 for other requirements and this is so if he puts into consideration of the optimal decisions obtained in this study for a period of five years.

This is in line with the view that developing optimum farm plans for smallholder farmers could lead to the resolution of the food crisis. To date, little attention has been devoted to the role of farm planning in the resolution of the food crisis (Igwe *et al.,* 2013).

However when the remaining balance after securing food , when it is divided by the number of days in a period of five years assuming a year consists of 360 days which totals up to 1800 day and then divided by the family size of six people comes up with an average value of 105 Uganda shillings per day.

Conclusions and recommendations

Conclusions of the study

From the of the observations, analysis secondary data and face to face interview conducted in the objectives during the study, that is to identify the main food crop and its contribution to farmer's income in the vicinity of kakira sugar estate specifically in Busedde sub county, to find out the contribution of sugar cane growing to farmer's income in a sugar cane based farming system, to determine the optimal crop enterprise combination in the vicinity of kakira sugar estate specifically in Busedde sub county and to identify recommendations about the best crop combination in a sugar cane based farming system in Jinja district specifically in Busedde sub county the following conclusions were made;

It has been found that maize is the main food crop with in the sub county of Busedde were by it was found out that 83.3% of the people in the study area depend on maize as the main source of food. In addition it was also found out that most of the people in Busedde sub county depend on agriculture as the source of income and a few are employed in other employment opportunities such as trade, that is 80% of the study population depend on agriculture as a source of income, and most of them depend on income from sugar cane growing because it is proved to be a profitable business as per the study.

However, from the findings of the study it was revealed that sugar cane growing as a single enterprise using the available resources is not a profitable business because it can not enable an individual to both have food and also cater for other requirements in a home. So it is not advisable to grow sugar cane while leaving some resources to growing of other food crops.

Also it has been found out that most of the small scale famers in Busedde Sub County have spent a period of 10-19 years in agriculture and also most of the farm owners are male and do not apply fertilizers on their farms and this account for the low yields.

Further more it was found out that for farmers to increase their profitability and also solve the problem of food security they should use 25% of the land utilized for agriculture that is for growing maize and sugar cane has to be allocated to maize growing and 74% has to be allocated to sugarcane growing, while producing 1 hectare of maize and 1 hectare of sugar cane. And also in the situation of optimal combination of sugar cane and maize the average maximum revenue gained for a period of five years is enough to ensure food security in the house holds consisting of an average of six people in the study area.

Recommendations.

First and fore most the small scale farmers should adopt the use of fertilizer such as use of the green manure in order to help them in increasing the productivity of the soil and this will in turn increase the yields on their firms hence increasing their levels of incomes and solving the problem of food insecurity in the vicinity of Kakira sugar estate.

Also farmers should find off farm employment opportunities so that they reduce the dependence on agriculture because it in associated with problems which may be beyond their control such as climate change, and this would help in increasing their incomes.

The farmers in the study area should also adopt ways of reducing on the number of dependants and children and these may include family planning in order to reduce on the amount of food required by the house holds in the area.

There is a need for the smallholder sugarcane farmers to adopt new technologies that are cost effective so that they can still continue to make profits from the product such as inter cropping and zero tillage.

Also the small scale farmer should acquire more land for maize production and also land for other food crops in order for them to stop depending on incomes from sugarcane in buying food and this could help in ensuring food security with in Busedde Sub County and Busoga region as a whole.

The small scale farmers should also use improved maize and sugar cane seed varieties which are resistant to the circumstances of climate change in order to increase their yields and also reduce the impacts of climate change on the yields.

Also the problem of food insecurity could be reduced by educating the small scale sugarcane farmers in improved techniques and proper use of available resources to boost their experience in the sugarcane production, hence policies designed to educate sugarcane farmers through proper agricultural extension services could have a great impact in increasing the level of technical efficiency and hence their crease in sugarcane productivity and levels of income.

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Effects of gyphosate rates and formulations on weed control and maize performance under conservation agriculture in eastern Kenya

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Abstract

Maize production lags behind the population demand in eastern Kenya, and this is attributed to weeds competition with the crop for various growth resources, among other factors. A study was conducted to determine the effects of two glyphosate formulations (Roundup Turbo and Roundup Weathermax) and rates on general weeds control and maize performance. The first (long rains 2011), second (short rains 2011) and third (long rains 2012) season's trial results observed that the glyphosate based herbicides are effective means of weed management in maize grown under zero tillage conservation agriculture systems. Roundup Turbo applied at 2.5 liters ha^{-1} and the three (1.5, 2.5 and 3.0 liters ha^{-1}) tested rates of Roundup Weathermax herbicide gave effective weeds control and improved maize grains and shoot biomass. Both formulations did not have any phytotocixity on the maize. Herbicides treatments had higher net benefits compared to un-weeded and conventionally tilled practices. The crop yields significantly ($p \leq 0.05$) differed between un-weeded and weed controlled treatments (both conventional and herbicide methods). Conventionally tilled treatment gave an average grain yield of 3.6 t ha^{-1} that was not significantly different from those from zero tillage treatments. The lowest grain yield (0.1 t ha^{-1}) was acquired from un-weeded treatment and significantly ($p \leq 0.05$) differed from those of conventional and herbicides treatments. The study concluded that the use of Glyphosate based herbicide is an appropriate and economic approach for weed management in maize grown under zero tillage conservation agriculture systems.

Key words: glyphosate, zero tillage, conventional tillage, weed control, maize yields.

Introduction

Maize is the most important staple crop in Kenya for over 90% of the population with the small holder farming systems accounting for about 75-80% of the total production (Muui *et al.,* 2007). While the crop is mainly grown for its grains, stovers are fed to livestock and empty cobs used as source of fuel for cooking. The average maize yield in Kenya is approximated at 1.5 t ha^{-1}, with most of small-holder farmers producing less than 1.8 t ha^{-1} (Muriithi *et al.,* 1999; Ouma *et al.,* 1999). Weeds competition with the crop for growth resources is singled out as one of the challenges faced by smallholder farmers and therefore limiting maize production (Terry and Michieka, 1987). The deleterious effects of weeds may be managed by use different methods, including hand weeding and herbicide sprays (Berca, 2004).

Hand-hoeing is constrained by limited labour and weeds that are difficult to manage due to their great diversity in terms of species and nutrient scavenging systems (Micheni *et al.,* 2002). Competition for labour during the peak weeding period affects maize production, because labour is utilized for higher income generating activities such as picking coffee and cattle rearing (Ouma *et al*., 1999).

In a socio-economic study on adoption of herbicide technologies in maize based cropping systems in central Kenya (Muriithi *et al.,* 1999) recognized that the use of herbicides is the most economical method for weeds control in maize production systems. Similarly, Muthamia *et al*. (2004) in conservation tillage studies in the central highland of Kenya reported that farmers have their farm benefits increased by using herbicides for weeds control. This calls for enhanced research on testing and promoting appropriate herbicide. It is therefore on this basis that study was conducted in the humic areas of eastern Kenya to determine the effects of *Glyphosate* based herbicide product on weeds management and maize performance when grown under zero tillage (ZT) conservation agriculture (CA) practices.

Materials and methods

Site

The study was conducted at the Kenya Agricultural research Institute (KARI- Embu) farm on the eastern slopes of Mt. Kenya at 00^0 33.18′S; 037^0 53.27′E; 1420 m asl and in the upper midlands (UM_3) zone. The region experiences 1250 mm average annual bimodal rainfall and warm temperatures, ranging from 21-28 and 16 - 21^{0}C mean maxima minima, respectively (Jaetzold *et al.,* 2006). The two rainy seasons are the long rains (LR) lasting from March to August and short rains (SR) from October to January (Jaetzold *et al.,* 2006). About 65% of the rains come during the March rains and in some years end in July-August with scanty showers that assist the late maturity maize varieties in grain filling. The eastern Kenya soil are dominated by humic *Nitisols*, which are of moderate to high inherent fertility due to their high minerals, available water and cation exchange capacity levels (Jaetzold *et al.,* 2006). However, over time the fertility has declined due to inappropriate soil management and nutrients depletion (Mwangi *et al.,* 1996; Gitari and Friesen 2001). The farming system is mainly of medium maturity maize varieties intercropped with beans (Waithaka *et al.,* 2006). The crops grain yields have constantly declined due to weed competition in the region.

Experimental design, treatments and blocking

The trials were laid out on a randomized complete block design (RCBD) with four replicates separated by paths measuring 2.0 m. A given replicate had six plots, each measuring 3.75 m (6 rows) x 4.00 m (9 hills of 2 plants each). The treatments were made of three rates (1.5, 2.5 and 3.0 lits ha^{-1}) of Roundup Weathermax herbicide and one rate (2.5 lits ha^{-1}) of Roundup Turbo Table 1). The fifth and sixth treatments were the un-weeded and conventional tilled weed management systems. The six weed management treatments were randomized within and between blocks, and any two plots within a block were separated by a 1.0 m buffer zone path to guard treatments from spilling over between plots. Likewise any two replications were separated by a 2 m buffer zone for the same purpose.

Table 1: Treatments description for Glyphosate based trials for the management of weeds in maize fields in humid areas of eastern Kenya

Glyphosate based herbicides	Application rate (lits ha^{-1})	Active Ingredient (gms Glyphosate lit^{-1})	Tillage method
Roundup Weathermax	1.5	540	Zero Tillage
Roundup Weathermax	2.5	540	Zero Tillage
Roundup Weathermax	3.0	540	Zero Tillage
Roundup Turbo	2.5	450	Zero Tillage
Un-weeded	N/A	N/A	Land left bushy
Hand hoed	N/A	N/A	Conventional Tillage

Trial establishment

The study was conducted for three seasons during 2011 – 2012 rainy seasons and every season the experimental sites were selected in a weedy field that had stayed for over 12 months without any kind of cultivation. Glyphosate herbicide sprays were applied after approximately a week after the on-set of the rains and when the weeds were actively growing. The one week planting delay was meant to allow the weeds to start growing actively after going through a period of "dormancy" observed during dry spells witnessed prior to the start of the rains. Plots were therefore marked out in the weedy field, and planted with medium maturity maize variety (var. DK 8031) spaced at 75 cm (between rows) and 50 cm (between hills). Three seeds were planted using sharp pointed *pangas* by carefully parting the weeds to access the soil, making holes, placing 10 gms (per hill) of N_{23}:P_{23}:K_0 fertilizer material and then sowing the maize seeds. The conventional tillage plots were prepared using conventional *folk-jembe* to achieve fine tilth for maize production. The same tool was used to make planting holes at the recommended plant population.

Treatments application

Herbicide treatments were applied a day after seeding. Adequate amounts of herbicides were drowned from their containers using graduated syringe with a needle before transferring the contents into mixing buckets. The herbicide/water solutions were then transferred into pre-calibrated CP3 15-liter Knapsack sprayers fitted with low volume herbicide application nozzle to deliver 200 - 250 lits hectare^{-1} of the solutions. The solutions were then applied evenly on the weeds in all but hand weeded and un-weeded plots.

Thinning and stem borers management

Immediately after the crop emergence, thinning was done leaving two plants per hill or to maintain 53,333 plants ha^{-1} plant population. The borers start invading maize immediately after the crop emergence causing up 40 % yield loss (Mulaa, 1995; Pingali, 2001). Borer-cide (*Bulldock* 0.05 GR) at the rate of 6.5 kg ha^{-1} was therefore applied every season a month after the crop emergence to control the pest. Two hand-weeding events were conducted only on the conventional plots at 15th and 85th day of the crop emergence.

Data management and reporting

Biophysical and socio-economic data were collected and analyzed using analysis of variance (ANOVA) method via Statistic Analysis System (SAS) computer programme. In addition, net-benefits were computed to determine profitability of the various weed management systems for maize production in eastern Kenya region.

Results

Main weed species at the trial site

Identification of weed species within the experiential area was done the same day of treatment application with the aim getting baseline information on weed species and biotypes within species which may ultimately compete with the crop if not managed. Broad and narrow leafed weeds were found with the couch grass (86%), *Richardia scabra (82%)* and *Oxalis (67%)* dominating the site in all three seasons. Additionally, *Bidens pilosa*, *Galinsoga parviflora*, *Cyperus spp.*, *Amaranthus spp.* and *Commelina spp.* were other very common weed species.

Percent (%) weeds suppression

Percent weed ground cover is one of the parameters used to provide guidelines on how weeds are suppressed by herbicides. This was achieved by using a 1.0m^2 quadrant randomly thrown in a given plot, followed by visually recording weed suppression status therein. The activity was conducted three times in a given season as follows:

- Weed suppression event 1 (WS^1): Taken 1 month after the crop/weed emergence
- Weed suppression event 2 (WS^2): Taken 2½ months after the crop/weed emergence.
- Weed suppression event 3 (WS^3): Taken 3½ months after the crop/weeds emergence.

Data gathered from the three events were later worked out into percent weed suppression (% ws) using the following formula:

$$\% \text{ ws} = \frac{(\text{Msut} - \text{Mst}) \times 100}{\text{Msut}}$$

Where: Ws = Weed suppression; Msut = Mean score of un-weeded treatment; and Mst = Mean score of a treatment.

The results showed that the critical time that the weeds/crop competes for resources was just before the crop flowering (2½ months after the crop emergence). This clearly witnessed in un-weeded treatment whose %ws differed ($p \leq 0.05$) significantly from those of herbicide and conventional tilled treatments during the three events that the parameter was monitored (Table 2).

Table 2: Percent weed suppression (ws) during different periods of Glyphosate based trials for the management of weeds in maize fields in eastern Kenya

Glyphosate based herbicides	Application rate (lits ha^{-1})	Tillage method	(%) WS^1	(%) WS^2	(%) WS^3
1. Roundup Weathermax	3.0	Zero Tillage	66.0^b	96.3^a	87.5^{ab}
2. Un-weeded	N/A	No Tillage	0.0^d	0.0^d	0.0 ^{d}
3. Conventional Tillage	N/A	Conventional	88.5^a	35.0	91.8^a
4. Roundup Weathermax	2.5	Zero Tillage	59.0^b	89.5^b	83.3^b
5. Roundup Turbo	2.5	Zero Tillage	58.8^b	94.8^{ab}	89.0^{ab}
6. Roundup Weathermax	1.5	Zero Tillage	49.5^c	82.8^c	75.3^c
Mean	-	-	53.6	66.4	71.1
LSD (0.05%)	-	-	9.2	5.3	5.8
%CV	-	-	11.4	5.3	5.4

Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = Coefficient of variation; LSD = Least Significant Difference; N/A = Not Applicable

Weed vigour

Information on weed vigour was recorded at 0 (treatment application day), 70 (crop flowering) and 120 (crop physiological maturity) days. This was achieved by visually observing the average weed vigour using a scale of 1 – 4, where 1, 2, 3 and 4 represented very low, low, medium and high weed vigour, respectively. The hand hoed plots were free of weeds resulting from fine and weed-free prepared seedbed. Low weed vigour was recorded in herbicide treated plots at the time of treatment application. The situation changed later to medium weed vigour in conventionally tilled plots calling for the first hand weeding event approximately eight days after crop/weeds emergence. There were declining trends starting from the start to the end of the seasons in weed vigour in all plots where the herbicides were applied.

Crop phytotoxicity

In the study plant phytotoxicity condition was considered to be any deviation from normal morphological or physiological changes due to biotic, abiotic or artificial influence. We therefore focused on scorching of the whole or parts of the plant; de-colouration of plant parts from the normal green colour for a healthy plant; deformation or dwarfing of all or some plants; and extra ordinary maturity of plants. The assessments were done at 30th, 70th and 120th day after the crop emergence using scores of 1, 2, 3 and 4, denoting: low, medium, high and very high phytotoxicity, respectfully. Only plants in un-weeded treatments showed significant differences ($p \leq 0.05$) in de-colouration of plant leaves and dwarfing of plants (Table 3). In addition, plants in the said plots died in approximately 10 days earlier than those under conventional or herbicide treated plots.

Maize days to physiological maturity

Crop physiological maturity was arrived at when over 90% of plants in a given plot stopped sinking nutrients into their system due to age effect. Our study recorded an average of 126, 133 and 136 days for DK 8031 maize variety from emergence to physiological maturity in LR 2011, SR 2011 and LR 2012 trials, respectively. The un-weeded plots had the crop maturing significantly ($p \leq 0.05$) earlier (approximately 10) than those under hand or herbicides treated plots. This was attributed to weeds withdrawing essential growth resources from the crop which suffered nutrients stress and therefore reached physiological maturity (died) earlier than expected.

Table 3: Crop phytotoxicity score at different periods of Glyphosate based trials for the management of weeds in maize fields in humid areas of eastern Kenya

Glyphosate based herbicides	Application ate (lits ha^{-1})	Phytotoxicity Score		
		1	2	3
Roundup Weathermax	3.0	1.5	1.5^{b}	1.5^{b}
2. Un-weeded	N/A	3.0^{a}	3.5^{a}	3.8^{a}
3. Conventional Tillage	N/A	1.3^{b}	1.3^{b}	1.5^{b}
4. Roundup Weathermax	2.5	1.5^{b}	1.5^{b}	1.0^{b}
5. Roundup Turbo	2.5	1.5^{b}	1.5^{b}	1.3^{b}
6. Roundup Weathermax	1.5	1.5^{b}	1.5^{b}	1.8^{b}
Mean	-	1.7	1.8	1.8
L.S.D (0.05%)	-	0.6	0.8	0.8
CV	-	24.5	31.0	28.1

Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = Coefficient of variation; LSD = Least Significant Difference; N/A = Not Applicable

Maize shoot biomass and grain yields

At physiological maturity stage maize shoot biomass and grain yields were determined. The two parameters significantly ($p \leq 0.05$) differed between un-weeded and conventional or the herbicide managed plots (Table 4). The zero tillage treatments had 4.4, 4.3 and 4.0 from Roundup Turbo (2.5 lits ha^{-1}), Roundup Weathermax (3.0 lits ha^{-1}) and Roundup Weathermax (2.5 lits ha^{-1}) treatments, respectively. The yields from zero tillage treatments were not significantly different from one another in the three seasons that the study was conducted. Conventionally tilled treatment gave an average grain yield of 3.6 t ha^{-1} that was also not significantly different from those from zero tillage treatments. The lowest grain yield (0.1 t ha^{-1}) was acquired from un-weeded treatment and significantly ($p \leq 0.05$) differed from those of conventional and herbicides treated plots.

Besides being grown for human food in eastern Kenya, maize is also grown to provide feed to livestock through provision of stovers in zero grazing livestock keeping management systems. The average shoot biomass in the three seasons was 8.1 t ha^{-1}from the weed management methods. The three rates, 1.5, 2.5 and 3.0 lits ha^{-1} of Roundup Weathermax had significantly ($p \leq 0.05$) higher biomass yields at 10.5, 9.8 and 9.2 lits ha^{-1}, respectively compared to un-weeded control. Although not significantly different, the conventional treatments gave 7.9 t ha^{-1} shoot biomass yields.

Table 4: Maize shoot biomass and grain yields of Glyphosate based trials for the management of weeds in maize fields in humid areas of eastern Kenya

Glyphosate based herbicides	Application rate (lits ha^{-1})	Shoot biomass (t ha^{-1})	Grain yield (t ha^{-1})
Roundup Weathermax	3.0	19.2^{b}	4.3^{ab}
2. Un-weeded	N/A	1.0^{c}	0.1^{c}
3. Conventional Tillage	N/A	17.0^{d}	3.6^{b}
4. Roundup Weathermax	2.5	19.5^{b}	4.0$^{a b}$
5. Roundup Turbo	2.5	21.6^{a}	4.4^{ab}
6. Roundup Weathermax	1.5	20.5^{ab}	4.5^{a}
Mean	-	16.5	3.5
L.S.D (0.05%)	-	1.9	0.9
C.V.	-	7.8	16.3

Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = Coefficient of variation; LSD = Least Significant Difference; N/A = Not Applicable

Net benefits

Economics of different weed management methods was done using data collected during the experiment. The data came from the local agric-stockiest(s), scientists, farmers and partners involved in maize industry in eastern Kenya. For each of the reported three seasons, the exercise assumed that:

- The average annual interest rate for money in a bank savings account to be 12%.
- The DK 8031 took 6 months from planting to marketing using farm-gate prices.
- The herbicides were priced at KES 1200 lit^{-1}. The total cost for any herbicide was therefore based on the rate(s) the product was tested on.
- The number of empty bags needed to hold the grains was based on the total grain yield per treatment; and that the grains were harvested and packaged in 90 kg bags.
- Stovers were sold at KES 2000 t^{-1} to buyers who collected them from the farm using their own labour and transport.
- The grains were sold at farm gate price at Ksh. 3000 per 90 kg bag.
- The formula, N-B = TC – TB was appropriate in working out the net-benefit (N-B). In the formula; N-B = Net benefit; TC = Total Cost: acquired from payment of factors of growing maize; TB = Total benefits: acquired from sale of stovers and grains.

The study realized average net benefits (NB) of KES 99,797, 90,123 and 94,392 for LR 2011, SR 2011 and LR 2012, respectively. The NB from un-weeded treatment was always significantly ($p \leq 0.05$) lower than what was observed from the herbicides and conventionally tilled plots.

Conclusions

Maize is the most important staple food crop in Kenya, but the production lags behind demand in eastern Kenya. While the crop is mainly grown for its grains, stovers are fed to livestock and empty cobs used as source of fuel for cooking. Among other reasons for low production are weeds. A study was conducted to determine the effects of Glyphosate-based herbicides on weeds management and maize performance in eastern Kenya. The first (LR 2011), second (SR 2011) and third (LR 2012) season's trial results observed that the herbicides are effective means of weed management in maize grown under zero tillage conservation agriculture systems. Roundup Turbo herbicide applied at 2.5 lits ha^{-1} and the three (1.5, 2.5 and 3.0 lits ha^{-1}) tested rates of roundup Weathermax herbicide performed comparatively well in terms weeds control and therefore improved maize yields (grains and shoot biomass). The product did not have any noticeable phytotocixity on the crop. Use of herbicides resulted in improved NB compared to results from un-weeded and the conventionally tilled fields.

The yields significantly ($p \leq 0.05$) differed between un-weeded and conventional or the herbicide managed plots. The zero tilled treatments (herbicides treated) were not significantly different from one another in the three seasons that the study was conducted. Conventionally tilled treatment had an average grain yield of 3.6 t ha^{-1} that was also not significantly different from those from zero tillage treatments. The lowest grain yield (0.1 t ha^{-1}) was acquired from un-weeded treatment and significantly ($p \leq 0.05$) differed from those of conventional and herbicides treatments.

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Enhancing food production in semi-arid coastal lowlands Kenya through water harvesting technologies

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Abstract

About 35% of coastal lowland Kenya is classified as semi-arid lands, and food production in these areas is constrained by low soil moisture. To address the constraint, two studies were conducted during the 2010 long rains, 2011 long rains and, both 2011 and 2012 short rains seasons to evaluate the performance of drought tolerant maize (*Zea mays* L.) varieties under different water harvesting technologies (Zai pits, tied ridges and conventional). The treatments were laid out in a split plot design with water harvesting methods as the main plots and maize varieties as the sub-plots. Four maize varieties (DK8031, DUMA 43, KDV1 and PH4) were evaluated under the three water harvesting technologies for the first experiment. For the second experiment, four maize plant population treatments of 3 (P3), 5 (P5), 7 (P7) and 9 (P9) plants per pit were used. Maize variety DUMA 43 was used alongside the four plant populations. The results for both experiments indicated that the maize yields in zai pits and tied ridges treatments were significantly ($P<0.05$) higher than for conventional treatment and the population of 5 plants per pit had significantly ($P<0.05$) higher grain yield than the rest of treatments.

Introduction

The coastal region of Kenya is a food deficit area with households purchasing one third of their food requirements, mainly because of insufficient food production on the farms. Maize is the most important food stable and constitutes a major component of the diet in the region (Wekesa *et al*., 2003; Waiyaki *et al*. 2006). More than 70% of maize area is cultivated by farmers in small holder units of less than 20 hectares of land (Doss *et al*. 2003). The crop is grown in all agro-ecological zones of the province including arid and semi-arid lands more suited for sorghum and millet (KARI, 2005; Wekesa *et al*., 2003). Although maize is the most important food crop in the region, the area produces 1.56 million bags, while the demand is 3.80 million bags leaving a shortfall of 2.24 million bags (MoA, 2012). The deficit has to be imported from abroad or other parts of the country. Over 75% of the coastal area is either arid or semi-arid (Jaetzold and Schmidt, 2006). Rapid population growth in the high and medium potential areas has forced farmers to immigrate to the marginal areas. In ASAL areas farmers grow local maize varieties recommended for the medium to high rainfall zones for lack of suitable varieties. This has in most cases resulted in crop failures since the drought sets in at the most critical stage of crop growth. Maize grown in plots demonstrating zai pits technology in semi-arid lands showed some yield advantage compared to tied ridges and flat planting (Sanginga and Woomer, 2009). However, zai pit construction was observed to be laborious and very expensive for farmers without adequate family labour or appropriate equipment (Kabore and Reij, 2004). This study was therefore carried out to determine the most adaptable drought tolerant maize variety under the various water harvesting methods, for high maize grain yield in semi-arid lands of Kilifi County. The objectives of the study were to determine the most suitable water harvesting technology for high maize yield in coastal lowland Kenya. Another study to determine the optimum plant population per zai pit was also carried out.

Materials and methods

The studies were conducted at the Kenya Agricultural Research Institute (KARI) testing site of Bamba in Ganze district which is described as a livestock-millet zone in Agroecological zone (AEZ) Coastal Lowland (CL) 5 (Jaetzold and Schmidt, 2006). They were carried out during the long rains of 2010and 2011 and theboth short rains seasons of 2011 and 2012. The Bamba site is characterized by unreliable and erratic

rainfall. The soils are rich in nutrients but crop productivity is limited by high ambient temperatures and low soil moisture. The natural vegetation consists of grass and thickets which is primarily utilized by cattle, sheep and goats. Eighty percent of the land is communally owned; communal grazing is practiced while the feeding system for livestock is free range grazing (Ramadhan *et al*., 2008). The major food crops grown in the area are maize, green gram, cowpea and cassava.

For experiment 1, four commercial drought tolerant maize varieties were evaluated under three water harvesting methods. The four varieties were DUMA 43, DK8031, KDV1 and Pwani hybrid (PH) 4. Pwani hybrid 4 was used as the local check. The three water harvesting methods included; Zai pits, tied ridges and conventional (flat). Zai pits are holes measuring 60 cm long, 60 cm wide and 60 cm deep. The pits were spaced 60 cm apart within the row and were 90 cm between the rows.

The treatments were laid out in a split plot design with water harvesting methods assigned to main plots and maize varieties assigned to sub-plots. Plots consisted of three rows of zai pits and one row comprised of four pits. At the time of excavation, soil from the first 30 cm was placed separately from that of the next 30 cm (31-60) cm. Before filling up the zai pits, dry grass was laid at the bottom up to about 15 cm and then compacted and the remaining portion of the hole was filled with a mixture of top soil and manure at the ratio of 2:1 up to a depth of 5 cm. Two seeds were planted at 9 equidistant spots within the zai pit and were thinned to one plant per hill resulting in 9 plants per pit.

Ridges were spaced at 90 cm. Crop spacing at the ridges and conventional method treatments were 90 x 60 cm. Three seeds were planted per hill and later thinned to two plants per hill. Farm yard manure was applied at the rate of 5 t ha^{-1} during planting to both tied ridges and the conventional treatments. Additional nitrogen fertilizer was applied as a topdress at a rate of 60 kg N ha^{-1} four weeks after planting. To control maize stalk-borer, 'Buddock' (0.05 GR 0.5 g/kg beta cyfluthrin) was applied at the rate of 8 kg ha^{-1} three weeks after planting. The crop in zai pits and tied ridges was weeded once while a second weeding was carried out at the conventional treatment plots.

Data was collected on: stand count, plant height, ear height, ear weight, grain moisture content, stover weight and grain weight. Agronomic data were subjected to analysis of variance and differences among treatment means compared using Fischer's Protected LSD test at $P < 0.05$.

For experiment 2, four maize plant population treatments of 3 (P3), 5 (P5), 7 (P7) and 9(P9) plants per pit were used. The density of 9 plants per pit was used as a check. Maize variety DUMA 43 was used alongside the four plant populations. More seeds were planted per hill and were later thinned to required plants per pit. Plots comprised of 3 rows of zai pits and each row comprised of 4 zai pits. Phosphatic basal fertilizer was not applied since farm yard manure had been applied to the zai pits during the 2011 long rains season. Nitrogen fertilizer was applied as a topdress at a rate of 60 kg N ha^{-1} four weeks after planting. To control maize stalk-borer, 'Buddock' (0.05 GR 0.5 g kg^{-1} beta cyfluthrin) was applied at the rate of 8 kg ha^{-1} three weeks after planting. Two weedings were carried out during the crop's growth. Data was collected on: stand count, plant height, ear height, ear length, field weight and moisture content. Maize was also shelled and grain weight recorded.

Results and discussion

Only the results for the effect of water harvesting technologies on maize performance are going to be presented in this paper. Water harvesting methods significantly influenced all the measured parameters (Table 1). Plants in the Zai pits treatment were significantly taller than those in tied ridges and the conventional tillage method. Though not quantified, it observed that the zai pits remained relatively moist for a longer time than the other treaments. This was attributed to enhanced water retention in Zai pits compared to the other treatments. However, the plants in zai pits were thinner than those for tied ridges and conventional treatments probably due to plant competition for light in zai pits. There were no significant differences in plant height between the tied ridges and conventional method. A similar trend was observed for ear height. Zai pits and tied ridges treatments indicated significantly ($P<0.05$) higher maize grain yield than the conventional method (Table 1). However, there was no significant ($P<0.05$) yield

difference between the Zai pits and the tied ridges. For maize stover, significant (P<0.05) differences were observed among all the water harvesting methods. The Zai pit method had significantly higher stover yield than both the tied ridges and conventional method. This was also attributed to enhanced water retention in zai pits. The maize stover yield from tied ridges was significantly (P<0.05) higher than from the conventional method. This was because plants in conventional treatments were stunted during the early stages of growth.

Table 1: Effect of method of water harvesting on plant height, ear height, grain and stover yield

Water harvesting method	Parameters			
	Plant ht (cm)	Ear ht (cm)	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})
Zai pits	187.3[a]	97.7[a]	2.4[a]	7.8[a]
Tied ridges	159.2[b]	76.3[b]	2.3[a]	5.1[b]
Conventional method	155.2[b]	74.9[b]	0.9[b]	3.5[c]
LSD	15.9	9.3	0.4	1.5

Means within a column followed by the same superscript are not significantly different (P≤0.05)

Results for experiment two showed differences in plant height but significant (P<0.05) differences existed for only P5 and P7. There was no significant (P<0.05) plant population effect on ear height. However, significant (P<0.05) differences were observed for both ear length and grain yield as indicated in Table 11. The populations of 3 plants per pit showed significantly (P<0.05) longer ears than both P7 and the check treatment (P9). However, there was no significant difference between P3 and P5. The longer ear size for P3 was expected because of less competition for nutrients amongst the plants due to lower density than the rest of treatments.

Grain yield was 2.72-4.97 t ha^{-1} for the populations of 9 and 5 respectively (Table 11). The population of 5 plants per pit showed significantly (P<0.05) higher grain yield than the rest of treatments. The population of 3 plants per pit was too low for the plants to compensate through ear size where as the population of 9 plants was too high hence presenting high competition for scarce resources. Though we used plant population to reduce competition, other workers have maintained the recommended population of 9 plants per pit while widening the pit from 60 x 60 cm to 75 x 75 cm (Njiru, 2012)

Table 2 : Effect of plant population on plant height, ear height, ear length and grain yield

Plant population	Parameters			
	Plant ht (cm)	Ear ht (cm)	Ear length (cm)	Grain yield (t ha^{-1})
P7	200.7[a]	85.3[a]	13.3[b]	3.53[b]
P9	195.7[ab]	77.0[a]	13.0[b]	2.72[b]
P3	184.0[ab]	75.6[a]	16.6[a]	3.07[b]
P5	169.6[b]	69.7[a]	14.7[ab]	4.97[a]
LSD	28.47	20.38	2.80	0.94

[abc]Means followed by the same superscript are not significantly different (P≤0.05) within the column

Conclusion

Both Zai pits and tied ridges methods of water harvesting are superior to conventional method of maize production and the two technologies would fit well in overcoming the adversaries of climate change in semi-arid lands. The plant population of 5 plants per pit was found to be optimum under the conditions of the current study area. Based on the findings this study Zai pit technology should be promoted in coastal ASALS with the emphasis of 5 plants per pit instead of 9 plants.

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Integration of indigenous knowledge in agricultural information and communication systems for adaptation to climate change by smallholder farmers of coastal Kenya

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Abstract

Indigenous technical knowledge is an accumulated experience over time, which could provide insightful guidance into management of climate variability if it was identified and recognised. This study aimed at identifying and integrating indigenous knowledge for adaptation to climate change by smallholder farmers in coastal Kenya. The study was able to identify existing integrating indigenous knowledge that farmers use. These include planting of drought-tolerant crops (44%) to cope with floods and 58% for erratic rainfall. Most (66.9%) of the respondents also indicated that they use traditional crop varieties to cope with drought. The study concludes that indigenous technical knowledge plays a big role in addressing many problems. Farmers in Kilifi use it in the management of climate change challenges. However, this knowledge needs to be recognised and integrated in the agricultural communication systems. It is, therefore, recommended that policy interventions be employed in creating strategies that would encourage identification and recognition of integrating indigenous knowledge and its inclusion into scientific agricultural practices that would enable farmers to plan for and cope with current climate risks and adapt to future climate change. This would ensure sustainability and vitality in improving agricultural production for food security.

Key words: climate change, indigenous technical knowledge, adaptation, integration, smallholder farmers.

Introduction

The worlds' climate is continuing to change at rates that are projected to be unprecedented in recent human history. Some models are now predicting that the temperature increases by the year 2100 may be larger than previously estimated in 2001 (Thornton *et al.*, 2006). Floods and droughts are becoming more frequent and severe, which is likely to seriously affect farm productivity and the livelihoods of rural communities. The impacts of climate change are likely to be considerably high in tropical regions. Sub-Sahara Africa is the most food-insecure region in the world (World Bank, 2008). Climate change threatens to aggravate the food situation unless adequate measures are put in place (IPPC, 2007). The environmental and social consequences of climate change put farmers' livelihoods at risk and this is worse where farming is done at small scales. These farmers have lived with climate variations for many years and have developed their own coping strategies, known as indigenous technical knowledge (ITK).

The usefulness of ITK in agricultural management has been overlooked by agricultural information and communication managers when advising policy makers. Of interest to climate change adaptation should be indigenous practices in food production systems, water-stress management, sociocultural systems, and cross-cutting and supportive issues represented in indigenous knowledge (Mazonde and Thomas, 2007). In Kenya, climate change effects have been felt most in the arid and semi-arid lands (ASAL). The agriculture sector, which forms the base of rural livelihoods is confronted with the major challenge of increasing food production to feed a growing and increasingly prolific population amidst decreasing availability of natural resources. This situation is exacerbated by the challenges related to climate change. To help farmers

overcome climate change challenges, researchers and extension agents have developed modern agricultural technologies, which they disseminate to farmers. There is, however, a wide gap between agricultural technologies produced in research institutions and their translation into increased yields and subsequent food security.

In coastal Kenya, a lot of indigenous knowledge is noticed in the farmers' way of carrying out agronomical practices. These hold crucial leads towards sustainable management of climate change related stresses. However, communication systems devoted to food production strategies have not been keen on incorporating ITK in their planning, thereby missing out on the many benefits that ITK brings into the agricultural information dissemination systems (Bernet *et al.*, 2003). Some of the dissemination models have completely left out farmers' contribution in the way that farming practices are carried out, making them mere recipients of technologies (Davis and Place, 2003). This study sought to find out the influence ITK might have in contributing to increasing food productivity. If ITK is well tapped, transformed and introduced in current technology development, it can help solve some of the problems faced by smallholder farmers.

Materials and methods

The target population comprised of all smallholder farmers from Ganze and Kikambala Divisions of Kilifi District. Ganze has a population of 52,330 persons while Kikambala has 60,040 persons (Central Bureau of Statistics, 2005). A sample frame consisting of smallholder farmers from the study area was developed using random sampling. A sample size of 167 household heads was arrived at using a formula developed by Yamane (1973). Agricultural extension officers from Kilifi and the Kenya Agricultural Research Institute (KARI)-Mtwapa were also interviewed as key informants. Data were collected by use of questionnaires (closed and open- ended).

The data collected was sorted before being coded and entered into the computer using Statistical Package for Social Science research (SPSS) version 15.0 software. The same software was used for data analysis. Data were analysed using descriptive (frequencies and percentages) and inferential statistics (Chi-square test).

Results and discussion

Indigenous technical knowledge practicesuUsed in managing floods

The most ITK practice used to manage floods is planting water tolerant crops and the least is digging trenches (Table 1). The reason could be that farmers tend to go for easy and low labour-intensive practices. Moving to higher grounds can only be practiced by those with available raised grounds. Traditional water conservation techniques known as zai pits and digging trenches could be labour-intensive and expensive to undertake.

Table 1: Frequency distribution of ITK practices used in managing floods

ITK practice	Frequency	(%)
Digging trenches	3	2
Moving to higher grounds	34	31.2
Planting water-logging/ flood tolerant crops	48	44.0
Traditional water conservation	26	23.9
Do nothing	11	10.1

Iindigenous technical knowledge practices used in managing erratic rainfall

In managing erratic rainfall, planting traditional seed is the ITK widely used by farmers while deep planting was the least (Table 2). These traditional seeds are with farmers and have been used for a long time. They, therefore, know their performance and reliability. As an opinion leader from Palakumi location asserted, "Giriama traditional maize seeds are more reliable and store well without being damaged by

pests unlike the hybrids." Extension providers are not directly interested in these traditional varieties, though farmers have found out that they have a role in managing erratic rainfall. Again, as in the earlier discussion, farmers tend to go for practices they perceive as easy to carry out.

Table 2: ITK practices used to manage erratic rainfall

ITK practice	Frequency	%
Deep planting	4	2.8
Planting fast growing crops	5	3.5
Using traditional varieties	83	58.5
Early/ Timely planting	43	28.2
Traditional water conservation	22	14.8
Do nothing	16	11.2

Indigenous technical knowledge practices used in managing drought

Planting drought-tolerant crops was cited as the ITK most farmers use to manage drought (Table 3). Farmers find it easy to adopt drought-tolerant crops because of their simplicity and avkailabilty locally. Focused group discussions clarified that the drought-tolerant varieties used in the study area include *Mengawa* and *Tela*. These traditional maize varieties withstand drought. The extension systems do not recognise them. Instead, Pwani hybrids (PH 1 and PH 4) are promoted as fast or early maturing crops that have been developed for the coast region. The main challenges that hinder the full adoption of hybrids are that i) their seeds are expensive and are not easily available to farmers and that ii) the hybrids cannot withstand the very low rainfall and the changing rainfall patterns in the coast. KARI-Mtwapa reported that PH 1 was developed for the coast region as an early maturing variety with a mechanism to escape drought. However, under low rainfall conditions like in the last four years, PH 1 has been performing poorly, thus discouraging farmers from its use. It can be concluded that some options promoted by the extension staff do not fit into the real environmental and farmers' situations.

Table 3: Distribution of ITK practices used to manage drought

Practice	Frequency	%
Deep planting	3	2.1
Early/timely planting	24	16.6
Leaving farm fallow	4	2.8
Mulching	22	15.2
Planting drought-tolerant crops	97	66.9
Planting fast/early growing crops	2	1.4
Traditional water conservation	24	16.6
Do nothing	10	6.9

Indigenous technical knowledge practices used in managing pests

Integrated pest management (IPM) is the most used method ITK to manage pests (Table 4). It involves the use of different methods in managing pests in crops, which include biological, cultural, chemical and mechanical methods. Harvested cereals are also preserved by keeping them above fireplaces in specially made stores known as *lutsaga.* However, farmers acknowledged that cereals stored in *lutsaga* still get infested by pests. They are not aware of the correct heap width, amount of heat needed and how long the *lutsaga* can remain effective. This is where researchers and extensionists could come in.

Table 4: Distribution of ITKs used in managing pest incidences

Practice	Frequency	%
Crop rotation	33	23.7
Integrated pest management	61	43.9
Selection/avoidance of crops	24	17.3
Shifting cultivation	4	2.9
Use of *mkilifi* tree	2	1.4
Use of sand	1	0.7
Do nothing	21	15.1

Farmers could find it easy to use integrated pest management (IPM) because of its diversity and accessibility. It also allows farmers to use their own knowledge to suit their environment and be compatible with their agricultural practices. Shifting cultivation could be limited to those with big parcels of land, thus discouraging its use. Use of preparations of *mkilifi* (*Azandrica indica*) tree or sand alone could be of low acceptability because farmers do not have proper preparation methods and dosage rates.

Indigenous technical knowledge practices used to manage heat on crops

About half of the respondents chose planting heat-tolerant crops as the ITK mostly used to manage the effect of excessive heat on crops (Table 5). Heat-tolerant crops like cassava (*Manihot esculanta*) and especially local varieties including *kibanda meno, kipenda roho* and *mzihana* are popular in coastal Kenya. Crops that are concentrated along cool river banks have been observed by farmers to get least affected by heat.

Table 5: Distribution of ITK practices used to manage heat on crops

Practice	Frequency	%
Mulching	52	38.5
Planting heat tolerant crops	66	48.9
Planting in cool areas	54	40
Do nothing	3	2.2

Integrating indigenous technical knowledge into scientific climate change adaptation practices

Farming practices promoted by extension officers, to a large extent do not include the ITK that farmers use. The potential of ITK practices can only be tapped if what is in custody of farmers is shared with the extension and other farmers. This is possible if the extension systems are open to integration of feedback in research agendas. The study results show that ITK is being used among farmers to manage challenges that they face in farming activities. Since ITK seems to play a significant role in managing challenges related to climate change, there is need to integrate it in extension messages. If farmers are involved, they will embrace the new technologies that are developed by researchers and passed to them by extension officers. Similarly, if they interact with extension personnel in receiving extension messages, the mutual gain favours the integration of ITK in modern technology development and testing.

Table 6: The extent to which ITK has been integrated into scientific climate change adaptation practices by location (%)

Extent of integration	Locations			
	Palakumi	Ganze	Mtwapa	Junju
Never	0	3.4	2.7	0
Very little	43.3	20.7	6.8	50.0
A little	13.3	24.1	24.7	27.8
Often	33.3	31.0	49.3	11.1
Always	10.0	20.7	16.4	11.1

Chi-square= 31.033, p-value= 0.02 ($p < 0.05$), Significant

Integration is highest in Mtwapa and lowest in Junju. Their level of integration could be different since Mtwapa is a cosmopolitan location with farmers who value extension services. Junju is remote and could be missing out on extension services with most of the farmers practicing only ITK methods of farming.

An opinion leader from Ganze Division while responding to the question on the extent of integration of ITK and scientific practices said that it is present to a large extent (Figure 1). The only drawback is that the researchers and extension officers have not shown interest in responses, making farmers fail to realise the full potential of integration. He gave an example of integrated pest management. Farmers in Kilifi have known the use of *lutsaga* in preserving their cereals but scientists have never come out fully to work on the correct depth, amount of heat or how long the cereal should stay in the *lutsaga* before it is treated with chemicals to avoid infestation by pests. A similar sentiment was given by a village elder from Kikambala Division while commenting on the traditional seeds that they use. The elder said that scientists have have never tried to bulk or even preserve them in anticipation of their extinction.

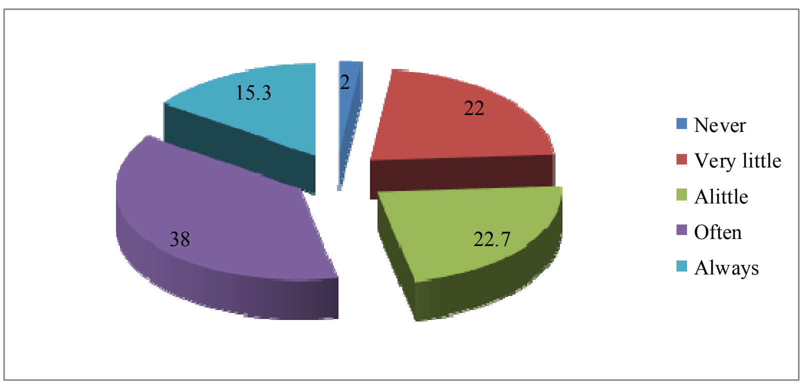

Figure 1: Extent of ITK integration (%)

Conclusion

The study aimed to evaluate the farmers' perception of effectiveness of agricultural communication systems and existence of farmer-extension interaction in the form of feedback, and to investigate the existence of ITK in management of climate change-related vulnerabilities. It was also to determine the extent to which agricultural information and communication systems (AICS) have integrated ITK for

climate change adaptation by smallholder farmers of coastal Kenya. The following conclusions were made from the study:

- The existing agricultural information and communication systems are perceived to be effective in disseminating agricultural knowledge to farmers, and encourages feedback. However, this feedback does not translate to farmers' needs and priorities being incorporated in research agendas
- Indigenous technical knowledge plays a big role in addressing many problems. Farmers use it in the management of climate change challenges such as floods, drought, erratic rainfall, pests and heat on crops
- Farming practices promoted by extension officers, to a large extent, do not include the ITK that farmers have

Recommendations

It is important to find ways by which the farmers can build their livelihood resilience through coping better with current weather-induced risks as a pre-requisite to adapting to future climate change. The study has therefore made the following recommendations;

- Agricultural knowledge and information systems (AKIS) which recognise ITK should be introduced in the present agricultural information and communication systems (AICS), and ITK should be included in development programs
- There is need for the Government to develop a participatory programme for seed improvement, production, preservation and distribution. This is important since traditional seeds used by farmers face the risk of extinction because farmers will most likely use them as food in case of famine
- There is need to target research to farmers' needs more effectively to produce technologies more appropriate to farmers, as there is a growing importance of farmer participation in defining research agendas and technology generation. Indigenous technical knowledge needs to be tapped using appropriate mechanisms to save it from disappearing

Acknowledgment

The Strengthening Capacity for Agricultural Research Development in Africa (SCARDA) through the Regional University Forum for Capacity Building (RUFORUM) funded this study. It was hosted by the Egerton University. Respondents in Ganze and Kikambala Divisions of coastal Kenya gave information and allowed for the collection of data.

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Climate change impacts and coping/adaptation strategies in semi-arid eastern Kenya

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Abstract

The study was carried out in Yatta district, Machakos County in semi-arid eastern Kenya. The study covered Katangi, Ikombe and Yatta divisions. Data was collected from 200 households through interviews using a structured questionnaire. The data were used to assess farmers' exposure to climate-related shocks and copping strategies, perceptions of climate change and climate change impacts, adaptation strategies and constraints to adaptation. The data collected was analysed through descriptive statistics using SPSS version 12.0. The study showed that drought is the key climate-related shock with 100% of households reporting that they had experienced drought. Erratic rainfall ranked second in importance, with 99.5% of households experiencing this climate shock. Floods affected a small share (5%) of households in the study area. The main effects of climate-related shocks were a reduction in crop yield (96%) and death of livestock (91%). Other effects reported by farmers include loss of entire crop (89%), food price increases (88%) and loss of income (86%). Purchasing food was the main coping strategy in response to climate-related shocks. The most common long-term adaptation strategies in response to climate change in the district were growing of drought escaping crops, water harvesting and change of crop varieties. The community ability to adapt to changing climate is constrained by many factors including lack of resources, lack of water, lack of access to inputs and lack of information on climate change and appropriate adaptation. Development of water systems for irrigation, easy access to inputs, provision of climate change information and appropriate adaptations, and provision of credit facilities were government interventions the community thought would enhance adaptation to climate change.

Key words: climate change, climate-related shocks, coping strategies, adaptation.

Introduction

As noted in the Intergovernmental Panel on Climate Change (IPCC) (2008) report, global climate change is affecting, and will continue to affect the semi-arid regions of the world in several ways, such as: temperature increases, reduced water availability, loss of natural vegetation and biodiversity, degradation of soil fertility, and reduced locally produced food supplies. This therefore emphasizes the urgent need to develop improved coping and adaptation strategies for these regions. Semi-arid lands in Kenya occupy over 35% of 582,646 km^2 of Kenya land area and supports over 25% of the human population as well as more than 26% of livestock in Kenya (Government of Kenya, 1992). Annual rainfall received in the region range from 900mm in the transitional zone, agro-ecological zone four (AEZ 4) to 450mm in the AEZ 5 with a high risk (25-75%) of crop failure (Jaetzold *et al.,* 2006). There are two cropping seasons in the region, the first season occurs in March-May as the 'long rains' (LR) and the second one in October-December as 'short rains' (SR).

Droughts frequently occur and vary in duration and severity. Temperatures and evaporation rates are generally high with February and September being the hottest months of the year. Minimum mean annual temperatures vary from 14^{0}C to 22^{0}C, while maximum mean annual temperatures vary from 26^{0}C to 34^{0}C (Rao *et al.,* 2011). These harsh climatic conditions make the agropastoralists in the semi-arid region highly vulnerable to climate change impacts. Poor social, economic and environmental conditions amplify their vulnerability to the negative impacts of climate change and reduce the capacity of the communities to cope with and adapt to climate change hazards.

Various reports indicate that when communities adapt appropriate measures they are better able to adjust to climate change effects and cope with adverse consequences ((IPCC, 2001; United Nations Framework Convention on Climate Change (UNFCCC), 2007)). The objective of this study was to assess and document farmers' perceptions of climate change, on-going adaptation and coping strategies, and their decision-making processes on coping mechanisms. This information would be useful in developing and promoting targeted adaptation strategies.

Materials and methods

Study sites

The study was conducted in Katangi, Ikombe and Yatta Divisions in Yatta District, Machakos County.

Katangi and Ikombe Divisions fall mainly within agro-ecological zone (AEZ) five with a small portions bordering Yatta Division in AEZ four (Jaetzold *et al.,* 2006). All sites exhibit low and variable rainfall and experience regular drought-related harvest failures with a bimodal rainfall pattern, with long rains falling from March to May, and short rains from October to December. Mixed crop-livestock production systems are the main farming enterprises with major crops being maize, green grams, pigeon peas and sorghum. In Yatta Division both rainfed as well as irrigated agriculture are practiced. Irrigation is facilitated through the Yatta furrow canal constructed in the 1950s.

Data collection

The assessment of the vulnerability and adaptation to climate change and impact by farmers was undertaken through field surveys of individual household interviews using a structured questionnaire. Differences in vulnerability and adaptation for different households was assessed based on selected factors such as sources and diversity of household members' livelihoods, ownership and access to resources, age, gender and level of formal education. In assessing the capacity to respond, we considered the consequences of short-term and seasonal drought at the household level, as these provide direct experiential evidence. In particular, we investigated the opportunities and constraints that shape patterns of coping mechanisms. Finally, we considered implications of the processes of adaptation and the policies that might facilitate the adaptive processes. In addition, the questionnaire was designed to assess the ability with which farmers could recollect the seasonal conditions that occurred during the past 20 years, their sources of weather information and constraints to adaptation. From each of the three selected division, a minimum of 50 households were randomly selected from a house-hold sampling frame provided by the area chiefs. A total of 200 questionnaires were administered.

Data analysis

The collected data were analysed through descriptive statistics using the Statistical Package for Social Sciences (SPSS) version 12.0 (SPSS Inc.,2003).

Results and discussion

Table 1 shows the socioeconomic characteristics of farmers in the study area. The majority of the respondents interviewed were men (80%) though women were more actively involved in agriculture in the study area. The main occupation of respondents was farming (73%) and 93% had some level of formal education. The age of respondents varied from 28 to 80 years with a mean of 51 and standard deviation of 9.8 years. Farm size varied from 2 to 132 acres with a mean of 10 and standard deviation of 11.1 acres, while the mean area under crops was 6 acres and standard deviation of 4.06 acres.

Table 1: Characteristics of respondents

Characteristics	% of respondents
Gender	
Male	79.8
Female	20.2
Formal education level of household heads	
None	7.1
Primary	48.5
Secondary	33.7
Post secondary	10.7
Main occupation	
Farming	73.1
Formal employment	11.2
Self employment / business	15.7
Characteristics	Mean
Age (years)	51.3 (9.8)
Farm size (acres)	10.35 (11.1)
Area under pastures (acres)	3.88 (2.71)
Area under crops (acres)	5.76 (4.06)

Number in parenthesis is the standard deviation

Seasonal farming patterns and constraints

Major crops in the study area included maize, cowpeas, beans, pigeon peas, green grams and sorghum grown under rain-fed conditions. Except for pigeon peas that are planted during short rains (October-December), the rest of the crops are planted in both long rains (March-May) and short rains season. Other crops grown under irrigation include french beans, kales, tomatoes and onions. The main factors determining the types of crops grown were season (99%), inputs availability (82%), food needs (75%) and water availability (71%). Eighty five percent of farmers were intercropping in both seasons. Major constraints to crop production were unreliable rainfall (93.5%), pests and diseases (65.8%), poor soil fertility (61.6%) and seed availability (53%). The type of livestock kept in the area included local breeds of cattle (80%, sheep and goats (shoats) (88%) and poultry (97%). In terms of contribution to household food and financial security, 89% of the participants reported that cattle was the major contributor. The main factors determining the type of livestock kept were feed availability (94%), water availability (84%), food needs (77%) and disease incidences (74%),while the main contraints to livestock production were lack of feeds (75%), unavailability of high yielding livestock breeds (69%) and lack of water during dry spells (58%).

Types, impacts and outcomes of climate shocks

The study showed that drought was the key climate-related shock with 100% of the households reporting that they had experienced drought (Figure 1). Erratic rainfall ranked second in importance, with 99.5% of households experiencing this climate shock. Floods affected a small share of the households (5%) in the study area.

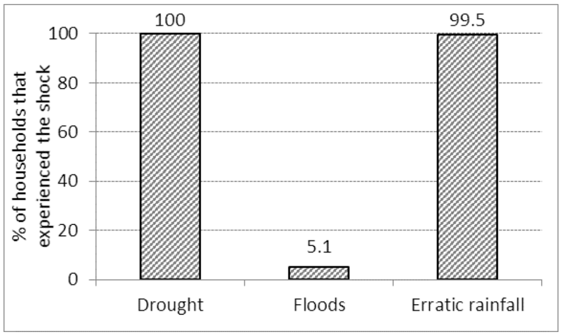

Figure 1: Climate shocks experienced

The main effects of climate-related shock were a reduction in crop yield (96%) and death of livestock (91%) (Figure 2). Other effects reported by farmers include loss of entire crop (89%), food price increases (88%) and loss of income (86%).

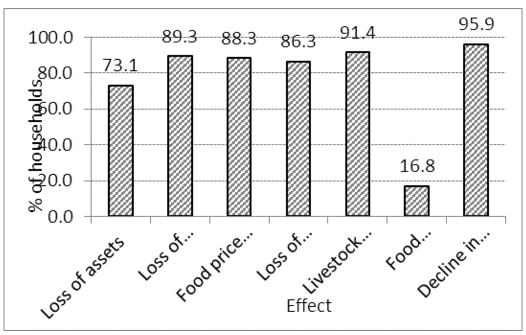

Figure 2: Effect of climate related shocks

Farmer perceptions of climate change

On perception of climate change over the last 20 years, 98.5% of farmers reported that there has been an increase in temperatures and 98% reported a decrease in rainfall amounts. Concerning rainfall variability, 98% of farmers reported that rains come later and has become more erratic (96%), while 90% reported longer droughts. Figure 3 show farmers' classification of good and failed long and short rains seasons over the last 20 years.

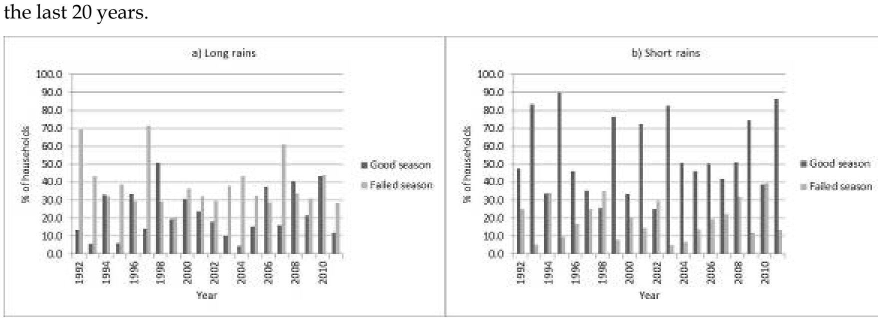

Figure 3: Farmers' classification of seasons from 1992 to 2011: (a) long rains (b) short rains

Farmers interviewed were able to recollect the past seasons fairly accurately especially the 'good' and 'failed' seasons which corroborated well with the meteorological records. This can be expected considering the high impact these events have on overall performance of the farming systems. For instance, over 30% of farmers classified the years 1994, 1996, 1998, 2000, 2006, 2008 and 2010 long rains seasons as good (Figure 3). This compares quite well with classification suggested by Rao *et al*. (2011) where seasons with rainfall in excess of 25% of long-term mean were classified as good, whereas those seasons with rainfall less than 25% below the long-term mean were classified as failed. From the analysis of rainfall data (Figure 4), only 1998, 2005, 2006 and 2010 long rains can be classified as good. Over 50% of farmers classified the years 1993, 1995, 1999, 2001, 2003, 2004, 2006, 2008, 2009 and 2011 short rains season as good (Figure 5), whereas on the basis of meteorological data (1992-2011), only 1994, 1997, 1999 and 2006 short rains seasons are classified as good (Figure 5).

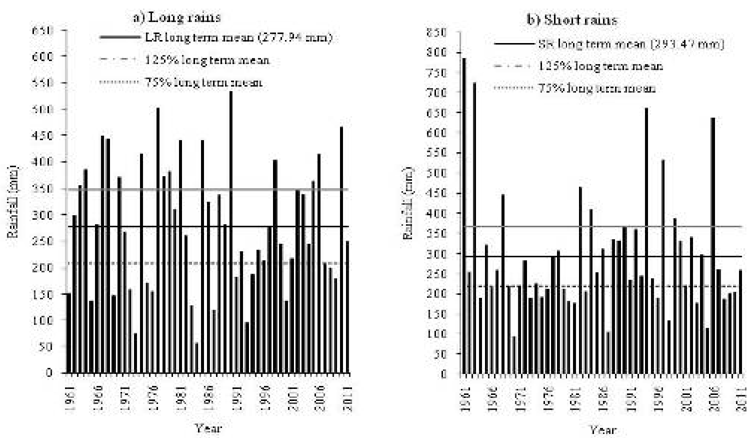

Figure 3: Seasonal rainfall classification: (a) long rains and (b) short rains

Climate information

The main type of climate information that farmers reported having access to were daily weather forecasts, advisories and alerts / early warnings. Daily weather forecasts was accessed through radio (97%), advisories through *barazas*, while alerts were accessed through newspapers (78%) and *barazas* (56%). Though not reliable as reported by 65% of farmers, daily weather forecasts was the most easily accessible and timely climate information. Alerts/early warnings were more relevant as reported by 72% of farmers and were easily accessible. Seventy-two percent of farmers indicated that they had indigenous technical knowledge (ITK) and skills on weather forecasting and could predict a wet and a drought season based on animals and plants behaviour. Indigenous knowledge on weather forecasting was reported by 81% of farmers to be helpful in farming decisionmaking especialy on the types of crops to be planted.

Copping and adaptation strategies and contraints to adaptation

Coping strategies are the actual responses to crisis on livelihood systems in the face of unwelcome situations, and are considered as short-term responses (Sharma, 2009). In general, this involves managing resources, both in normal times as well as during crises or adverse conditions. The fact that the communities living in the area covered by this study have survived droughts for many years is an indication that they have developed indigenous mechanisms and strategies to cope with these droughts. A better understanding on how local populations have coped with previous droughts has the potential of providing

important guide for addressing current and future climatic events. The communities interviewed have developed various coping strategies and adaptation mechanisms that have enabled them reduce their vulnerability to past climate variability and change. Figure 5 gives an illustration of coping strategies used to deal with climate shocks. Given that the main result of the climate shocks was a decline in crop yield (or in some cases a loss of the entire crop) it is not surprising that the main coping strategy involve the purchase of additional food, reducing consumption, or consuming different foods. Purchasing food was particularly important in which 82% of the households reported purchasing food in response to climate-related shocks. This suggests that access to markets and affordable sources of food are important for households facing climate shocks. However, as was mentioned above, food shortages and price increases are other common effects of climate shocks heightening the situation of food insecurity. This indicates that households affected by shocks may face difficulties meeting their consumption needs for multiple reasons. Given that in order to buy food, households must afford it somehow, we looked into what other coping strategies that these households employed. Among those household that reported buying food as a coping strategy, 86% sold livestock, 55% borrowed from relatives, 61% sought off-farm employment, 62% received aid, and 61% were engaged in charcoal burning.

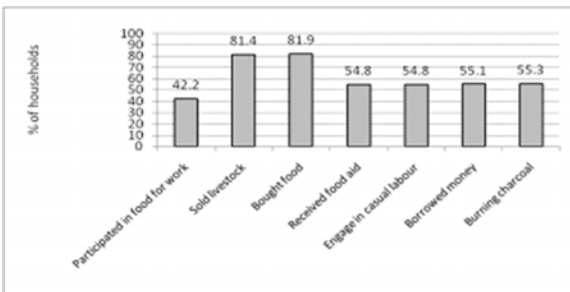

Figure 5: Coping strategies in response to climate change

Adaptation is defined as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007). Adaptation has the potential to reduce the negative impacts of climate change. However, the ability to adapt is particularly related to socioeconomic circumstances. Adaptation techniques could include changes in crop or livestock types, water harvesting, irrigation and fertilizer use. Identifying which areas and populations are at greatest risk from climate change or are most vulnerable, can help in setting priorities for adaptation. Obviously, adaptation strategies are expected to be many, and their combinations in various ways will be required in any given location. With respect to crop production, surveyed farmers took a range of adaptation strategies (long term measures in response to perceived climate change) (Figure 6). The most common responses included growing of drought escaping crops (87%), water harvesting (67%), changing crop varieties (63%) and improvement of soil fertility (52%). Other responses included changing crop type (48%), soil conservation practices (43%) and changing of planting dates (39%).

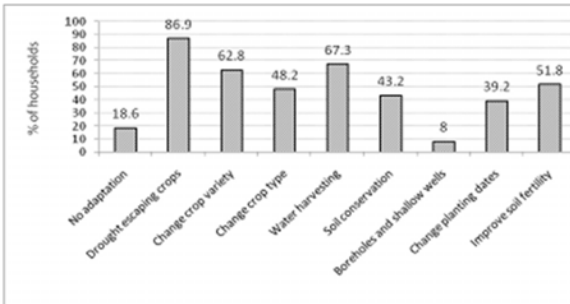

Figure 6: Adaptation strategies in crop production undertaken by farmers in response to perceived climate change

On livestock production, farmers also undertook several adaptation strategies (Figure 7). The most common strategies included decreasing the number of livestock kept (52%), mixing of crop and livestock production (38%) and changing of animal breeds (27%). Other strategies included diversifying livestock feeds (22%) and supplementing livestock feeds (22%).

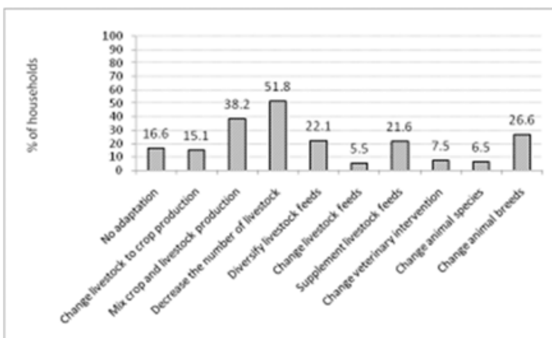

Figure 7: Adaptation strategies in livestock production undertaken by farmers in response to perceived climate change

The proportion of farmers that did not take any adaptation strategies on crop production was 19%, while on livestock production was 17%. This compares well with a similar study conducted in 7 districts of Kenya where 19% of farmers did not take any adaptive strategies (Bryan *et al.,* 2011). Farmers were also asked what measures they would like to implement to adapt to changing climate variables like rainfall patterns and amounts, longer droughts and hot temperatures. The most common response was water harvesting (35%) through building of water pans and dams, and digging of shallow wells, planting of both natural and fruit trees (30%) and construction of soil and water conservation structures (5%).

The various constraints that hinder implementation of adaptation strategies to climate change are shown in Figure 8.

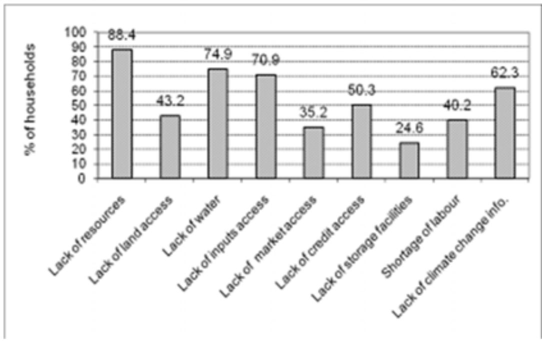

Figure 8: Constraints to adaptation

The most common responses included lack of resources (88%), lack of water (75%), lack of access to inputs (71%) and lack of information on climate change and appropriate adaptation (62%). Other responses included lack of access to credit (50%) and land (43%) and shortage of labour (40%).

Surveyed farmers reported a number of government incentives/policies that they thought would enhance adaptation to climate change (Figure 9). The most common responses included development of water systems for irrigation (92%), easy access to inputs (89%), provision of climate change information and appropriate adaptations (89%) and provision of credit (80%).

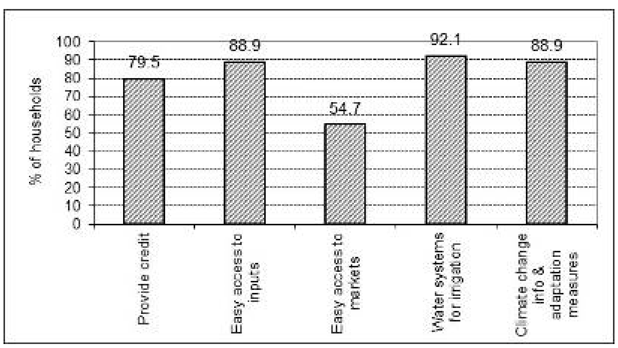

Figure 9: Policies perceived to enhance adaptation to climate change

Conclusions

Frequent droughts and erratic rainfall, the main climate shocks in Yatta results in reduction in crop yields and death of livestock. Purchasing food is the main coping strategy in response to climate-related shocks. In order to purchase food, farmers have to sell livestock, engage in casual labour or burn charcoal. The most common adaptation (long-term) strategies are growing of drought escaping crops, water harvesting and change of crop varieties. The community ability to adapt to changing climate is constrained by many factors including lack of resources, lack of water, lack of access to inputs and lack of information on climate change and appropriate adaptation. In order to adapt to changing climate variables like variable rainfall pattern and amount, longer droughts and hot temperatures, the community intended to undertake measures like water harvesting through building of water pans, dams, shallow well; planting of both natural and fruit trees and construction of soil and water conservation structures. While the community undertook these measures, there are government policies that they thought would enhance adaptation to climate change. These are development of water systems for irrigation, easy access to inputs, provision of climate change information and appropriate adaptations, and provision of credit facilities.

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THEME 2. INTEGRATED NUTRIENT MANAGEMENT

Appropriate integrated nutrient management and field water harvesting options for maize production mitigating drought in the semi-arid southern rangelands of eastern Kenya

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Abstract

The Southern Rangelands of Kenya are prone to frequent droughts and crop failures leading to serious food shortages. The effect of the farmer practice (flat seedbed), tied-ridging and contour furrows water harvesting techniques and five integrated nutrient management practices on the performance of rainfed maize was studied on-station (Katumani) and on-farm at the southern rangelands of Kenya (Kibwezi) during the 2006 short rains season. Both shelled and unshelled maize yields responded positively to both water harvesting techniques and integrated nutrient management options. Under water harvesting techniques, the tied ridging had the highest positive effect on grain yield. Among the integrated nutrient management options, manure at either 5 or 10 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 kg ha^{-1} had the most positive effect on maize yields. A combined application of manure and inorganic fertilizers has a highly positive on maize yields. In the absence of inorganic fertilizers, a minimum of manure at 10 t ha^{-1} should be applied on maize plots. The tied-ridging water harvesting technique should be recommended to farmers in the Machakos and Kibwezi in the southern rangelands of semi-arid Kenya.

Key words: Maize, drought, integrated nutrient management, water harvesting techniques

Introduction

African soils have inherent difficulties for agriculture in terms of low nutrient stocks and availability, acidity, and poor drainage (AFNET, 2007). In addition, inappropriate land use practices during the past several decades have worsened the situation through nutrient mining by crops, leaching and inadequate soil erosion control. The southern rangelands of semi-arid eastern Kenya, which are prone to erratic rainfall, drought, and other vagaries of nature are no exception. This results to limited livelihood options in addition to making crop production a risky undertaking resulting in rampant food insecurity and poverty. In trying to achieve their economic ends communities in the drylands engage in the growing of crops and trees to supplement returns from the main rangeland activities like livestock rearing (GoK, 2004). The major impediment to crop and tree production in these areas is low moisture stress characterized by low and erratic rainfall and high transpiration rates. In order to improve crop and tree production in these areas, sustainable on-farm rainwater management techniques are required. Some of the options being upscaled in semi-arid eastern Kenya include proven appropriate water harvesting techniques and integrated nutrients management options. Several studies have demonstrated the positive benefits of simultaneous application of manure and inorganic fertilizers. Esilaba *et al*. (2000) showed that the combined application of inorganic fertilizers and manure on maize significantly reduced striga emergence and increased crop yields at Sirinka, Ethiopia, during the second season. Other studies by Okalebo *et al*. (1999) and Fritz *et al*. (2001) demonstrated that larger yields were obtained when organic and inorganic inputs were applied to soils, particularly when soil moisture was adequate and the organic inputs were higher in mineralisable nutrients. Jager *et al.* (2001) concluded that both subsistence-oriented farm management systems result in serious N-depletion and that 60-80% of farm income is based upon nutrient mining. High-level compost application treatments in maize are attractive if labour and organic inputs are available. Results of work by Saini *et al.* (2005) suggested that for maximum crop yield only 50% of the required fertilizer might be

supplied along with bio-inoculants or manure. In long term experiments in southwestern Nigeria, Vanlauwe *et al.* (2005)reported added benefits due to the combined use of fertilizer nitrogen and organic residue application on maize yields over the years. The principle source of nutrients that is available for the crops of resource poor subsistence farmers in the semi–arid areas of eastern Kenya is farmyard manure produced on their holdings. Studies by Itabari *et al.* (2004) demonstrated that higher yields of maize and beans can be achieved when both manure and inorganic fertilizers are combined. This study also showed that combinations of farmyard manure and run-off harvesting significantly increased grain yield while application of farmyard manure alone had no significant effect on grain yield. Most soils in the arid and semi-arid areas of Kenya are fragile and prone to dramatic decline in fertility. As such, good soil fertility management must go hand in hand with the use of soil and water conservation practices in order to give the farmer good crop yields. The challenge for research is therefore to develop practical methods of maintaining soil fertility to enable farmers get the benefits of their soil and water conservation efforts against a backdrop of diversity, vulnerability and transition, to produce sustainable management of arid and semi-arid lands. This study aimed at validating and hence upscaling some of these practical water harvesting techniques and integrated nutrient management options in the southern rangelands of semi-arid eastern Kenya.

Materials and methods

Researcher-farmer managed on-farm trials and demonstrations were conducted at KARI Katumani Research Center and on-farm at Kibwezi in the southern rangelands in Kibwezi Makueni District in Kenya to study the effect of different water harvesting techniques and different integrated nutrient management practices on the performance of rainfed maize (pioneer hybrid). The trials treatments included three water harvesting techniques, contour furrows, farmer practice (flat seedbed) and tied-ridging; five integrated nutrient management practices, control (farmers practice - nil fertilizer), farm-yard manure at 10 t/ha, farm-yard manure at 10 t/ha + 20kgN/ha + 20kgP/ha, farm-yard manure at 5 t/ha and farm-yard at manure 5 t/ha + 20kgN/ha + 20kgP/ha. Each treatment was replicated four times in a randomized complete block design (RCBD). The trial was planted at the onset of the 2006 short rains and harvested four months later. During harvesting, total fresh weight was taken and the yields sub-sampled where necessary and whole fresh weight taken where the yields were very low, the sub-sample fresh weight was taken. The samples were oven dried and dry weights taken. The weights taken were used to extrapolate the yields per hectare in each treatment. This was used for water harvesting and integrated nutrient management (INM) response comparison. The data collected was subjected to analysis of variance using the method described by Gomez and Gomez (1984) and the treatments means were separated using the Least Significant Difference (LSD) test using the SAS statistical package (SAS 1990).

Results and Discussion

Figure 1 shows maize planted on the flat with nil fertilizer at KARI Katumani during the 2007 long rains 2 weeks after planting. Farmers practice involves planting maize on the flat with nil fertilizer in the semi-arid areas of southern lowlands which leads to low yields in a good year and total yield loss in a bad year. The maize were yellowing indicating loss of chlorophyll and were generally weak.

Figure 1: Maize crop planted on the flat with nil fertilizer at KARI Katumani 3 months after planting during the 2007 long rains

Figure 2 shows maize planted in tied ridges at Katumani in Machakos County during the 2007 long rains. The tied ridges had trapped pools of water that would be released slowly to the maize plants assuring their good performance.

Figure 2: Maize crop planted under tied ridges and inorganic fertilizer at KARI Katumani 3 months after planting during the 2007 long rains

The results in Table 1 showed that there were significant differences ($P<0.05$) between water harvesting techniques and integrated nutrient management (INM) options. Under water harvesting techniques, the tied ridging had the highest grain yield (3905 kg ha^{-1}), which was significantly different ($P<0.05$) from the other water harvesting techniques (Table 1) during the 2006 short rains. The short rains are usually longer, heavier and more reliable than the long rains.

Table 1: Responses of maize yields (Kg) under different water harvesting techniques at KARI Katumani Semi-Arid Eastern Kenya during the 2006 short rains

Treatment	N	Means	*t Grouping
Tied-ridging	20	3904.9	A
Contour furrows	20	2744.9	B
Farmers practice (flat seedbed)	20	2844.9	B

* Values with the same letter are not significantly different (P<0.05)

Table 2 : Responses of maize yields (Kg) under different water harvesting techniques at KARI Katumani Semi-Arid Eastern Kenya during the 2007 long rains

Treatment	**N**	**Mean**	***t Grouping**
Tied-ridging	55	1768.7	A
Contour furrows	55	1800.7	A
Farmers practice (flat seedbed)	55	1815.5	A

* Values with the same letter are not significantly different (P<0.05)

Figure 3 shows maize crop planted under contour furrows at KARI Katumani during the 2007 long rains 3 months after planting. The picture depicts plants that are starting to dry up and which seems to have a poorer stay green ability than those planted under tied ridges (Figure 4). Stay green ability affects the rate of photosynthesis with consequent positive or negative effect on yield.

Figure 3: Maize crop planted under contour furrows and inorganic fertilizer at KARI Katumani 3 months after planting during the 2007 long rains

Figure 4: Maize crop planted under contour furrows with both manure and inorganic fertilizer at KARI Katumani 3 months after planting during the 2007 long rains

Figure 5 shows maize plants grown under tied ridges had a higher stay green ability than those under contour furrows and farmers practice. It was visually obvious that the plants under tied ridges had more vigorous plants and bigger maize cobs than those under contour furrows (Figure 4) and flat seedbeds.

Figure 5: Maize crop planted under tied ridges at KARI Katumani during the 2007 long rains 3 months after planting

Among the INM techniques, manure at 10 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 kg ha^{-1} had the highest maize yield (3568 kg ha^{-1}), which was significantly different from the other INM options except under manure at 5 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 kg ha^{-1} (Table 3). The results suggest that a combination of both manure and inorganic fertilizers have a more positive effect on maize yields than sole manure or nil fertilizer. The results also suggest that the INM option under manure at 5 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 kg ha^{-1} could be recommended in these semi-arid lands as it required only a half (5 t ha^{-1}) of the manure to give similar yields as 10 t ha^{-1} of manure. Table 4 showed similar results except that the maize yields were much lower probably due to the fact that these were produced during the 2007 long rains which were less reliable than

those received during the 2006 long rains. This suggests that maize is best planted during the short rains and with manure.

Table 3: Responses of maize yield (Kg) under different integrated nutrient management techniques at Katumani Semi-Arid Eastern Kenya during the 2006 short rains

Treatment	Means	N	*t Grouping
Farmers practice (nil fertilizer)	2717.7	12	B
Manure 5 t ha-1	2851.8	12	B
Manure 5 t ha-1+20 kg N+20 kg P2O5 ha-1	3547.5	12	A
Manure 10 t ha-1	3138.7	12	BA
Manure 10 t ha-1+20 kg N+20 kg P2O5 ha-1	3568.1	12	A

*Values with the same letter are not significantly different (P<0.05)

Table 4: Responses of maize yield (Kg) under different integrated nutrient management techniques at Katumani Semi-Arid Eastern Kenya during the 2007 long rains

Treatment	Mean	N	*t Grouping
Farmers practice (nil fertilizer)	1518.2	11	B
Manure 5 t ha-1	1845.6	11	A
Manure 5 t ha-1+20 kg N+20 kg P2O5 ha-1	1923.0	11	A
Manure 10 t ha-1	1690.0	11	AB
Manure 10 t ha-1+20 kg N+20 kg P2O5 ha-1	2008.0	11	A

* Values with the same letter are not significantly different (P<0.05)

Combined analysis (Table 5) showed manure 10 t ha-1+20 kg N+20 kg P_2O_5 ha-1 under tied ridging water harvesting technique had the highest maize yields (4890 Kg/ha) though not significantly different from manure 5 t ha-1+20 kg N+20 kg P_2O_5 ha-1. This suggests that a farmer does not need to apply more than manure 5 t ha-1+20 kg N+20 kg P_2O_5 ha-1. This also suggests that there are beneficial effects in combining manure with inorganic fertilizers concurring with Itabari *et al*. (2004). There were no significant differences between the five integrated nutrient management options under contour furrows and farmers practice (flat seedbed and zero fertilizer application). This implies that the tied-ridging water harvesting technique was more responsible for increased maize yields at Katumani than nutrients. Thus, moisture is a more limiting factor than nutrients. It is a well-known fact that manure improves soil water retention, cation exchange capacity, and aeration. Githunguri *et al*. (2007) and Kathuku *et al*. (2007) reported similar results under cowpeas and maize respectively.

Table 5: Responses of maize yield (Kg) under combined different integrated nutrient management and water harvesting practices at KARI Katumani Semi-Arid Eastern Kenya during the 2006 short rains

Treatment	Tied ridging	Contour furrows	Farmers' practice
Farmers practice (flat seedbed and nil fertilizer)	3404.70	2249.60	2498.70
Manure 5 t ha-1	3303.50	2572.90	2679.20
Manure 5 t ha-1+20 kg N+20 kg P2O5 ha-1	4495.90	3244.60	2902.00
Manure 10 t ha-1	3430.10	3169.70	2816.20
Manure 10 t ha-1+20 kg N+20 kg P2O5 ha-1	4890.30	2487.60	3326.40
LSD	1320.80	1084.30	910.72

Table 6 shows results on unshelled maize (maize grains that are attached to the cob) yields at KARI Katumani during the 2006 short rains season. Under tied ridging water harvesting technique, the highest unshelled maize yield (7585 kg ha^{-1}) was recorded under manure at 10 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 kg ha^{-1}, which showed significant differences ($P<0.05$) from the farmer's practice (flat seedbed and zero INM) and manure at 5 t ha-1 (Table 5). On the other hand, under contour furrows and farmer's practice (flat), the highest unshelled maize yields were observed under manure at 10 t ha^{-1} and 10 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 kg ha^{-1} respectively, even though there were no significant differences between the INM options. The results strongly suggest that the tied ridging has a positive effect on unshelled maize yields while a combined application of manure and inorganic fertilizers boosts maize yields. In the absence of inorganic fertilizers, a minimum of manure at 10 t ha^{-1} should be applied on maize plots.

Table 6: Responses of unshelled maize yield (Kg) under combined different integrated nutrient management and water harvesting practices at KARI Katumani Semi-Arid Eastern Kenya during the 2006 short rains

Techniques	Tied ridging	Contour furrows	Farmers' practice
Farmers practice (flat seedbed and nil fertilizer)	5843	3850	4659
Manure 5 t ha-1	5773	5030	4705
Manure 5 t ha-1+20 kg N+20 kg P2O5 ha-1	7207	5600	5090
Manure 10 t ha-1	6092	5748	4601
Manure 10 t ha-1+20 kg N+20 kg P2O5 ha-1	7585	4472	5341
Mean	6500	4940	4879
LSD	1655	1372	1588

Tables 7 and 8 shows results on maize yield at Kibwezi in the southern rangelands during the 2006 short rains season. The water harvesting techniques showed no significant differences but the different integrated nutrient management options showed significant differences ($P<0.05$). Manure at 10 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 ha^{-1} performed much better than all the other INM practices irrespective of any water harvesting practices. Under the tied ridging treatment, the highest maize yield (2157 kg ha^{-1}) was recorded under manure 10 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 ha^{-1}, which was significantly different ($P<0.05$) from the other integrated nutrient management treatments. Under the contour furrows, the highest grain yield (1943 kg ha^{-1}) was observed under manure at 5 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 ha^{-1}, but was not significantly different ($P<0.05$) from the other INM treatments. Under the farmer's practice (flat and zero INM) the highest grain yield (2038 kg ha^{-1}) was observed under manure 5 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 ha^{-1}, which was significantly different from the other INM treatments except manure 10 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 ha^{-1}. As suggested earlier, it is clear from the results that a combination of manure and inorganic fertilizers was having positive effects on maize at the farmer's field concurring with Okalebo *et al*. (1999) and Fritz *et al.* (2001). This moves away from the 'fertilizer package' approach, which has frequently failed in Africa (Swift and Shepherd, 2007). However, the water harvesting techniques did not show any significant differences probably due to the above normal rainfall that was received during that season. Moisture was not a limiting factor during the 2006 short rains and as such, there is need to repeat the experiments during a normal season.

Table 7: Analysis of variance of responses of maize yields (Kg) under different integrated nutrient management and water-harvesting techniques at Kibwezi in the southern rangelands of Semi-Arid Eastern Kenya during the 2006 short rains

Source of error	DF	SS	MS	F Value	Pr>F
Model	16	39662765.9	2480172.9	7.98	0.0001
Rep	10	34694752.6	3469475.3	11.17	0.0001
Water harvesting technology	2	62974.7	31487.3	0.10	0.9037
INM technology	4	4925038.7	1231259.7	3.96	0.0044
Error	148	45970626.6	319612.3		
Total	**164**	**85653392.5**			

Table 8: Responses of maize yield (Kg) under combined different integrated nutrient management and water harvesting practices at Kibwezi in the southern rangelands of Semi-Arid Eastern Kenya during the 2006 short rains

Treatment	Tied ridging	Contour furrows	Farmers' practice
Farmers practice (flat seedbed and nil fertilizer)	1400.40	1636.30	1517.90
Manure 5 t ha-1	1990.70	1817.10	1714.20
Manure 5 t ha-1+20 kg N+20 kg P2O5 ha-1	1787.90	1942.90	2038.10
Manure 10 t ha-1	1508.00	1760.30	1801.60
Manure 10 t ha-1+20 kg N+20 kg P2O5 ha-1	2156.60	1853.50	2005.80
LSD (0.05)	482.79	452.11	407.44

Conclusions and recommendations

Both shelled and unshelled maize yields responded positively to both water harvesting techniques and integrated nutrient management options. Under water harvesting techniques, the tied ridging had the highest positive effect on grain yield. Among the integrated nutrient management options, manure at either 5 or 10 t ha^{-1} plus 20 kg N plus 20 kg P_2O_5 kg ha^{-1} had the most positive effect on maize yields. This means that a farmer needs to apply only manure 5 t ha-1+20 kg N+20 kg P_2O_5 ha-1. A combined application of manure and inorganic fertilizers boosts maize yields. In the absence of inorganic fertilizers, a minimum of manure at 10 t ha^{-1} should be applied on maize plots. The tied-ridging water harvesting technique was more responsible for increased maize yields at Katumani than nutrients meaning that moisture is a more limiting factor than nutrients.

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Response of maize crop to Sulphur in Ruvuma Region, Tanzania

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Abstract

Good growth and productivity of crops require availability of necessary nutrient elements in balanced proportions. In mid 2000s, inadequate responses of maize crop to Urea were observed in Ruvuma region. It was also reported that, blending of Urea and Sulphate of Ammonia (SA) improved maize yields. Field observations and soil testing from 2008 to 2009 revealed deficiency of sulphur in soils of Ruvuma region. This study aimed to establish rate of S-nutrient to apply for optimum maize production and monitor changes in soil reaction. Researchers-designed and researchers-farmer implemented and managed experiment in three districts: Namtumbo (Suluti), Songea (Mletele) and Mbinga (Mtama and Kitanda). Composite soil samples (0-30cm) were taken and analyzed for physical-chemical properties. In 2010/11 to 2011/12 cropping seasons, 5-treatments were imposed on RCBD, replicated three times per site in plots sizes of 5m x 5m. Treatments had control (no external S and N nutrients applications), Urea alone and three blends of 10, 20 and 30 kg S/ha as SA, and Urea, all adjusted to 100 kg N/ha. All treatments received basal applications of 20 kg P/ha as TSP and 20 kg K/ha as Muriate of Potash. Maize yield was a main data collected. Optimum S-rate was estimated by using curvilinear regression analysis and differentiation of the quadratic response equation as: $\partial y/\partial x = 0$. Soil results revealed acidic soils in all sites, with pH ranging 5.49 – 5.89. All soils show low level of N, P, S and Ca for optimum maize production. The rate of 10 kg S/ha increased maize grain yield by about 1t/ha. In depth analysis using curvilinear regressions and differentiation of the derived equation ($Y= -9.97X^2 +249.95x +2370.1$) revealed that 12.53 kg S/ha is plateau point of grain yield response. There were no consistent pH changes, which suggest that applications of these small amounts of SA are not harmful. Economic optimum rate of about 11kg S/ha is recommended for maize production in Ruvuma.

Introduction

Plants take necessary essential nutrients required for its growth from the soil, air and water. The air and water supply carbon, hydrogen and oxygen and rest are from the soil. The nutrient required for crop growth, is a macronutrient, if absorbed by plants in large quantities and is a micronutrient, if taken by plants in small quantities. The air and water supplied nutrients are found in ample amounts, thus generally do not lead to limitation in crop growth. For a crop to grow well on the soil you require healthy soil, that can supply all crop nutrients in balanced amounts required by that crop. A deficiency symptom of a nutrient occurs in a crop if it cannot get adequate supply of a nutrient from the soil. This is an indication that, crop must receive additional supply from external source, such as mineral or organic fertilizer. In soils, where multiple nutrients deficiencies exist, use of compound or complex multi-nutrient fertilizers or blends of straight fertilizers, become necessary to supply essential nutrients elements for maintenance of soil health and/or enhancing the productivity of the soil.

In general, good growth and productivity of crops require availability of necessary nutrient elements in balanced proportions (FAO and IFA, 2000). If the concentration of a given element in the crop root zone is low, a deficiency of that element occurs and crop growth is restricted. The soil testing is one tool to understand levels of nutrients in the soil, in order to recommend maintenance and/or ameliorative measures for high production and healthy soils. However, this requires to be supported by response studies to establish necessary amount of the nutrients from the external source, such as fertilizers.

In mid 2000s, inadequate responses of maize crop to Urea as N-source fertilizers were observed by farmers and extension workers. It was also reported that, blending of Urea and Sulphate of Ammonia (SA) improves the crop response. In response to this concern, expert field observations and soil testing from 2008 to 2009 revealed deficiency of sulphur (S) in soil of Ruvuma region (Malley, 2010). Simple exploratory study further attested the laboratory soil testing results. However, the amount SA to externally supply S-required for rectifying the deficiency to optimize maize production was not known. Thus this formed a research gap for appropriate advice to extension workers and farmers in blending Urea and SA fertilisers in maize production. Based on this background it was important to set an experiment on blending of Urea with SA in 2010/11-2011/12 seasons in few representative sites in three Districts of Ruvuma region. Objective of the trial was therefore, to establish necessary rate of S-nutrient for external supply in optimum maize nutrition and monitor any consistent changes in soil reaction.

Materials and methods

Approach

Researchers-designed and researchers-farmer implemented and managed experiment for establishing sulfur rate for optimum production of maize was conducted in Namtumbo (Suluti), Songea (Mletele) and Mbinga (Mtama and Kitanda) Districts in Ruvuma region. These sites were selected as representatives in those Districts, based on concerns of poor response of maize to Urea fertilizer alone as N-source, expert field observations and soil testing results. In each site, composite soil samples were collected at a depth of 0-30cm for physical-chemical analyses as presented in Table 2.

Experimental design and data collection

In 2010/11 to 2011/12 cropping seasons, 5-treatments were imposed on Randomized Complete Block Design (RCBD), replicated three times per site in plots sizes of 5m x 5m. Treatments had control (no external S and N nutrients applications), Urea alone and three Urea-SA blends with varied S-levels as indicated in Table 1. All treatments received basal applications of 20 kg P/ha (from TSP) and 20 kg K/ha as Muriate of potash (MOP). Used maize seed in the experiment was variety UH6303. All other recommended maize agronomic practices were timely followed. Maize yield was main data collected as indicator of response to S rates from SA as a source.

Table 1. Treatments and their application descriptions

Treatments	Treatments application descriptions
Control (0S & 0N)	-
Urea alone for N	N=100kg/ha (1/3 2WAP* and 2/3 before maize tasseling)
10 kg/ha S from SA	Adjust N with Urea to N=100kg/ha (1/3 2WAP and 2/3 before maize tasseling)
20kg/ha from SA	Adjust N with Urea to N =100kg/ha (1/3 2WAP and 2/3 before maize tasseling)
40 kg S/ha from SA	Adjust N with Urea to N =100kg/ha (1/3 2WAP and 2/3 before maize tasseling)

*2WAP= Two weeks after planting

Data analysis

Maize grain yield data was analyzed using the two- way ANOVA to assess response to treatments using a model: $Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$, $i = 1 \ldots a$, $j = 1 \ldots b$; whereby: μ = overall mean; α_i = treatments effects; βj = replications effects and ε_{ij}, = error term. The optimum S-rate was estimated by using curvilinear regression analysis and then differentiation of the quadratic response equation as: $\partial y/\partial x = 0$, whereby Y is maize yield response and X is rate of S, at point where there is no further yield increase i.e. at zero slope on the response curve.

Results and discussion

Soil characteristics

Soil testing results show, in all trial sites soils were acidic with pH below optimum of easy nutrients availability (Table 2). Soil pH is above the critical lower point of 5.5 for optimum maize growing. The surface soils were sandier in both Mbinga sites (Table 2), which indicate clay and bases migrations to sub-soils through the leaching process (Malley *et al.,* 2006). This is also supported by soil evaluation commissioned by Mbinga District council in 2009 (Malley *et al.,* 2010). All soils show low level of N, P, S and Ca for optimum crop production. This means external supply of these nutrients is required to ameliorate low soil productivity in Ruvuma. Large number of farmers (86%) use Urea as N-source in maize production in Ruvuma (Malley *et al*., 2010). The multiple nutrients deficiencies observed show imbalanced nutrient supply for maize production and thereby causing to low response to N- from Urea alone. One of the nutrients which critically deficient is sulfur ranging between 0.08 to 1.78 mg/kg. However, optimum nutrition of many field crops, soil sulfur concentration of 6-12mg/kg is required (Landon, 1990).

Table 2: Physical-chemical characteristics of the trial sites

Soil characteristics	Study sites			
	Suluti	Kitanda	Mtama	Mletele
Soil pH-H2O (1:2.5)	5.77	5.49	5.76	5.89
Particle Size Distribution				
Clay(g/kg)	464	300	120	-
Silt (g/kg)	352	72	76	-
Sand(g/kg)	184	628	804	-
Total nitrogen N (g/kg)	1.4	2.4	2.2	1.10
Organic Carbon (g/kg)	8.6	30.3	17.6	11.4
Available Sulfur (mg/kg)	0.08	0.70	1.78	0.68
Available P (mg/kg)	13.58	11.90	8.61	5.84
Exchangeable bases				
Calcium (cmol/kg)	0.45	1.00	2.11	0.92
Magnesium (Cmol/kg)	1.22	1.10	1.53	0.68
Potassium (Cmol/kg)	0.61	0.74	1.12	0.72

Maize grain yield response

Analysis of mean maize show there is grain yield response to S-applications. Results for two seasons in which trials were conducted are presented in Table 3. From the results it is evident that rate of about 10 S/ha is sufficient and increases grain yield of maize by about 1t/ha. In depth, analysis using curvilinear regressions and differentiation of the derived equation ($Y= -9.97X^2 +249.95x +2370.1$) revealed that 12.53 kg S/ha is plateau point of grain yield response. This is biological optima point, which according to Tisdale *et al.,* (1990), economic optimum is 90% of it, which thus gives optimum rate of sulfur application for rectification of deficiency in soil of Ruvuma region of about 11kg S/ha. This rate is in agreement with observed response in Table 3, whereby in all locations a rate of 10kg/ha gave best response. Same rate was found optimum in maize production elsewhere in similar tropical soil environments (Ray personal communication).

Table 3: Maize yield data from sites across Ruvuma Region (season 2011/2012)

Treatment	Maize mean yield (kg/ha)									
	Mletele		Suluti		Mtama		Kitanda		Pooled across sites	
	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12
Control	2119	2513	2837	2037	2836	2280	1326	3011	2280.00	2460.25
Urea alone	3276	4576	4067	3573	4001	5107	2613	3767	3489.25	4255.75
10 kg S/ha	5045	5411	5102	4550	5110	5300	3464	5201	4680.25	5365.55
20 kg S/ha	4668	4910	4725	4057	4778	5597	3407	4106	4394.50	4667.50
40 kg S/ha	5348	5191	6115	5133	5508	5223	3003	4091	4993.50	4909.50
LSD (0.05)	762.9	1180	2297	2388	1361	1048	1966	1349		
CV (%)	9.90	13.88	26.70	32.73	15.55	11.37	38.36	17.52		

Changes in soil pH

All N-sources fertilizers acidify soils. However, it is generally believed that, use of SA fertilizer hastily acidify soils than any other fertilizer. Results of monitoring of soil pH over the two seasons in the trial plots are presented in Table 4. There are no consistent pH changes, which suggest that applications of these small amounts of SA as source of S in maize production is not harmful as believed. This is supported by 8-year study on SA acidification in Mbinga district, which found continuous N-application as high as 150 kg N/kg from SA-source for over 5 years resulted into 1 unit pH drop (UAC, 1989/90). This rate is equivalent to applications of 700kg of SA/ha, which supplies 168 kg S/ha into the soil. To supply 11-12 kg S/ha from SA, 45-50kg of SA/ha is required to be blended with Urea for meeting both S and N nutritional requirements of current maize varieties recommended for Ruvuma region environment.

Table 4: Soil reaction (pH in water) over two years of study

Site	Treatment	Initial pH	pH after two seasons	Mean pH difference
Suluti	No fertilizer	5.77	5.77	0.00
	Urea only	5.77	5.70	-0.07
	10kg S N/ha	5.77	6.01	0.24
	20kg S N/ha	5.77	5.84	0.07
	40kg S N/ha	5.77	5.80	0.03
Kitanda	No fertilizer	5.49	5.49	0.00
	Urea only	5.49	5.60	0.11
	10kg S N/ha	5.49	5.70	0.21
	20kg S N/ha	5.49	5.57	0.08
	40kg S N/ha	5.49	5.63	0.14
Mtama	No fertilizer	5.76	5.76	0.00
	Urea only	5.76	5.73	-0.03
	10kg S N/ha	5.76	5.71 -0.05	
	20kg S N/ha	5.76	5.63	-0.13
	40kg S N/ha	5.76	5.84	0.08
Mletele	No fertilizer	5.89	5.89	0.00
	Urea only	5.89	5.85	-0.04
	10kg S N/ha	5.89	5.82	-0.07
	20kg S N/ha	5.89	5.88	-0.01
	40kg S N/ha	5.89	5.77	-0.12

Conclusion and recommendation

Maize grain yield increased substantially by external S applications from SA fertilizer as a source. Analysis established that a rate of 11 kg S/ha was optimum for maize production in soil of Ruvuma region. Application of S at this small rate is not deleterious to soil pH over two years and would earn farmer additional 1t/ha. We recommend farmers should use a blend of 45-50 kg of SA/ha with 125 kg of Urea/ha at first topdressing of maize in Ruvuma region.

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Drought mitigating technologies: lessons learnt from sorghum and cowpea production in semi-arid areas of Embu County, eastern Kenya

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Abstract

The lower parts of Embu County in eastern Kenya are characterised by poor harvest due to poor rainfall distribution, among other factors leading to declining poverty levels. Rainfed agricultural productivity has continually declined due to unpredictable and unreliable rainfall patterns. The decline in crop productivity has been as a result of inadequate understanding of intra-seasonal rainfall variability to develop optimal cropping calendar. A study was conducted to access the effect of various water harvesting and integrated soil fertility management technologies for enhanced sorghum (*Sorghum bicolor* L.) Moench) and cowpea (*Vigna unguiculata* L.) productivity in Mbeere South sub-County. The field experiment was laid out in Partially Balanced Incomplete Block Design (PBIBD) with 36 treatments replicated three times. The treatments of tied-ridges and contour furrows under sorghum alone and intercrop plus external soil amendment of 40 K kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1} had the highest grain yield of 3.1 t ha^{-1}. The soil fertility levels differed significantly from one another (p=0.0001) in terms of sorghum and cowpea grain yield. Generally, all experiment controls had the lowest grain yields as low as 0.3-0.5 t ha^{-1}. Therefore, integration of minimal organic and inorganic inputs under various water harvesting technologies could be considered as an alternative food security initiative towards climate change mitigation for Mbeere South sub-County, Embu County in eastern Kenya.

Key words: climate change, food security, soil amendments, Mbeere south sub-county, eastern Kenya.

Introduction

Agricultural productivity is constrined by climate change, declining soil fertility, degradation of natural resources, inefficient markets, weak institutions and policies in semi-arid areas of Kenya. More than 13 million of the 38 million people live below the poverty line of less than one USD a day. Agriculture is the mainstay of the Kenyan economy contributing about 55% of the gross domestic production (GDP). The sector further provides 80% employment, accounting for 60% of the exports and 45% of the government revenue (Ragwa *et al.,* 1998). The Government of Kenya (GoK) has put in place the Agricultural Input Subsidy Program (AISP) to support farmers so that they can access inputs such as inorganic fertilisers. In its "Vision 2030", the government also spells out the desire to use agriculture as the vehicle to transform the country to industrialisation (CAADP, 2008). However, more than 80% of Kenya is classified as arid and semi-arid which is characterised by low and erratic rainfall, high evaporation rates and fragile soils that are unsuitable for sustainable rainfed agriculture (Miriti *et al.,* 2012; McCown and Jones, 1992). Rainfed productivity has continually declined due to unpredictable and unreliable rainfall patterns in Embu County. The decline in food productivity has been as a result of inadequate understanding of intra-seasonal rainfall variability to develop optimal cropping calendar. Understanding spatio-temporal rainfall patterns rainfall has been directly implicated to combating poverty and hunger through agricultural enhancement

(IPPC, 2007). The amount of soil-water available to crops depends on rainfall onset, length and cessation which influence the successfulness or failure of a crop. This is particularly important in sub-Sahara Africa (SSA) where agricultural productivity is principally rainfed yet highly variable (Jury, 2002).

The drier parts of Mbeere sub-County of Embu in Kenya experiences elevated rainfall variations, persistent dry spells, prolonged droughts and high annual potential evapotranspiration (2000-2300 mm year^{-1}) (Micheni *et al.,* 2004). There is generally enough water on the total. However, it is poorly distributed over time (Kimani *et al*., 2003) with 25% of the annual rain often falling within rainstorms, that crops suffer from water stress, often leading to crop failure (Meehl *et al*., 2007). Quite often, analyses on rainfall patterns have been based on annual averages, thus missing on characteristics of seasonal variations (Barron *et al.,* 2003). Sivakumar *et al.* (1993) reported that understanding the average amount of rain per day is essential in assessing inter- and intra-seasonal variability. Evaluating mean duration between successive rain events also aids in understanding these variability (Akponikpè *et al.,* 2008). Recha *et al.* (2011) noted that most studies do not provide information on the much-needed character of within-season variability despite its implication on soil-water distribution and productivity. There has been interest in understanding seasonal rainfall patterns by evaluation of its variables including rainfall amount, rainy days, lengths of growing seasons and even dry-spell frequencies. Studies done by Tilahun (2006) noted high variations in annual and seasonal rainfall totals and rainy days in Ethiopia and Sudano-Sahelian regions. Mugalavai *et al.* (2008) analysed onset and cessation of rainfall in Kenya and linked their variation to atmospheric, oceanic and local geographic conditions. Hitherto, the much-needed information on inter- and intra-seasonal variability of rainfall in Embu County is still inadequate despite its critical implication on soil-water distribution, water use efficiency (WUE), nutrient use efficiency (NUE) and crop yield. Recent studies have yielded little evidence on occurrence of dry spells to increase the frequency of rain water use efficiency in semi-arid areas of Africa (Stroosnijder, 2009). This has been contributed by mixed crop-livestock systems being projected to see reduction in crop production as a result of drought throughout most East Africa regions due to climate change by 2050 (Thornton *et al*., 2010)

The challenge now remains on how to maximise any drop of rain water which falls on the ground to increase agricultural production in semi-arid areas of Embu County. The low crop production in central Kenya is also often associated with lack of appropriate farming practices that are suited to the fragile ecosystems (Bationo *et al*., 2004; Mbogoh, 2000). Most of the smallholder farms are characterised by nutrient mining as a result of crop harvest and residue removal (Mugendi *et al*., 2003; Bielders *et al*., 2002) as well as lack of resources to invest in mineral fertilisers or very little nutrient replenishment is practiced (Mugendi *et al*., 2010). The recommendation of African Fertiliser Summit (2006) '*to increase the fertiliser use from the current 8 to 50 kg ha^{-1} nutrient by 2015*' reinforces the role of fertiliser as a key entry point for increased crop productivity and attaining food security and rural well being in SSA. Alternatively most farmers cannot afford to buy inorganic fertilisers due to their high prices (Sanginga *et al.,* 2009; Crew and People, 2004). Many agricultural systems revolve around inorganic fertiliser use rates and concentration of nutrients in manure. Inorganic fertilisers and high quality manure are often expensive for most smallholder farmers. Due to these inappropriate farming systems, they lead to land degradation as a result of soil erosion and soil fertility decline in cultivated areas resulting to low crop yields (Njeru *et al.,* 2011a; Kimani *et al.,* 2007). The soil fertility decline is as a result of a combination of processes such as high rates of soil erosion, nutrient leaching, removal of crop residues, continuous cultivation of the land without adequate fertilisation and fallowing (Njeru *et al.,* 2011b; Okalebo *et al.,* 2006). The average annual loss in soils nutrients of 42 kg Nitrogen (N), 3 kg Phosphorus (P) and 29 kg Potassium (K) ha^{-1} in Kenya is among the highest in Africa (Smaling *et al.*, 1997). The rising cost of inputs has lead to many smallholder farmers reducing or abandoning the use of chemical fertiliser altogether (Gachimbi, 2002).

Therefore, food security situation is expected to continue deteriorating and could worsen in future if water harvesting and integrated soil fertility technologies are not taken up quickly in semi-arid areas of Embu County. Improving agricultural productivity is crucial for resolving food crises, enhancing food security and accelerating pro-poor growth. Yet, sorghum and cowpea are locally important for food and household nutrition, and provide income opportunities for the most vulnerable people and women in particular.

These premium crops have potential to diversify the farming systems, adapt to spread risks and are more resilient to climatic variations and climate change variability. This study assessed the effect of various water harvesting and integrated soil fertility management technologies for enhanced sorghum and cowpea productivity in Mbeere South sub-County.

Materials and methods

Site description

The study was conducted in Kiritiri Division (S0.91672 and 37.47680 N; S0.47330 37.91238 E at 800 m) in Mbeere South District which lies in the southeastern slopes of Mt. Kenya. It receives an average rainfall of 700-900 mm and has temperatures of 21.7-22.5^{o} C. The soil type is ferralsols. Besides differences in agroecological zones along the altitudinal gradient, agricultural systems differ from upper to lower zones. Kiritiri Division, Mbeere South District is generally a low potential dry zone. It is covered by three agroecological zones; the marginal cotton zone (LM4); the lower midland livestock-millet zone (LM5); and the lowland livestock millet zone (L5). The study was conducted in agroecological zone (LM4/5) during the 2012 long rains (Jaetzold *et al*., 2007).

Experimental design

The treatments were arranged in a factorial structure with each treatment being a combination of one of the three levels of water harvesting techniques (tied-idges, contour furrows and conventional tillage-farmers' practice), two levels of cropping systems (sole sorghum-Gadam, sorghum and cowpea (M66) intercrop and six levels of soil fertility amendment options (control, 40 kg P ha^{-1} + 40 kg N ha^{-1}, 40 Kg P ha^{-1} + 20 kg N ha^{-1}, 40 kg P ha^{-1} + 40 kg N ha^{-1} + manure 5 t ha^{-1}, 40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1} and manure 5 t ha^{-1} thus giving a total of 36 treatments. They were laid out in a Partially Balanced Incomplete Block Design (PBIBD) with six incomplete blocks per replicate each containing six treatments, replicated 3 times making a total of 108 plots. Treatments were assigned to blocks randomly with plot size of 6 × 4 m. The dryland sorghum (Gadam) and cowpea (M66) varieties were used as the test crops. Farmers were invited to evaluate each plot by scoring on a scale of good, fair and poor according to their own observation on crop performance and this was compared with scientific data collected on crop productivity at the end of the 2011 long rains. They were all given equal opportunity to evaluate 108 plots in the field experiment. They were also asked the kind of water harvesting and soil fertility management they used in their farms.

Data analysis

The difference between treatment scores and gender was significant ($P \leq 0.05$). The biophysical data on crop yield was analysed using statistical Analysis of Variance (ANOVA) using SAS version 8. Differences between treatment effects were declared significant ($P \leq 0.05$).

Field experiment results

The results (Table 1) underscore the scientific crop evaluation from the field experiment during the 2011 long rains.

Three types of water harvesting, two cropping system and six fertility amendment levels but only fertility levels that differed significantly from one another (p=0.0001) in sorghum grain yield (Table 1). The three levels of water harvesting and the two cropping systems did not differ significantly in grain yield among themselves (p=0.8513) and (p=0.7001), respectively. The total dry matter amount varied significantly among levels of cropping system and fertiliser application (p= 0.0111 and 0.0001), respectively. However the total dry matter amount did not vary significantly across water harvesting methods (p=0.5333). The sorghum biomass were significantly different among cropping system (p=0.0020) while water harvesting and fertility levels did not differ significantly (p=0.3820 and 0.0854).

Table 1: The effects of water harvesting, cropping system and soil fertility regimes on sorghum yields in Kiritiri Division

Water harvesting	Cropping system	Soil fertility management regimes	Total DM (t ha^{-1})	Biomass + husks (t ha^{-1})	Grain yield (t ha^{-1})
Tied-ridges	Sole crop	40 kg P ha^{-1} +20 kg N ha^{-1} + manure 2.5t ha^{-1}	6.1	3.0	3.1
Contour furrows	"	"	6.1	3.0	3.1
Tied-ridges	Intercrop	"	6.1	3.0	3.1
Contour furrows	"	"	6.1	3.0	3.1
Tied-ridges	"	40 kg P ha^{-1} + 20 kg N ha^{-1}	5.9	2.9	3.0
Contour furrows	"	Manure 5 t ha^{-1}	5.9	2.9	3.0
Tied-ridges	"	40 kg P ha^{-1}+40 kg N ha^{-1}+ manure 5 t ha^{-1}	5.9	2.9	3.0
"	"	40 kg P ha^{-1}+40 kg N ha^{-1}	5.8	2.8	3.0
Contour furrows	"	40 kg P ha^{-1}+40 kg N ha^{-1} + manure 5 t ha^{-1}	5.7	2.8	2.9
Tied-ridges	Intercrop	"	5.6	2.7	2.9
Contour furrows	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1}	5.6	2.7	2.9
"	"	40 kg P ha^{-1} + 20 kg N ha^{-1}	5.4	2.6	2.8
Tied-ridges	Intercrop	"	5.4	2.6	2.8
Contour furrows	"	40 kg P ha^{-1}+40 kg N ha^{-1} + manure 5 t ha^{-1}	5.2	2.5	2.7
Tied-ridges	"	40 kg P ha^{-1}+40 kg N ha^{-1}	5.2	2.5	2.7
Contour furrows	"	"	5.1	2.5	2.6
"	"	40 kg P ha^{-1} + 20 kg N ha^{-1}	5.0	2.4	2.6
Tied-ridges	Sole crop	Manure 5 t ha^{-1}	4.9	2.4	2.5
Contour furrows	Intercrop	"	4.8	2.3	2.5
Tied-ridges	"	"	4.8	2.3	2.5
Farmers practice	"	40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5t ha^{-1}	4.6	2.2	2.4
"	Sole crop	40 kg P ha^{-1}+20 kg N ha^{-1}	4.6	2.2	2.4
"	"	40 kg P ha^{-1}+40 Kg N ha^{-1}	4.5	2.2	2.3
"	"	40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1}	4.4	2.1	2.3
"	Intercrop	40 kg P ha^{-1} + 40 Kg N ha^{-1}	4.3	2.1	2.2
"	"	40 kg P ha^{-1} + 20 kg N ha^{-1}	4.2	2.0	2.2

“	Sole crop	40 kg P ha^{-1} + 40 kg N ha^{-1} + manure 5 t ha^{-1}	4.1	1.9	2.2
“	Intercrop	”	3.9	1.8	2.1
“	“	Manure 5 t ha^{-1}	3.9	1.8	2.1
“	Sole crop	“	3.7	1.7	2.0
Tied-ridges	“	Control	1.7	1.2	0.5
“	Intercrop	“	1.6	1.1	0.5
Contour furrows	Sole crop	“	1.5	1.1	0.4
“	Intercrop	“	1.4	1	0.4
Farmers practice	Sole crop	“	1.3	1	0.3
“	Intercrop	“	1.1	0.8	0.3
Means			4.5	2.2	2.3
CV			17	22.8	20.4
LSD			1.92	1.41	0.20

Combination effect

The results further indicated that sorghum without manure did not differ significantly in yield with treatments that did not receive fertiliser. However, plots that received fertiliser and no manure gave slightly higher sorghum yield than plots that received manure and no fertiliser (Table 1). The highest sorghum yield of 3.1 t ha^{-1} was from tied-ridges under sole sorghum and intercrop cropping system with external nutrient replenishment of 40 kg P ha^{-1} + 20 Kg N ha^{-1} + manure 2.5 t ha^{-1}. The top eight treatments yield did not differ significantly ($p<0.05$) from one another. The lowest sorghum yield of less than 2.0 t ha^{-1} was in the control with neither fertiliser nor manure regardless of other intervention (water harvesting methods or cropping systems). The total dry matter and biomass were highest in tied-ridges under sole cropping of soil fertility amendment of 40 kg P ha^{-1} +20 kg N ha^{-1} + manure 2.5 t ha^{-1} (6.1 t ha^{-1}) and (3.0 t ha^{-1}), respectively.

Discussion

Treatment performance

There is a consistency in the results (Table 1) on high grain yields, biomass and total dry matter at 3.1, 3.0 and 6.1 t ha^{-1}, respectively, in tied-ridges under sorghum alone with a minimum combination of organic and inorganic inputs at half dose application of N and manure. This was an indication that minimal nutrient replenishment was required in all the seasons. Studies by Mugendi *et al*. (2010) and Gachimbi (2002) have also reported that farms in central Kenya highlands require nutrient replenishment every season from manures, fertilisers and crop residue return in their farms. It has also been reported by Njeru *et al*. (2010, 2009) and Mairura *et al*. (2007) that soil fertility can also be be accessed through visual observation on crop performance and yield. The results (Table 1) further shown that water harvesting technologies and integrates soil fertility management technologies played a major role in moisture conservation and increased crop productivity. This is in agreement with what Miriti *et al*. (2012) and Mucheru-Muna *et al*. (2009) found that by incorporation of water harvesting and legumes on-farm the can enhance crop productivity in eastern Kenya. The results further shows that the third and the fourth treatments of tied-ridges and contour furrow under sorghum and cowpea intercrop with the same soil fertility management options were dominated by their sole cropping systems. This could be as a result of nutrient competition since cowpeas are heavy nutrient miners as they are associated with interspecific competition in mixed stands. The same results have been reported by Katsaruware *et al*. (2009) that crop

yield reduction can be experienced in intercrops where they are associated with interspecific competition in mixed stands and the absence of interspecific competition in the monocrops. The results further indicate that intercropping sorghum with cowpea depressed sorghum yields. This influenced farmers' decision on crop performance. This outcome for sorghum (Table 1) could be in line with reports for maize from Kenya (Nadar, 1984) and in Tanzania (Jensen *et al*., 2003) where maize grain yields reduction of 46-57% and 9% occurred when maize was intercropped with cowpea due to the competition for moisture between the two crops. Alternatively, due to slow mineralisation of manure which needed several seasons to meet the level of nutrient competition (Lekasi *et al*., 2003). The results by Miriti (2011) have also shown that cowpea was a nutrient competitor for maize production in semi-arid areas of eastern Kenya. This is in line with continuous cultivation of the same piece of land as this will lead to nutrient depletion and requires nutrient replenishment (Mugwe *et al*., 2009; Miriti *et al*., 2003). This has lead to land degradation contributing to reduced crop production as a result of failure of rainfall distribution in semi-arid areas of Kirinyaga West County. However, farmers are discouraged from adopting these water conservation structures because they are labour-intensive in and land tenure uncertainty (Demelash and Stahr, 2010). Therefore, land productivity can be improved by using appropriate agricultural technologies which suit these semi-arid areas of Mbeere south sub-County, eastern Kenya.

Conclusion

The results reported here demonstrate that there is need to incorporate water harvesting and integrated soil fertility management technologies in sorghum and cowpea productivity. This will also suggests that only low-input technologies are suitable and need to be adopted through a known crop intensification technologies that could be enhanced. The results have also demonstrated that there is need for nutrient replenishment on-farm every season to enhance sorghum and cowpea productivity. Therefore, integration of minimal organic and inorganic inputs under various water harvesting technologies could be considered as an alternative food security initiative towards climate change mitigation for Mbeere South sub-County, Embu County in Eastern Kenya.

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Impact of SO7 project on adoption of soil fertility management strategies in western Kenya

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Abstract

Increase in population and associated decrease in per capita land sizes has resulted in intensive cultivation of the available crop land. Intensive cultivation is therefore being practiced without adequately replacing nutrients taken up by crops and ultimately leading to degraded soils and low crop yield. Consequently, soil infertility remains the major biophysical root cause of low yields and food insecurity. In solving this problem, Strategic Objective Seven (SO7), a soil fertility improvement initiative was introduced by Kenya Agricultural Research Institute (KARI), in 2005 - 2008. The project was implemented in Kakamega North and Khwisero districts with the aim of improving soil fertility status and crop yield in the region. This necessitated the need for an impact study to assess the impact of the project. The study compared the farmer's situation before the project and four years after completion of the project. The two sites are also unique because scaling up of lime was later done Khwisero while the other site had no follow-ups. The specific objectives therefore were: to assess farmers adoption levels of the SO7 technologies and to determine the socio economic factors that influenced adoption. A total of 149 respondents were interviewed. SPSS software was used to analyze the data. Quantitative data was analyzed by use of logit model. Results indicate that farmers perceived that soil fertility status had improved (83%) from poor to average, while 77% of the respondents noted that maize yield had increased. Adoption levels varied. Forty six (46%) of the respondents had adopted lime with a higher percentage being from Kakamega North. Eighty five (85%) adopted farm yard manure, 87% green manure, 36% compost manure and 36% had adopted green manure with a higher percent of the adopters being from Khwisero. Household participation in the project and farmers belonging to a group significantly ($p < 0.05$) influenced farmer's adoption of the soil fertility management strategies. There was clear difference in adoption of the new technologies in the two sites. Adoption was higher where there was follow up after completion of the project. There is need to develop good exit strategy for improved adoption and sustainability of introduced technologies.

Key words: soil fertility, awareness, adoption, impact.

Introduction

Agriculture is the main stay of Kenyan economy. The long term economic development blueprint for Kenya "Vision 2030" identifies agriculture as one of the key sector to deliver a 10% annual economic growth (GOK 2007) Majority of households in of Sub-saharan Africa (SSA) Kenya included are small scale holders who live in rural areas and depend on agriculture as their major economic activity (World Bank, 2005). Due to increase in population, and associated increased demand for land by the predominantly rural populations, there has been a reduction in per capita land sizes which has resulted in intensive cultivation of the available crop land. In most cases this intensive cultivation has been practiced without adequately replacing nutrients taken up by crops and ultimately leading to degraded soils and low crop yield (Ojiem, 2006, Kiptot, 2008; Sanchez *et al*., 2009)). Consequently, soil infertility remains the major biophysical root cause of declining food availability on small holder farms due to reduced agricultural yields.

Research in western Kenya by Kenya Agricultural Research Institute (KARI) in collaboration with many other development agencies has demonstrated the potential of using improved technologies to improve soil fertility and address food insecurity (Odendo *et al*., 2012). Despite this potential, a few of the farmers have continued to use these improved technologies. Many communities go back to where they were after

the expiry of these projects, continuing a vicious cycle of research projects, which generate positive results and non-adopting farming communities over time.

To break this vicious cycle, Strategic Objective Seven (SO7) Soil Fertility Initiative was introduced by KARI. This project was undertaken in Kakamega North district and Khwisero districts, with the aim of improving soil fertility status and crop yield in the region. The project was implemented from 2005 to 2008.

At the initial implementation of SO7 project, it was noted that the yield of staple food crop maize was on decline in Western Kenya. These very low yields were attributed to factors such as low soil fertility, use of unimproved seed varieties, poor agronomic practices, striga weed and in desperate circumstances to witchcraft. However, a study conducted by KARI Kakamega through revealed that low soil fertility coupled with soil acidity were the main causes of low yields. It was demonstrated that when agricultural lime was added to the fields with multi nutrient fertilizers, the yields of maize drastically increased from less than 1MT to 4-6 MTh^{-1}. (Mbakaya *et al.,* 2004). As an outcome of these encouraging results, other development partners including the Alliance of Green Revolution in Africa (AGRA) came in with a view to scaling up the use of agricultural lime to other areas of western Kenya.

Though the SO7 project reported improved soil fertility and higher yields, the adoption levels and the driving factors to adoption of the introduced soil improvement strategies was not clear. The study therefore compared farmers' situation at the beginning of the project and four years after the project. The two sites are unique because one site is used in the scaling up of lime use while the other was left on its own with no follow-ups. The specific objectives were: a) To assess farmers adoption levels of the soil fertility improvement strategies. b) To determine the socioeconomic factors that influence adoption and c) To assess opportunities and challenges realized since the introduction of the project. The results of the study will give recommendations that would assist other similar studies in the region, and other areas with similar biophysical and socio-economic constraints.

Materials and methods

The study was conducted in Khwisero and Kakamega North Districts. The districts are in Western Province. Kakamega north is predominantly a sugarcane zone while in Khwisero is characterist by a subsistence oriented mixed crop–livestock system with major crops being maize intercropped with beans (Adolwa *et al*. (2008). Soils are depleted with over cultivation of sugarcane. The choice of the study district was because they had earlier received training on soil fertility management strategies by the SO7 project. Household data was collected using a semi structured questionnaire. A total of 149 respondents were interviewed. Data were collected on household characteristics, food security and soil fertility. It was analyzed by descriptive statistics using Statistical Package for Social Scientists (SPSS) computer software. Descriptive statistics such as percentages, frequencies, means and standard deviations were applied. Quantitative data was analyzed by use of logit model.

Results and discussion

Perception on soil fertility status and crop yield before and after the project

The research sought to find out farmers perception on the soil fertility and crop yield before and after the introduction of SO7 technologies. Most of the respondents noted that before SO7, the soil fertility was poor, 36% for Kakamega North and 47% for Khwisero. The soil fertility has then changed from poor to average (49%) and good (39%). The increase in soil fertility is more in Kakamega North than Khwisero. Crop yield has increased (77%) in the past five years, however, 16% of the farmers noted that crop yield had decreased in the recent years (Table 2). Majority of the farmers (77%) plant the hybrid maize varieties.

Table 1: Farmers perception of soil fertility status in Kakamega North and Khwisero Districts before and after SO7

Soil fertility Status	Before SO7 (%)			After SO7 (%)		
	Kakamega North	Khwisero	Total	Kakamega North	Khwisero	Total
Good	2	2	4	22	18	39
Average	11	2	13	23	26	49
Poor	36	47	83	3	7	12

Table 2: Crop yield trend in the past 5 years in Kakamega North and Khwisero districts

Status	District		Total (%)
	Kakamega north (%)	Khwisero (%)	
Decreased	6	10	16
Increased	38	38	77
No change	2	2	4
Not keen	3	0	3
Variety of maize planted	Improved – 77%; Local – 33%		

Lime adoption trend

Adoption trend determines the adoption level. Twenty two of the farmers had used lime in the years before including the long rains season of 2012 when the study was conducted. Those who had used before but not in long rains 2012 were 24% (Table 3). The reasons given for the preference to use lime include improve soil fertility (24%), fast impact (18%) and long residual effect (14). Few (12%) had stopped using lime while 47% had never used it.

Table 3: Lime adoption trends in Kakamega north and Khwisero districts

Status	District (N=149)		Total (%)
	Kakamega North (%)	Khwisero (%)	
Used before and in 2012long rains (Adopters)	14	2	22
Used before but not in long rains 2012 (Adopters)	21	3	24
Stopped using Lime (Non Adopters)	6	6	12
Never used	13	34	47

Though most farmers know about lime, usage is reducing. Eighty percent of those who stopped using lime are from Khwisero. Unavailability (80%) of the lime was noted as the major reason for stopping as illustrated in Figure 1.

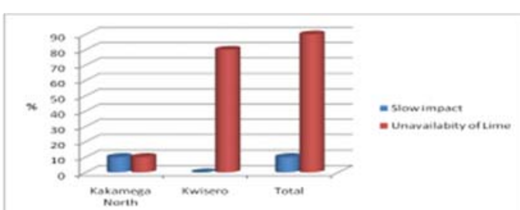

Figure 1: Reasons for stopping to use lime

Inorganic fertilizer adoption trend

Table 4 indicates that majority of the farmers (87%) have adopted the use of inorganic fertilizer. However farmers are not using the fertilizer according to the recommended rates. Some of the reasons given for the preference to use inorganic fertilizer include; ease to apply (49%) and fast impact (32%). Farmers are unaware that inorganic fertilizer adds value to the soil since none of the farmers noted that inorganic fertilizer improves soil fertility (Figure 2).

Table 4: Inorganic fertilizer adoption trend by farmers in Kakamega north and Khwisero districts

Use Status	District (%)		Total (%)
	Kakamega North	Khwisero	
Used before and in 2012 long rains	45	43	87
Used before but not in long rains 2012	4	5	10
Stopped using	0	1	1
Never used	0	1	1

n=149

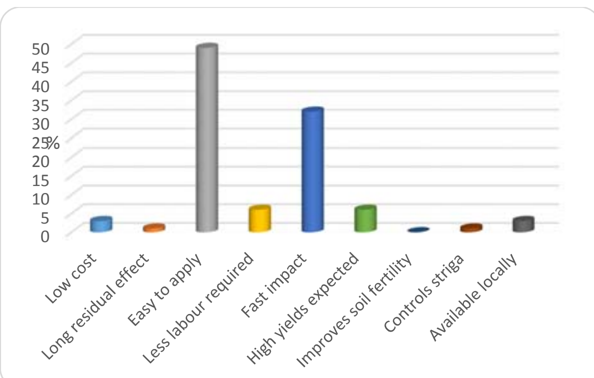

Figure 2: Reasons for preferring to use inorganic fertilizers

Green manure adoption trend

Farmers in Khwisero have adopted the use of green manure for soil fertility management more than those in Kakamega North as indicated in Table5. Figure 3 gives a summary of the reasons for preference to use green manure. These include low cost (54%) and improvement of soil fertility (11%). Though majority of the farmers have heard about green manure, the number of those who have never used green manure as a soil fertility measure is too high (48%).

Table 5: Green manure adoption trend in Kakamega north and Khwisero districts

Use Status	District (%)		Total (%)
	Kakamega North	Khwisero	
Used before and in 2012 LR	11	25	36
Used before but not in long rains 2012	4	9	12
Stopped using	0	4	4
Never used	33	15	48

n=147

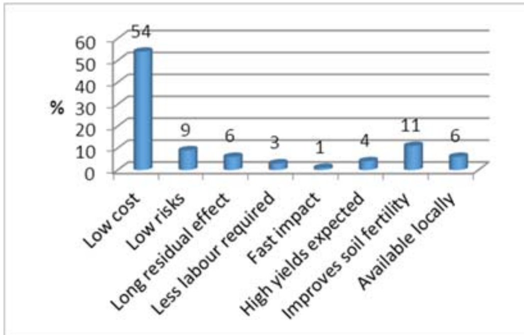

Figure 3: Reason for farmer's preference to use green manure

Compost manure adoption trend

The adoption of compost manure is low especially in Kakamega North as indicated in Table 6. The farmers prefer compost manure due to low cost incurred (34%), availability of the materials locally (19%) and the long residual effects it has on the farm (18%). However, the number of those who don't use compost is high (48%). Eight six percent of the farmers noted they lack technical knowledge on the use of compost manure.

Table 6: Compost manure adoption trend in Kakamega north and Khwisero districts

Use Status	District (%)		Total (%)
	Kakamega North	Khwisero	
Used before and in 2012 long rains	11	25	36
Used before but not in long rains 2012	4	9	12
Stopped using	0	4	4
Never used	33	15	48

n=149

Factors that influenced farmers adoption of the Soil improvement technologies

Farmers' awareness and adoption of any given technology is influenced by different socio economic aspects. These may include farm characteristics, farmer characteristics and in some cases farmer perceptions (Baltenweck *et al.,* 2006) Table 7 shows the socio economic factors that influenced adoption of different SO7 technologies. Adoption of lime was significantly ($P<0.05$) influenced by the farmers participation in the SO7 project and the district where one belongs. These could be associated by the up-scaling the use of lime in Kakamega North by the AGRA lime up scaling project. Farmer were exposed more on the use of lime. Participation in SO7 also significantly ($P<0.05$) influenced adoption of green manure. However, as opposed to lime adoption, Khwisero farmers adopted the use of green manure more than Kakamega North. Farmers who belong to a group were also more likely to adopt green manure more than those who did not belong to any group.

Table 7 : Factors that influence adoption of soil fertility improvement technologies

Independent Variables	Coefficient (B)	Sig.
Use Lime		
Sex of household head (0=Female 1=Male)	.005 (.596)	.993
District (1=Kakamega North 2=Khwisero)	-2.038 (.704)	.004**
Household participated in SO7 project (0=No 1=Yes)	2.916(1.08)	.007**
Visited any agricultural office (0=No 1=Yes)	.560(.582)	.336
Member of any group (1=yes 2=No)	-17.172 (9843)	.999
Use Compost		
District (1=Kakamega 2=Khwisero)	.466 (.369)	.207
	.356 (.380)	.349
Visited any agricultural office (0=No 1=Yes)	.227 (.412)	.581
Sex of household head (0=Female 1=Male)	-.067(.375)	.857
Use Green Manure		
District (1=Kakamega 2=Khwisero)	1.205 (.454)	.008**
Household participated in SO7 project (1=No 1=Yes)	1.323(.579)	.022**
Visited any agricultural office (0=No 1=Yes)	.154 (.109)	.741
Sex of household head (0=Female 1=Male)	.238 (.442)	.590
Belong to any group (1=Yes 2=No)	.272 ((124)	.028**
Use inorganic fertilizer		
Household participated in SO7 project (1=No 1=Yes)	-1.123 (.814)	.168
Visited any agricultural office (0=No 1=Yes)	.508 (.722)	.482
Sex of household head (0=Female 1=Male)	.596 (.637)	.349
Use Farm Yard Manure		
Visited any agricultural office (0=No 1=Yes)	1.073 (.678)	.114
District (1=Kakamega 2=Khwisero)	-.587(.519)	.259
Sex of household head (0=Female 1=Male)	.299 (505)	.553

Dependant variable = Use of any of the SO7 technologies (0=No 1=Yes); ** indicate significant at 5% level of probability

Impact of SO7 soil fertility improvement strategies in Khwisero and Kakamega north

Development of any given technology is intended to improve the livelihoods of a given community. The improvement starts at household level and broadens to the community and neighboring communities. Figures 4 shows that through increased yields the farmers have been able to pay school fees better (24%).. Other benefits include increased number of meals per day, improved soil fertility and bought livestock. The benefits have also extended to the community and neighboring communities. The village has generally improved its food security status. Neighboring community members are interested in joining their groups. The community has also become an icon. They receive a lot of visitors since the region has become a learning Centre (Figure 5).

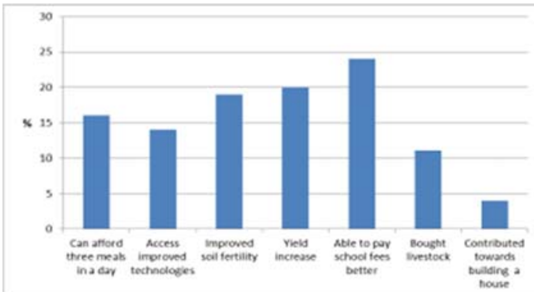

Figure 4: Impact to the household

Figure 5: Impact to the community

Conclusion and recommendation

The mean age of the studied household head was 51 years. Fifty four percent (54%) of the households were headed by men. Soil fertility status in Kakamega North and Khwisero has changed from poor (83%) to average (49%) and good (39%) in the studied regions. The farmers also noted that yields have increased. The use of lime was higher in Kakamega North (36%) than Khwisero (5%). On the other hand, use of green manure was higher in Khwisero (34%) than Kakamega North (15%). Continued use of lime in Kakamega North is associated with the AGRA lime up-scaling project that came in after the SO7 Project. A sustainable exit strategy for any given project is important to ensure continuity of the activities even after the exit of any given technology

Farmers' adoption of the SO7 technologies was greatly influenced by several socio economic factors. The district in which one belonged and household participation in SO7 influenced adoption of lime while adoption green manure was influenced by the district, household participation in SO7 project and farmers belonging to a group. Improved yields improves peoples livelihood both at household level and community level.

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Soil fertlity improvement using crop residues and azolla for sustainable production of rice and fish in irrigated rice-fish farming system in the Lake Victoria Basin

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Abstract

A balance, equitable and sustainable food supply to the rural farmer, local market and export can only be achieved, if potential resource productivity is addressed. An experiment was set up in Lake Victoria basin, West Kano Irrigation Scheme (WKIS) with the objective of increasing both water and land productivity through poly-culture of rice and fish cheap and readily available soil fertility. The treatments comprised of; Urea at 72 kg N/ha + fish (T1), Urea at 72 kg N/ha + 2 ton/ha azolla [*scientific name and authority*] incorporation + fish (T2), Urea at 48 kg N/ha + 2 ton/ha azolla incorporation + fish (T3), Urea at 72 kg N/ha + 3 ton/ha straw incorporation + fish (T4), Urea at 48 kg/ha + 3 ton/ha rice straw incorporation + Urea 48 kg N/ha + fish (T5), fish as the only input (T6), and a control (T7). A Completely Randomized Design (CRD) with four replications was used.. Results showed that application of nitrogen bio-fixer Azolla at 2 ton/ha + 72 kg N-urea/ha + fish and that of 72 kg N-urea /ha + fish resulted in a significant ($P<0.05$) increase in plant height compared to control. Application of nitrogen bio-fixer Azolla at 2 ton/ha + 72 kg N-urea/ha + fish also gave the highest grain yield. The two Azolla containing treatments did not differ significantly ($P\leq0.05$) from each other despite having different levels of commercial urea. Fish culture (fish droppings) applied a lone in paddy field significant ($P\leq 0.05$) increased irice grain yield. Fish alone (T6) gave the highest grain yield.

Key words*:* poly-culture, nitrogen fixation, immobilization, puddling, fish yield

Introduction

Fresh water fisheries account for almost all of annual national production and almost all fisheries production is derived from Lake Victoria. The Lake has the highest concentration of fishermen (mainly small-scale). In 2000, the total catch landed by approximately 33,037 fishermen using 10,014 vessels was 192,738 t valued at KES 7,468,968,000. The lake accounts for about 92% of the total fish production in the country (reference). A recent dispute in the fish-rich areas of Lake Victoria e.g. Mighingo deprives Kenya of its potential fisheries production. Lesson from Japan showed that problems of food supplies during the Second World War stimulated extensive fish culture in paddy -fields (Kuronuma, 1954). The Mighingo case, coupled with natural and artificial decay of fish, influenced by animals and human activities called for stimulation of off-lake culture of fish (Not clear repharase). Fish production from aquaculture in Africa is still insignificant at the global scale and according to the FAO 2004 and statistics from FISHSTAT (FAO, 2006a; FAO, 2006b), the continent contributed only 1% to the total world aquaculture production. Currently the dominant aquaculture production systems in Africa, particularly in sub-Sahara Africa (SSA) are earthen ponds. It is only during the global economic recession that the Government of Kenya (GoK) through economical stimulus package rolled out KES 1.12 billion programme funded by treasury targeting construction of 28,000 earthen ponds in 140 constituencies (GoK, 2010).This should be complemented by exploring other potential production systems such as paddy-fields.

Paddy-fields are potential fishponds since in its aquatic phase the rice field can produce a crop of fish. The use of rice fields to grow rice and raise fish concurrently or rotationally is one way of increasing productivity of paddy-fields. It is generally accepted that integrated rice- fish farming often increase rice yield and produce fish while using the same resource based of land, water, fertilizer, and labour. The accessibility of rice to the rural poor, and the fact that little extra capital investments are required to modify rice field for rice-fish culture, farmers' needs awareness on compensatory income gained despite losing

part of their rice-field to pond construction. Rice –fish farming is therefore relevant to agricultural development plan of increasing productivity, framer's income and improving nutrition of the rural population. Inorganic fertilizer required to increase rice productivity of small scale resource- poor farmer remain an expensive commodity.

In West Kano Irrigation Scheme (WKIS) low cost rice nutrient sources which included; rice straw, azolla, and fish in combination with high cost commercial urea-46%N fertilizer at two levels 48% N and 72% N are being used to ehance rice and fish productivity This project was based on the fact that capitalizes on rice-fish symbiosis where rice benefit from; urea-rich fish droppings, pest control and soil physical properties improvement and on the other hand fish benefit on physical protection and attraction of food-insect and that of Azolla [scientific name and authority] and blue-green algae Anabaena. The symbiosis is based on nitrogen fixation, the fern utilizing nitrogen from the algae and algae benefiting by mineral and physical protection from the fern. The potential of using azolla in rice cultures as a source of nitrogen is well documented and based on studies done mainly in china and other Asian countries (Lejeune *et al*., 1999). Rice straw though considered cheap nutrient source may be less beneficial depending on its quality and time of incorporation. Nitrogen is immobilized by microbes and often inhibits the growth and N uptake of paddy rice if C:N ratio is high beyond threshold values. Limited data is available of the potential mutual benefits of this integrated fish – paddy rice farming in Kenya.

Materials and methods

The on-farm experiment was carried out at West Kano Irrigation Scheme (WKIS) Kisumu County, Kenya. The farms are owned by small scale farmers who usually grow a crop of maize and legumes, besides having rice-fields within the irrigation scheme. The site lies between 00 6'S and 00 12'S latitude and 34 48' E and 34 57'E and at 1137 m. It receives average annual rainfall of about 1100 mm which is distributed as long rains from March to early June and short rains from September to December.

The six treatments experiment were laid out in a Completely Randomized Block Design (CRD) replicated four times. The treatments comprised of; Urea at 72 kg N/ha + fish (T1), Urea at 72 kg N/ha + 2 ton/ha azolla incorporation + fish (T2), Urea at 48 kg N/ha + 2 ton/ha azolla incorporation + fish (T3), Urea at 72 kg N/ha + 3 ton/ha straw incorporation + fish (T4), Urea at 48 kg/ha + 3 ton/ha rice straw incorporation + Urea 48 kg N/ha + fish (T5), fish as the only input (T6), and a control (T7).

Each plot measured 5 by 5m and had elevated dikes with base of 0.6 m, top width 0.4 m and height of 0.4 m having separate screened water inlets and outlets. The plots were physically modified to provide refuge for the fish by constructing peripheral trenches each with an area of 5 m^2 and a depth of 0.5 m.The plots were ploughed, flooded and paddling followed prior transplanting of rice. Rice straws and azolla green manure were incorporated to the soil 2 weeks to rice transplanting.

variety IR 2793 -80-1 rice seeds were germinated and seedling managed for 30 days. Rice seedlings were transplanted from the nursery to experimental plots at 35 days after seeding (DAS) and at spacing of 25 cm between the rows and 10cm within the rows, with 2 seedlings per hill. The seedlings were allowed to establish at a shallow water level of less than 5cm to allow anchoring and then raised to 25 cm on the day of fish stocking (DFS) 14 days after transplanting (DAT) at a rate of 6000 fingerlings per hectare. The average weight of the fingerlings at stocking was 15.4 ± 0.6 g. During the experiment the fish in the rice-fish culture received supplementary feeding of rice bran at 3% of body weight. The feeding was started 1day after stocking and was provided manually into two equal daily portions at 9.00 h and 15.00 h until 98 days after fish stocking. Nitrogen fertilizer Urea was applied manually, placed at 5 cm below soil surface in three parts to give the total prescription in each urea-containing treatments. This was according to Rao *et al*., (1971), who concluded that a transplanted rice crop needs half of the total quantities of N fertilizer at transplanting time then 25% about 3 weeks later and the balance at panicles initiation. During fertilization flooded field were drained and fish made refuge in trenches.

Water physical and chemical properties were monitored during the culture period to ensure fish growth was not inhibited (Table 1).

Table 1: Physical and chemical properties in the two rice cultures in West Kano Irrigation Scheme (WKIS)

Parameter	Rice-monoculture	Rice-fish culture
Depth of water	Minimum; above soil field capacity: Ideal; continuous flooding starting at 3 cm depth gradually increasing to maximum of 15cm 60 days after transplanting and complete draining 2 weeks to harvest.	15 cm at transplanting and 25 cm after stocking with fish
Water temperature	Water and soil temperature of up to 40 ºC with diurnal range less than 10 ºC	25-35 ºC with diurnal range of less than 10 ºC (6.5-9.0) (Boyd 1979)
Water pH Oxygen/dissolved oxygen (DO)	Neutral to Alkaline; Important during seedling stage for development of radicles	Neutral to Alkaline; Preferably near saturation or saturation level (5.0-7.5ppm) depending on temperature.

Rice performance was monitored in terms of plant height, productive tillers/m², straw yield, and grain yield, N in grain sink and N in straw all at harvest. Pre-cultivation and post harvest soil nutrient status was monitored by soil analysis for pH, total Carbon, total Nitrogen, and available OlsenP. Characterization of soils and N-rice tissues was performed using the following laboratory analyses; soil carbon was determined by Walkley and Black sulphuric acid-dichromate digestion followed by back titration with ferrous ammonium sulphate (Nelson and Sommer, 1982). Total N determined using Se, $LiSO_4$, H_2O_2 and conc. H_2SO_4 digestion (Anderson and Ingram, 1993) followed by colorimetric calibration. Soil pH was determined using a glass electrode pH meter at 1:2.5 soil: water ratio (Okalebo *et al*.,.2002).The available P was extracted by the Olsen method as described by Okalebo *et al*., (2002) . Rice grain, rice straw and fish fresh weights was determined using digital balance and extrapolated to yield/ha is conversion; Yield/ha = Plot yield* Hectare size/plot size

Results

Table 2 gives parameters of rice plant growth and Nitrogen assimilation as influenced by treatments. Urea at 72 kg N/ha + 2 ton/ha azolla incorporation + fish (T2) and Urea at 72 kg N/ha + fish (T1) resulted a significant ($P<0.05$) increase in plant height of 25.9% and 15.8%, respectively compared to control. Urea at 48 kg/ha + 3 ton/ha rice straw incorporation + Urea 48 kg N/ha + fish (T5) significantly gave 21% decrease on plant height compared to control. The remaining three treatments had no significant difference on plant height as compared to control. T1, T2 and T3 gave higher productive tillers/m² than the control while the other three were of the contrary. Highest grain yield was recorded in T2 yielding 4.160 ton/ha but this yield did not differ significantly to T3. T5 was significantly ($P<0.5$) different in yield compared to control. Nitrogen assimilated in rice grain sink differed significantly within all treatments and also when each treatment is compared to control. Nitrogen content in straws had the same trend as that in rice grain as influenced by the six treatments. Plant height indicated positive correlation with both grain-N and straw-N. Postharvest soil status data are presented in Table 3. Only treatments T1 and T2 had significant increase in pH compare to control but the former had the highest value 6.68. Organic input of either azolla or straw yielded significant increase in soil organic carbon as compared to control. Control (T7) had the least decline in available phosphorus when compared to all treatments. Combination of the two treatments with azolla had the higher residual nitrogen. Low postharvest soil Nitrogen status was registered in T1 despite having high input of commercial urea fertilizer (Table 4). Fish alone (T6) had significantly higher postharvest Nitrogen than the control. All the soil treatments except that of Urea at T3 had significant ($P=0.05$) lower fish yield than fish alone treatment (T6). Urea at T1 had the lowest fish yield. Comparing the two Urea levels at 72 kg N/ha and 48 kg N/ha, the higher dose of Urea had negative effect on yields of fish but to less extend on combination with Azolla.

Table 2: Mean effects of treatments on rice growth components and grain yield in West Kano Irrigation Scheme

Treatment	Height (cm)	Productive tillers m^2	Grain yield ton/ha	Grain-N kg/ha	Straw-N kg/ha
T1	104b	302f	3.670c	51.00b	20.900a
T2	133.2ª	308.5e	4.160a	53.30a	21.175a
T3	84.5c	235.7a	4.140a	44.18c	17.750c
T4	85.0c	219.5d	3.505d	32.80d	18.900b
T5	71.0d	194.5g	2.120e	23.25g	12.750d
T6	89.2c	230 c	3.980b	26.75f	12.925d
T7	89.75c	233.6b	3.070e	27.83e	13.050d
LSD (0.05)	5.533	2.13	0.0859	0.946	0.5575
SED	2.634	1.001	0.0409	0.450	0.2654

Values in the column followed by a common letter are significantly difference at ($p \leq 0.05$)

Table 3: Postharvest soil nutrient status after treatment application in West Kano Irrigation Scheme

Treatment	Soil pH	Soil Carbon (%)	OlsenP (mg/kg)	Soil Nitrogen (%)
T1	6.683a	2.397d	55.82c	0.158c
T2	6.115c	3.000	45.54b	0.345a
T3	6.145c	3.745c	47.86e	0.323a
T4	5.963b	3.990b	51.36d	0.251b
T5	6.328b	4.075a	51.00d	0.167c
T6	6.003d	2.412d	57.84b	0.179c
T7	5.988b	2.397d	59.63a	0.104d
LSD (0.05)	0.1351	0.0504	0.851	0.0302
SED	0.0881	0.02399	0.405	0.0143

Values in the column followed by a common letter are significantly difference at ($p \leq 0.05$)

Table 4: Yield of fish as affected by other paddy-field nutrient input in West Kano Irrigation Scheme

Treatments	Fish yield (kg/ha)
T1	104.0d
T2	114.7c
T3	131.0a
T4	108.3cd
T5	121.0b
T6	134.7a
LSD (0.05)	7.80

Values in the column followed by a common letter are significantly difference at ($p \leq 0.05$)

Discussion

Plant height may be determined by the genetic constitution of the cultivar. Additionally plant height may be influenced by external factors, including status of soil fertility. The later is testified by the experiment results in which higher application of Nitrogen resulted to taller rice crop than in low or no Nitrogen application. A combination of azolla, urea and fish resulted higher grain yields even at low N-rates of

commercial urea this was evident when the results showed no significant difference (P≤.05) between two urea rates N at 48 kg/ha and at 72 kg/ha in two treatment combination T2 and T3.The findings concur with those of (Watanable, 1981; Ladha *et al.,* 1992), incorporation of two crops of azolla led to rice yield increase by about 20-42% accompanied by improvement of soil structure. The yield increase is due to decomposition of the incorporated azolla releasing nitrogen for the rice crop (Liu, 1979). Bohlool *et al*. (1992) showed that azolla fixes N which is made available to rice upon death and decay. According to IRRI (1990), a combined rice –Azolla-fish culture protects the environment and increases the farmer's income through fish production and reduces fertilizers and pesticides.

Yields of the treatments combination (T4 and T5) with straw incorporation were lower; this is attributed to immobilization of nitrogen by soil microbe. This had been noted by Bird *et al.,* (2001); that immobilization of fertilizer nitrogen and crop residue N is one of the most critical aspects affecting long-term fertility in rice. They also showed that increased retention of N in the residue incorporated plots contribute to increased plant N availability in the second crop cycle in a fertilizer ^{15}N study. Although the low N organic compounds will release ammonium ions, they decompose slowly under anaerobic conditions, so only substances with higher N percentages will release appreciable amounts of ammonium over a period of few weeks (Russell, 1989).

The significant (P≤0.05) higher rice grain yield in treatment with fish alone compare to control can be explainedby improved nutrient availability resulting from the excrements produced by fish as well as aeration of the growth medium as the fish move around. Fertilizer requirement is reduced with the introduction of fish (Gupta *et al*, 1998) and a rice field has a higher capacity to produce and capture nitrogen than one without fish. Assimilation of nitrogen in grain and straw is dependent on the N-sources applied to the soils. The nutrient replenishing idea can be explained taking reference to control in which during the experimental season 40.88Kg N was siphoned out without addition of nitrogen. Long term fertility trail in tropical and temperate region have shown that about 50 kg N/ha is absorbed by each rice grown without addition of fertilizer (Koyama and App, 1979). Singh showed that 32-52 kg N/ha was absorbed by the rice crop in the field without N application. This is a range within which the experiment results fits. Considering that on average fish input for each treatment was about 90 kg (15 g × 6000 fingerling/ha), there was a net gain in fish weights in all treatments at time of harvesting (98 DAS). The gains seem to have been influenced by environment, food supply or both. Addition of ammonia to the soil is always accompanied increase in soil pH. Hydrolysis of ammonia liberate OH- ions responsible for increase in soil reaction, this explain the value in treatment T1. Treatments with OMs straw or azolla exhibited a buffering effect and there was no significant difference at (P ≤0.05) when compared to control, mainly due weak organic acid produced under anaerobic decomposition which tend to counter the increase in soil pH. Urea rich fish droppings was confirmed by significant (P≤0.05) increase in soil pH in treatment T6 fish alone compare to control, due urea dissociation followed ammonium formation with hydroxyl ion liberation. OMs inputs addition to soil increased soil carbon was confirmed by significant increase in soil total carbon in treatment T2, T3, T4 and T5 compare to control. Significant (P≤0.05) higher post-harvest Olsen P in control explains importance of synergic effect of soil N on uptake of phosphorus i.e. increase in available N and its higher subsequent uptake phosphorus increases uptake, and vice versa is true. This means absence of nitrogen input in control resulted low available nitrogen to boost phosphorus uptake.

Conclusion

Rice-Azolla- fish culture exhibits high potential in increasing resource productivity and environmental conservation. Azolla a cheap nitrogen source, on application showed improvement of soil nutrient status and rice yield. Straw application was accompanied by poor yields, due to N immobilization by microbes to decompose the carbon-rich material. There is need to culture fish under low nitrogen beyond rice harvest time 98 days after transplanting (DAT) probably for two season to achieve appreciable fish sizes by local who are used huge-sized from the Lake.

Recommendations

Rice-Azolla-fish team backed by a strong background of three season experiments recommends rice-fish culture with application of 2ton /Ha Azolla + 48 Kg N /Ha as the most economical practice for sustainable production of rice –fish poly-culture. It also recommends extension of fish culture beyond that of rice (during the fallow or ratoon period) to attain higher yields of fish.

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Farm stratification for targeting soil fertility management options in smallholder farms in central Kenya

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Abstract

Quantification of nutrient balances under integrated soil fertility management practices is important in ensuring sustainable crop yields in sub-Sahara Africa. A study, involving Participatory Learning and Action Research and nutrient monitoring, was carried out in central Kenya. A multidisciplinary team of scientists, extension agents and farmers conducted the exercise. The study was carried out to complement the Kenya National Agricultural Livestock and Extension Program focal area approach, involving about 300 farmers in each district. Farms were stratified on the basis of soil fertility management and resource endowment into three farm typologies. The typologies were classified as good, medium and poor. Stratification was also done within individual farms at three levels of good, medium and poor soil fertility management patches. Soils were sampled in the patches of the various classified farms after which wet chemistry was run. The farm typologies differed significantly (P = 0.05) in soil fertility levels. In Kiambu significant differnces were observed in soil nutrient content across the farm typologies and also in soil fertility patches within the same soil fertility management class. Nutrient monitoring carried out across the farm typologies for two cropping seasons showed negative nutrient balances.

Key words: soil fertility classes, nutrient balances, nutrient mining.

Introduction

Declining soil fertility resulting from continuous cropping without adequate nutrient replenishment is a major concern in mixed farming systems of the central highlands of Kenya. Continuous cultivation in these areas without requisite management has resulted in accelerated soil erosion, depletion of the soil nutrient reserves and a decline in the soil physical and chemical characteristics (Kilewe and Thomas, 1992; Gachene, 1989; Mahaney, 1979; Mwonga and Mochoge, 1989). The depletion of some soil nutrients, especially nitrogen (N), is particularly high in the densely populated Kenya highlands (Smaling, 1993; Smaling *et al*., 1993; Stoorvogel *et al*., 1993). The declining productive capacity of the soil is demonstrated by the yield decline in experimental and farmers' fields over time. An analysis of a long-term experiment in the highlands of central Kenya showed a decline in maize yield from three to one tonne per hectare for 20 years of continuous cropping (Swift *et al*., 1994). Variable organic inputs at the farm level have been used to mitigate this decline in soil fertility (Vanlauwe and Sanginga, 2004). The factors influencing the level of soil nutrient depletion are many and complex, including nutrient management, regeneration and plant protection, livestock integration, soil and water conservation, biodiversity management, agricultural policies and marketing structures. Nutrient depletion is the result of a net imbalance, between incoming and outgoing nutrients in farm inputs and outputs. Causes are high crop yields in most cases accompanied by inadequate, untimely or inefficient application of manure or fertiliser, farm management practices, leading to high levels of losses such as leaching and erosion, and inefficient recycling of existing nutrients on the farm and decreasing fallow rates (de Jager *et al*., 1998). Farmers are primarily concerned about the short-term crop and animal production, for present and possibly the forthcoming season. Long-term processes that adversely affect sustainability, such as decrease of soil nutrient stocks, are less conceptualised and may therefore, receive a lower priority at farm level. Importantly, however, soil fertility management takes place at farm level and at the level of farm activities such as crop and livestock activities,

since decisions are taken by individual farm households or by groups of households at community level. Decision concerning soil fertility management, are determined by the household objectives on the one hand and the available resources and the socioeconomic environment on the other hand (Van den Bosch *et al*., 1998). The sustainability of a farming system can then be estimated through calculating nutrient balances and relating the costs of replacement to the net farm income. This study sought to understand soil fertility status and capture nutrient flows in farming systems in central Kenya. While studies on nutrient balances are common in Kenya, there is very limited consideration of variability within an ecosystem. This study therefore went a step further to capture variability across farms (catchment level) and within individual patches of the same farm. Documentation of such variability will lead to better understanding of management options that need to be effected, in order to stem the decline in soil fertility. This in turn would lead to increased agricultural productivity and better livelihoods for smallholders.

The objectives of this study were to

- To stratify farm typologies based on farmers' perception of soil fertility management, and soil chemical analysis
- To monitor nutrient flows within the farm typologies using nutrient monitoring package
- To determine nutrient balances under different crops within an individual farm

Methodology

Study sites

The study was carried out in Kirinyaga central Kenya. District Kirinyaga District occupies 1437 km². Mukanduini village (S′ 0°34.68′ E′ 37°16.22′) where the study was carried out is in Kerugoya Division at an altitude of 1303 m. The soils are Humic Nitisols. Eighty percent of the district is arable. It has about 97,970 farm families occupying about 96,938 farm holdings with an average farm size of 1.25 ha. per family. Main agroecological zones include UH0, LH1, UM and LM3 while main enterprises include maize-bean, tomatoes, French beans and bananas production. Mukanduini village is in UM2 AEZ, (Jaetzold *et al*., 2006) which is a marginal zone characterised by coffee, maize-bean, tomatoes and bananas production.

Participatory learning and action research

A multidisciplinary team of scientists from the Kenya Agricultural Research Institute (KARI) and extension agents from the Ministry of Agriculture (MoA) conducted a participatory learning and action research (PLAR) in Kirinyaga District of central Kenya with National Agricultural Livestock and Extension Program (NALEP) focal areas. One NALEP focal area covers a minimum of 300 farmers. The facilitators held discussions with 20-30 farmers in each focal area, who were representatives of about 300 farmers in each focal area. The discussions in each focal area took three to four days. The first day was for a team building. During this exercise, tools such as introductory village meetings, village (focal area) maps, transects, organisation diagrams, wealth ranking, soil fertility management diversity and farm classification, resource flow models and closing village meetings were reviewed according to methods described by Defoer *et al*. (2000). The team facilitators were divided into five sub-groups, mainly socioeconomics, crops, livestock, land use, soils and agroforestry. One of the days was devoted to learning about resource flow maps. The facilitators held group discussions followed by plenary sessions to share the findings. Farmers determined the criteria to be used in ranking the households in soil fertility management. Three categories or classes were determined comprising of good (class I), average (class II) and poor (class III) soil fertility management. The farmers classified all the households within the focal area according to the above categories. Among the classified farms, ten were selected to represent the group for soil fertility management. The classified farms were further stratified according to crop performance and fertility perceptions of particular portions in the farms. Based on crop performance, patches were classified as good soil fertility patch (SFP), medium SFP and poor SFP. Topsoil samples (0-20 cm) were taken from each farm and analysed in laboratory according to methods described by Okalebo *et al*. (2002).

Nutrient monitoring

After PLAR was carried out, nutrient monitoring (NUTMON) studies were introduced to the farmers through individual farm visits. In each class, two farmers were selected for NUTMON questionnaire administration. The farmers were visited in their farms during cropping season for two cropping seasons. During the visits which involved systematic discussions, farm plans were drawn and soil fertility gradient and cropping pattern in the farms observed. Within the farm, sections with different characteristics based on slope, crop performance, soil colour or presence of stones or sandy areas was marked as farm section units (FSU). Portions in the farm occupied by different crops such as coffee (*Coffea canephora*) sole crop or intercropped with maize (*Zea mays*) or beans (*Phaseolus vulgaris*), maize-bean intercrop or maize sole crop were marked as primary production units (PPU). The types and number of livestock, owned, whether confined or grazed was captured as secondary production unit (SPU). The demographic household structure was also captured, as the number of people living together and sharing food, the age and academic level. Nutrient flows were quantified in different ways. Flows directly related to farm management were quantified by asking the farmers on inputs to and outputs from the different compartments in their farm on monthly or a cropping season basis. Flows quantified this way were the use of mineral fertilisers (IN1), organic inputs (IN2), farm products (OUT1) and removal of crop residues (OUT2). Soil nutrient level, soil physical characteristics and percent nutrient level in farm products was analysed in the laboratory, climatic characteristics obtained from the nearest Ministry of Water weather stations and crop classification like C-factor obtained from the literature. The NUTMON questionnaire findings were entered into the NUTMON data entry model and analysed using the NUTMON data processing model.

Results

Findings of the Participatory learning and action research

During the PLAR exercise, the farmers identified some factors which were perceived as indicators of declining soil fertility. These included low and declining crop yields over time (from 25 bags of maize to three bags per hectare). Poor performance of certain crops such as citrus, pigeon pea (*Cajanus cajan*), bananas (*Musa* (genus)., arrowroots and pumpkins (*Cucurbita pepo*) over time, and dominance of some weed species in spots of the farm. Other indicators included low crop yields and change in soil colour (from dark colour when soils are fertile to reddish as they become infertile) were also cited by farmers. Other observations associated with low soil fertility included change in leaf colour of crops for example maize from green to yellowish and purplish during the crop growth period, an increased disease and pest incidences, as well as declining soil water holding capacity. The causes of soil fertility decline were listed as soil erosion, continuous cultivation, inadequate organic matter, improper crop rotation practices, poor tillage practices, use of inappropriate fertilisers, and poor organic matter management. These results were ranked by farmers and are shown in Table 1.

Table 1: Pair-wise ranking of causes of overall decline in soil fertility

Causes of fertility decline	SE	CC	IOM	ICRP	PTP	UIF	POM	Score	Rank
Soil Erosion (SE)		SE	SE	SE	SE	SE	SE	6	1
Continuous Cultivation (CC)			CC	CC	PTP	UIF	CC	3	4
In-adequate Organic Matter (IOM)				ICRP	PTP	UIF	POM	0	7
Improper crop rotation practices (ICRP)					ICRP	UIF	POM	2	5
Poor Tillage Practices (PTP)						UIF	POM	2	6
Use of In-appropriate Fertiliser (UIF)							POM	4	3
Poor Organic Matter Management (POM)								4	2

According to the classification by the PLAR exercise, class I farmers used manure and mineral fertilisers, construct soil conservation structures and performed deep tillage. Class II farmers used fertilisers and

mineral fertilisers but at a lower rate than the class I farmers and had less elaborate soil conservation structures thanthose in class I. Class III farmers applied manure at very low rates with little-to-very little mineral fertiliser and had poorly maintained soil conservation structures. The differences in soil nutrient levels among the Classes were associated with the farmers' resource endowment levels. Class I were seen as more resource endowed than those in Class I according to the classification. This is in agreement with similar studies done in western Kenya (Tittonell *et al.,* 2005).

The participatory studies identified the soil fertility management problems and ranked them (Table 1). This made it easy to target soil fertility problems facing the farmers in the villages. The soil analysis showed a close relationship between the farmers' observations and interpretations (according to how they classified the farms into different classes) that is the farmers' perception on soil fertility and the chemical laboratory analysis results. At Mukanduini village, Kirinyaga district, N (%) levels in soils were low in all the Classes (0.05-0.12% N), the coefficient of variation of N (%) levels in the soils was about 36%, showing a moderate variation of N (%) content in soils among classes (Table 1). Potassium levels in the soils were generally high (> 300 ppm K) in all the classes and showed a higher variation among the classes. Carbon (%) content in soils in Classes I and II was moderate (1.5-3.0% C) but low in Class I farms (0.5-1.5% C), though the variation from class to class was low (16.2%). There were no significant (P = 0.05) differences in pH level, K, CEC contents in the soils between the classes. NNitrogen (%), ppm P and content (%) in the soils differed significantly (P = 0.05) between Classes I and III and between Classes II and III but the nutrients had no significant differences between Classes I and II.

It is a common phenomenon in smallholder Kenyan agroecosystems to find variability within the same farm. In this study there were portions/patches within the same farm which were lower in fertility /crop yields than others as reported by Giller *et al*. (2005) and Tittonel *et al*. (2005) on work done in western Kenya. The soil analyses results for these patches in Mukanduini (Table 3) show that there were no significant (P=0.05) differences in soil in nutrient content within patches of the same farm within the soil fertility management classes. The variation in N (%), ppm P and ppm K between good, medium and poor patches were high (48-62%) in Class I farms, but within the other classes a close variation was observed. Rather surprisingly, enormously high amounts of P were observed in Kirinyaga. This could be attributed to commercial farming mainly for tomatoes and French bean, which have higher returns on fertiliser inputs.

Table 2: Soil nutrient levels in soils in Classes within farm typologies in Mukanduini village, Kirinyaga District, central Kenya

SF Class	Farm nutrient levels					
	pH	N (%)	ppm P	Ppm K	C (%)	CEC cmol/100g
Class I	5.60	0.10	441.23	410.45	1.59	7.21
Class II	5.75	0.07	632.67	384.62	1.52	7.95
Class III	5.78	0.09	649.83	428.52	1.39	6.82
Mean	5.72	0.09	582.10	409.93	1.49	7.28
Cv %	7.17	35.68	24.84	45.49	16.21	19.61
r^2	0.04	0.12	0.31	0.01	0.12	0.11
Rating						
High		>0.25	>40	175-300	>3.0	
Moderate		0.12-0.25	20-40	50-175	1.5-3.0	
Low		0.05-0.12	10-20	50-100	0.5-1.5	
Very low		<0.05	<10	<50	<0.5	

Variability within and among farms

There was a narrow variation (6-19.99) in soil nutrient levels of pH, N (%), P, C and CEC but the level of K in the soil varied widely in Class II farms in good, medium and poor patches of the same farm. A similar

variation in soil nutrient content was observed in Class III but N (%) and ppm K showed a wide variation in nutrient content in good, medium and poor soil fertility patches in the same Class (Table 3).

Table 3: Soil fertility patches within soil fertility classes in Mukanduini village

SF Class	Farm patches nutrient levels						
	SF Patches	pH	N (%)	ppm P	ppm K	C (%)	CEC cmol/100g
Class I	Good	5.62	0.09	447.31	428.90	1.52	7.20
	Medium	5.71	0.11	400.87	384.63	1.48	6.41
	Poor	5.48	0.10	475.52	417.83	1.75	8.03
	Cv%	9.20	37.27	62.32	48.77	9.24	14.81
	SE	0.21	0.02	158.77	115.57	0.08	0.62
Class II	Good	5.91	0.09	681.52	528.52	1.67	8.81
	Medium	5.58	0.07	657.80	351.42	1.55	8.32
	Poor	5.77	0.06	558.67	273.93	1.36	6.73
	Cv%	6.11	19.99	10.09	40.08	9.43	19.12
	SE	0.20	0.01	36.85	89.01	0.08	0.88
Class III	Good	5.60	0.10	674.21	456.57	1.21	6.87
	Medium	6.04	0.09	596.75	480.35	1.58	7.36
	Poor	5.72	0.09	678.53	348.65	1.38	6.25
	Cv%	7.16	43.91	9.66	49.88	20.85	22.26
	SE	0.21	0.02	31.37	106.88	0.15	0.76

Findings by NUTMON

The nutrient balance is a mixture of primary data, estimates and assumptions. To make clear distinction between primary data and estimates and assumptions, two different balances were defined. The partial balance at farm level (IN1 + IN2-OUT1-OUT2) is made up solely of primary data and mainly reflects the 'way of farming' though there are background calculations, which cannot be directly quantified. OUT1 only reflects the farm products that leave the farm to external destinations for example what is sold to the market or to neighbours. Home consumed farm products are reflected by OUT6. The full balance defined as (IN1-IN4)-(OUT1-OUT6) is a combination of partial balance and the emissions (atmospheric deposition and N fixation) and emissions (leaching, gaseous losses erosion losses and human excreta) from and to the environment respectively (Table 6).

Nutrient balances

In Kirinyaga District, maize-bean mixtures, maize monocultures, coffee and tomato farming characterised most of the farms. A few farmers in Class I planted French beans both under irrigation and rainfed. They had extreme nutrient input and mining and could not represent the other farmers well.

In class I farm (Table 7), high levels of mineral fertiliser input (IN1) were observed, 80 kg N, 21 Kg P and 14 kg K. Harvest of crop products (OUT1) was the leading channel through which most of the nutrients were lost. About 75 kg, 7 kg and 18 kg of N, P, and K, respectively, was lost through crop harvest. This was more prevalent in coffee and tomato fields. Food consumption within the farm was the second channel through which nutrients were lost from the farm. Working nutrient balances (partial balances) were positive but full balances in kg ha^{-1} turned out to be negative, -2.1 for N and -4.1 for K.

Table 6 : Nutrient flows and descriptions for NUTMON

Nutrient flows	Description
IN1	Mineral fertiliser
IN2	Manure
IN3	Atmospheric deposition
IN4	Biological nitrogen fixation
OUT1	Harvested products
OUT2	Removal of crop residues
OUT3	Leaching
OUT4	gaseous losses
OUT5	Erosion
OUT6	Human excrement

Table 7: Nutrient flows and balances in three farm typologies in Mukanduini, Kirinyaga District

Nutrient flows	Class I			Class II			Class III		
	N	P	K	N	P	K	N	P	K
IN1	79.9	21.1	14.7	30.3	5.8	6.9	20.4	7.5	5.1
IN2	7.0	2.3	5.8	5.6	1.3	4.8	3.2	1.2	3.6
OUT1	74.7	6.9	18.3	27.6	2.3	15.1	50.9	7.1	25.1
OUT2	0.6	0.1	0.8	0.2	0.0	0.2	2.6	0.5	0.7
OUT3	3.3	0.0	4.3	4.6	0.0	5.7	0.0	0.0	0.0
OUT4	3.3	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0
OUT6	7.1	1.9	1.2	5.8	1.6	1.0	4.0	1.1	0.7
Full balance (kg ha^{-1})	-2.1	14.5	-4.1	-6.9	3.9	-10.3	-8.2	0.3	-17.8
Partial balance (kg)	11.6	16.4	1.4	8.1	4.7	-3.6	-29.9	1.1	-17.1

In Class II (Table 7), lower level of mineral fertiliser inputs were observed 30, 6 and 7 kg N, P and K respectively. Removal of nutrient through crop harvest reflected high nutrient mining compared to input (about 10 kg K was removed than was input). Other channels through which N was lost was leaching and gaseous losses covering up to 30% of N lost in both gaseous losses and leaching. Partial balances was positive for N and P but K was negative (-3.6), while full balances were negative for N and K. In Class III, very low mineral nutrient inputs were reflected (20, 7.5 and 5.1 kg ha^{-1} year^{-1}, N, P and K respectively). Nutrient mining through crop harvest exceeded nutrient inputs by more than 100% for N and K. Both

partial and full nutrient balances were negative in Class III farm, giving negative nutrient balances. A similar scenario was observed in western Kenya (Vitousek *et al.,* 2009).

Cropping pattern and nutrient balances in Mukanduini

Mukanduini village farms are characterised by well-designed primary production units in the farm, whereby a particular portion of the farm's main crop is coffee or maize-beans intercrops, or Napier grass. The largest primary production unit in Class I farms was occupied by maize-bean intercrop followed by coffee while the largest in class III was maize-bean intercrop. In Class I farm, maize monoculture, maize-bean intercrop occupied 0.07% and 36% of the cultivated land, while Coffee, tomato and Napier grass occupied 29, 14 and 0.07%, respectively (Table 8). Coffee fields received high amounts of mineral fertiliser at 69, 108 and 302 kg ha^{-1}, N, P and K, respectively; and organic fertilisers at 12.3, 4.3, and 12 kg ha^{-1}, N, P and K, respectively. Removal of nutrients through crop harvest (OUT1) was high, but nutrient inputs (IN1 and IN2) exceeded output, thus giving positive nutrient balance, both partial and full balances in coffee fields. Negative nutrient balances were recorded under Napier grass, maize, maize-beans fields. These fields received low mineral and organic nutrient inputs (4.2, 0.7 and 1.4 kg ha^{-1}, N, P and K, respectively, mineral fertilisers and 1.2, 0.2 and 0.8 kg ha^{-1}, N, P and K, respectively, organic nutrient inputs). The partial balances in the food crops were negative, indicating that the farming system was unsustainable. A similar study carried out in western Kenya recorded negative nutrient balances in food crops (Roy *et al.,* 2003); confirming that most of the farming systems were unsustainable due to more soil nutrients being removed than added.

Table 8: Nutrient mining level in major crops grown in a Class I farm in Mukanduini

			Nutrient balances					
			Full balance (kg ha^{-1} yr^{-1})			Partial balance (kg)		
Crops grown	Cultivated area (m^2)	Total yield (kg)	N	P	K	N	P	K
Maize, bean	5058	765	-37.2	-5.7	-21.6	-8.1	-1.0	-4.2
Sweetpotato	1012	70	-0.9	-0.2	-1.4	-0.1	0.0	-0.1
Tomato	2023	2650	-27.2	23.7	-53.4	-2.8	2.4	-5.4
Maize	1012	360	-52.0	-12.7	-14.5	-5.3	-1.3	-1.5
Coffee	4047	5870	8.6	6.1	2.8	3.5	1.5	2.7
Napier grass	1012	1200	-47.2	-5.0	-63.4	-4.8	-0.5	-6.4

In Class II farm, 12% of cultivated land was allocated to maize while and 63% was allocated to maize-bean intercrops (Table 9). Napier grass had 0.01% while coffee-maize fields had 12%. Very high negative nutrient balances (-393 N kg ha^{-1} yr^{-1}) and (–157.4 N kg ha^{-1} yr^{-1}) were observed under Napier grass and maize-bean intercrop, respectively. Napier grass fields rarely receive mineral nutrient inputs except occasional organic inputs while harvesting goes on throughout the year. Maize-bean fields received no mineral fertiliser inputs but received organic inputs, farmyard manure (0.9, 0.3 and 1.0 kg ha^{-1}, N, P and K, respectively) and in fields with maize-tomato received 0.4 kg N mineral fertilisers.

Table 9: Nutrient mining levels in major crops grown in a Class II farm, in Mukanduini

			Nutrient balances					
			Full balance (kg ha^{-1} yr^{-1})			Partial balance (kg)		
Crops grown	Cultivated area (m^2)	Total yield (kg)	N	P	K	N	P	K
Maize, beans	10118	538	-157.4	-13.0	-83.0	-17.8	-1.8	-9.5
Maize, tomato	1012	530	-23.9	-3.0	-17.0	-2.4	-0.3	-1.7
Irish potato	809	100	91.2	4.9	-24.8	7.4	0.4	-2.0
Coffee, maize	2023	1185	-8.6	12.7	23.3	-1.7	2.6	4.7

Napier grass	202	2000	-393.4	-41.8	-528.6	-8.0	-0.8	-10.7
Maize	2023	180	-13.0	-3.2	-3.6	-2.6	-0.6	-0.7

In Class III, 72% of the cultivated area was allocated to maize-bean intercrop and 25% to coffee (Table 10). Napier grass was not grown. In the primary production units, negative nutrient balances prevailed in both partial and full balances.

Table 10: Nutrient mining level in major crops grown in a Class III farm, in Mukanduini

			Nutrient balances					
			Full balance (kg $ha^{-1}yr^{-1}$)			Partial balance (kg)		
Crops grown	Cultivated area (m^2)	Total yield (kg)	N	P	K	N	P	K
Coffee, tomato	9105	3500	-8.9	2.7	-13.7	-8.1	2.5	-12.4
Maize, bean	26305	5190	-14.7	0.3	-7.4	-38.7	0.7	-19.4
Sweetpotato	1012	700	-8.0	-1.9	-12.2	-0.8	-0.2	-1.2

Discussion

Soil fertility sustainability is a major concern in the fragile agricultural ecosystems in central Kenya. In Kirinyaga District at Mukanduini village, there were low levels of soil N (%) content, pH and high extractable K values. Class I farms had high soil organic carbon while Classes II and III had moderate soil organic carbon. According to farmers' observations, the fertility varied within farms. However, there were no significant differences in soil nutrient contents among the three patches within a farm, though there was a wide variation (45.5%). This indicates that a blanket recommendation made for all the farms would not be desirable. Just as observed in other parts of Kenya (Roy *et al.*, 2003; de Jager, 2005; Tittonell *et al.*, 2005; Vitousek *et al.*, 2009), negative nutrient balances dominated the farming systems. A more targeted recommendation regime would result in better efficient resource allocation. In Kirinyaga, There was decreasing preference to napier grass growing from Class I to Class III farmers. This was associated with the fact that Class I owned two to three heads of cattle and Class III owned one or none, according to participatory learning and action research carried out in the area. In the longer term, soil fertility in these agroecosystems may not be unsustainable due to higher negative nutrient balances.

Conclusions

The PLAR exercise showed that farmers in central Kenya can use indigenous technical knowledge to identify indicators of soil fertility potential. In addition farmers were able to stratify the environment they live in with regard to soil fertility management. This in turn shows that using farmer knowledge, it is possible to target soil fertility efforts to address "hot spots" within a farming system. This has two implications that it is possible to target intervention measures to for instance through subsidies, to vulnerable areas, which would lead to improved livelihoods. The general soil fertility decline as shown through NUTMON studies confirm that soil fertility decline continues to be an insidious process, and is likely to remain so in the foreseeable future. This study however presents an opportunity to better target the decline, by considering the variability concept, and possibly the choice of crop.

The nutrient concentrations show that P levels in the study area are not limiting. This is possibly due to increased use of mineral fertiliser levels usually in combination with organic fertiliser. This has been driven

by the responsiveness of farmers in this area to the use of fertiliser, propelled by the market demand for horticultural crops. This suggests that a market driven agricultural production is possibly the way forward in addressing the problem of nutrient mining, and presents a window of opportunity towards general increase in productivity and general livelihoods in smallholder farms of central Kenya.

Recommendations

- Indigenous knowledge on soil fertility and soil fertility declined need to be supported scientifically and not overlooked
- Farmers understand their soils well and support is needed to enable them be more productive
- With proper soil fertility amendments, high crop yields can be achieved; and hence application of both organic and inorganic fertilisers should be encouraged

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Performance of soybean genotypes evaluated for yield and protein content in Nakuru County, Kenya

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Abstract

There are varying regional ecological conditions in Kenya and it's extremely important to select soybean cultivars for each environment. A study was established to identify soybean genotypes with high seed yield and protein content for Lanet region in Nakuru County. Fifteen soybean genotypes of varying maturity were used for the study. Analysis of variance indicated significant ($P \leq 0.01$) differences in yield, days to flowering, days to harvest maturity, number of pods plant $^{-1}$, number of nodes plant^{-1}, number of branches plant^{-1}, seed weight and protein content ($p \leq 0.05$) among the genotypes studied. Days to harvest maturity ranged from 145-193 days for genotype DPSB 19 and genotype DPSB 3, respectively. The mean number of pods plant^{-1} was 45.2 with genotype SBH 3/8/4/1 having the highest number of pods plant^{-1} of 54.3. One hundred seed weight was highest for genotype Gazelle (20 g) and lowest for DPSB 3 (11 g). The highest seed yield was observed on genotype Gazelle (2179 kg ha^{-1}) and this was not significantly different for 73% of the genotypes. Genotype DPSB 3 gave the least yield of 792.6 kg ha^{-1}. Protein content ranged from 40.5-35.9 for genotypes DPSB 3 and 931/5/34, respectively. Genotypes Gazelle, Nyala and EAI 3600 may be recommended for commercial production in Nakuru County.

Key words: soybean, protein content, adaptability, yield

Introduction

There are wide climatic conditions in Kenya that require specific soybean (*Glycine max* (L.) Merrill) genotypes for production. Soybean is an important legume oil seed crop accounting for 54% of global oil seed production (Ramana and Satyanarayana, 2006). The high interest in soybean is due to its high protein content of about 40% in the seed that is an important source of protein for human food and animal diet (Hungria *et al.*, 2006). Soybean farming is one of the most effective ways in which smallholder farmers can maintain soil fertility and yet reap higher incomes from succeeding crop (Osunde *et al.*, 2003). Popularity of soybean is expected to grow in the near future because of increasing need for food and fodder Mugendi *et al.*, (2010). Soybean is known for its high nitrogen fixation thus improving soil (N) content. Soybean improves soil fertility by fixing atmospheric nitrogen with some varieties fixing 44-103 kg N ha^{-1} annually (Sanginga *et al.*, 2003). Nodulation and nitrogen fixation in soybean occurs effectively if other elements such as Phosphorus, Potassium and Sulphur are present in the soil (Mugendi *et al.*, 2010). Soybean for the consumption market in Kenya was estimated to be 150,000 MT per year by 2014 (Jagwe and Nyapendi 2004). Adoption of soybean production in this region would improve cash incomes through direct seed sales, value addition, preparation of homemade feed rations for livestock and improvement of soil fertility through nitrogen fixation. Soybean is used for manufacture of foods and feeds, anti-corrosion agents, bio-fuels, disinfectants, pesticides, paints, adhesives, antibiotics and cosmetics among other industrial uses (Chianu *et al.*, 2008). The objective of the study was to identify genotypes high in seed yield and protein content suitable for the region that have potential to improve food security, alleviate poverty and improve soil fertility.

Materials and methods

The study was conducted at Lanet in Nakuru County. Lanet (0°18'S, 36° 09'E) is situated at an altitude of 1920 m above sea level. The rainfall is bimodal at an average of 800mm per annum. The temperatures are

cool at a minimum of 10°C and a maximum of 26°C (www.kalro.org). The site is situated in agro-ecological zone UM4. The soils are classified as ando-haplic phaozems. The soils are well drained, moderately deep to deep, friable, sandy clay loam to sandy clay with a humic top soil (Jaetzold *et al.,* 2010). Genotypes evaluated in this study were accessed from oil crops breeding programme at the food crops research Centre Njoro. Eight of the genotypes had been developed locally while seven had been acquired as introductions. Genotype EAI 3600, a medium maturing genotype was used as a check. Genotype DPSB 19 and DPSB 8 were dual purpose in that they were developed to give high seed yield and biomass. Genotype DPSB 3 and DPSB 19 are resistant to the Asian soybean rust disease (*Phakospora pachyrrhizi*). A randomized complete block design (RCBD) with three replicates was used for the experiment. Planting was done by hand in 3 × 2.7 m plots consisting of six rows with 45 cm row spacing at a seed rate of 75 kg ha^{-1}. Diamonium phosphate fertilizer was applied to supply 22 kg N ha^{-1} and 57.5 kg of P ha^{-1} at planting. Sencor® (metribuzin) a pre-emergent herbicide at the rate of 360g a.i ha^{-1} was used for weed control. During the crop growing season, foliar application of Folicur® (Tebuconazole) at 250g a.i ha^{-1} was done to control fungal diseases. Several traits were measured from each plot that included days to 50% flowering, plant height, days to harvest maturity, number of nodes $plant^{-1}$, number of pods $plant^{-1}$ and number of branches $plant^{-1}$. Days to 50 % flowering were determined when at least 50% of all plants in a plot had flowered. Plant height (cm) was measured on a sample of five plants from four centre rows of each plot as the distance from the ground to the apex of the extended plants. The number of branches $plant^{-1}$, nodes $plant^{-1}$ and pods $plant^{-1}$ were determined from a sample of five plants selected from four central rows of the plots. The mean seed count from twenty pods was observed as the number of seeds pod^{-1}. To calculate 100-seed weight, 100 seeds were counted using a seed counter and weighed. Seed yield was determined from seeds harvested from four central rows of each plot. Seed protein content was determined using Near Infra-Red Refractometer equipment (Infratec ™ 1241 Grain Analyzer ISW 3.20: Foss analytical AB, P.O box 70, SE-263221 Hoganas, Sweden). The data was subjected to analysis of variance for each characteristic. The statistical analysis systems (SAS) general linear model (GLM) procedure (SAS institute, 1999-2000 release 8.1) was used for analysis. Separation of means due to varieties was done using least significant difference (LSD).

Results

The analysis indicated significant ($P \leq 0.01$) differences in all traits studied (Table 1). Days to 50% flowering ranged from 70.3-95.0. Genotype DPSB 19 flowered earliest at 70.3 days while genotype DPSB 3 was latest at 95 days. Days to 50% flowering were not significantly different for SBH 10/5/6, SBH 1/12/19, SBH 7/1/1, SBH 6/6/6/2 and SBH 3/8/4/1 which took fewer days than the mean of 79. 2 days to flower. Days to harvest maturity followed the same trend with a range of 145.0-193.3 days for genotypes DPSB 19 and DPSB 3, respectively. Only 33% of the genotypes took longer than the mean of 165.9 days to mature. Genotype DPSB 8 had the highest number of nodes plant-^{1} and genotype SBH 6/6/6/2 had the least number of nodes $plant^{-1}$. Genotype DPSB 8 was the tallest with a plant height of 102.8 cm which was 42.1%.

above the trial plant height mean of 72.3 cm. Genotypes SBH 6/6/6/2, SBH 3/8/4/1, DPSB 3, SBH 10/2/3, SBH 4/6/6, 931/5/34 were not significantly different in height from Nyala which recorded the shortest height of 51.1 cm. Branching was more pronounced in genotype 931/5/34 which had a mean of 6.1 branches $plant^{-1}$ in comparison to SBH 7/1/1 which had the least number (3.5) of branches $plant^{-1}$. There was low diversity among the genotypes for the number of branches $plant^{-1}$ given that 67% of the genotypes were not significantly different in this trait. The trial mean number of branches plant was 5.1 (Table 2). The trial mean number of pods $plant^{-1}$ was 45.1 with the highest number (54.3) observed on genotype SBH 3/5/8/1. Genotype DPSB 3 which was the latest to flower and mature recorded the least number of pods $plant^{-1}$. Genotypes SBH 10/5/6, SBH 7/1/1, Gazelle, SBH 10 /2/3, SBH 4/6/6, Nyala, DPSB 8, DPSB 19, 931/5/34 and SBH 3/8/4/1 were not significantly different in the number of pods $plant^{-1}$. The weight of 100-seeds ranged from 11.0-20.0 g for genotypes DPSB 3 and Gazelle, respectively. Genotypes Gazelle, SBH 10/2/3, SBH 4/6/6, Nyala, EAI 3600 and 931/5/34 had 100-seed weight above the trial mean of 15.6 grams.

Table 1: Mean squares from analysis of variance for flowering, maturity, plant height, number of pods $plant^{-1}$, seeds pod^{-1}, branches $plant^{-1}$, nodes $plant^{-1}$, seed yield, 100 seed weight and protein content for soybean genotypes evaluated at Lanet in 2011

		d		cm		No.			Kg ha^{-1}	g	%
Source	d.f	50% flowering	Harvest maturity	Plant height	Pods $Plant^{-1}$	Seeds pod^{-1}	Branches $Plant^{-1}$	Nodes $plant^{-1}$	Seed Yield	100 seed wt	Protein content
Replicate	2	10.15	91.46	57.48	184.81	0.09	4.22	1.69	201356.68	3.8	26.80
Genotype	14	100.79**	582.71**	1085.61**	159.85**	0.11**	1.80**	27.58**	38159.72**	25.97**	6.91*
Error	28	2.72	67.87	40.23	61.48	0.03	0.62	1.64	71992.13	0.98	2.76
cv (%)		2.08	4.96	8.77	17.35	7.52	15.49	9.19	15.30	6.38	4.33
R^2		0.94	0.81	0.93	0.60	0.65	0.66	0.89	0.74	0.93	0.66

**Significant at $p \le 0.01$,* Significant at $p \le 0.05$

Table 2: Mean values of yield, agronomic traits and quality traits of fifteen soybean genotypes evaluated at Lanet in 2011

	d		cm		No.			kg ha^{-1}	g	%
Genotype	50% Flowering	Harvest Maturity	Plant height	Pod plant^{-1}	Seeds pod^{-1}	Branches plant^{-1}	Nodes plant^{-1}	Seed yield	100 seed weight	Protein
SBH 10/5/6	75d	162.0dc	94.9ab	39.6b-e	2.3a-d	4.8a-d	16.7a-c	1748.8a-c	14.7c	38.6a-d
SBH 1/12/19	75.7d	157.7d-f	98.1ab	46.8a-d	2.5a-d	4.6b-d	17.8ab	1932.1a-c	14.0c	36.9de
SBH 7/1/1	75.7d	173.3bc	96.1ab	45.3a-d	2.3c-e	3.5d	18.7a	1975.3a-c	14.3c	37.7a-e
Gazelle	82.0bc	165.7dc	78.2c	48.8a-c	2.0f	5.0a-c	15.1cd	2179.0a	20.0a	36.0e
SBH 4/4/4	75.0d	157.3d-f	89.3b	36.5c-e	2.5a-d	4.0cd	16.3bcd	1668.5bc	13.7cd	37.2b-e
SBH 10/2/3	79.7c	163.0dc	56.5ef	51.8ab	2.6ab	6.0a	11.1f	1804.9a-c	18.0b	40.0ab
SBH 4/6/6	79.3c	159.0de	61.0d-f	46.7a-d	2.6a	6.0a	11.1f	1933.9a-c	17.7b	39.8a-c
Nyala	81.3bc	166.0dc	51.1f	51.2ab	2.3b-e	5.2ab	12.0f	1992.6ab	19.7a	37.1c-e
EAI 3600	80.3c	162.7dc	66.0de	34.5de	2.5a-d	5.6ab	10.9f	2036.4ab	17.7b	38.0a-e
SBH 6/6/6/2	75.7d	165.0dc	54.9f	40.9b-e	2.4a-d	5.3ab	10.8f	1538.9cd	14.3c	38.6a-e
DPSB 8	83.7b	183.0ab	102.8a	45.7a-d	2.23e-d	4.7b-d	18.8a	1816.1a-c	12.3de	39.1a-d
DPSB 19	70.3e	145.0f	69.3dc	52.7ab	2.5a-c	4.4b-d	14.3de	1175.9ed	12.3de	39.9a-c
931/5/34	84.0b	189.3a	54.4f	52.5ab	2.3a-c	6.1a	12.2ef	1930.8a-c	19.7a	35.9e
DPSB 3	95.0a	193.3a	56.8ef	30.4e	2.0ef	6.0a	12.5ef	792.6e	11.0e	40.5a
SBH 3/8/4/1	75.7d	145.7ef	54.4f	54.3a	2.3a-d	4.9a-c	10.9f	1778.4a-c	14.3c	40.2a
Mean	79.2	165.9	72.3	45.2	2.3	5.1	13.9	1153.6	15.6	38.4
CV (%)	2.1	5.0	8.8	17.4	7.5	15.5	9.2	15.3	6.4	4.3
Lsd	2.7	13.8	10.6	13.1	0.3	1.3	2.2	448.8	1.7	2.8

Means followed by the same letter are not significantly different at P=0.05

The mean seed yield at the site was 1153.6 Kg ha^{-1} (Table 2). Genotype Gazelle recorded the highest yield at 2179 Kg ha^{-1} which was not significantly different from that of EAI 3600 (2036.4 Kg ha^{-1}) the check genotype. Genotype DPSB 3 which was latest in maturity and had least number of pods $plant^{-1}$ recorded the least yield of 792.6 kg ha^{-1}. Sixty seven percent of the genotypes studied were not significantly different in terms of protein content. It ranged from 35.9% for genotype 931/5/4 to 40.5% for genotype DPSB 3. The check genotype recorded protein content of 38.0%. Genotypes SBH 1/12/19, SBH 7/1/1, Gazelle, SBH 4/4/4, Nyala, EAI 3600 and 931/5/34 had protein content lower than the mean of 38.4%.

Discussion

Genotype adaptability is tested by evaluating genotypes for several years in order to capture genotype by year interactions. Adaptability is the capability of a genotype to make use of environmental effects that warrants a high yield level (Cucolotto *et al.,* 2007). This study covers one of those years. There were significant differences among genotypes for the traits. Days to flowering and days to harvest maturity had the same trend with early flowering genotypes maturing earlier than late flowering genotypes. There were differences on periods from 50% flowering to harvest maturity. Soybean in this environment took 5-6 months to mature. The best yielding varieties Gazelle, Nyala and 931/5/34 matured in >5 months (150) days. This could be attributed to low temperatures as modulated by high altitude of 1920 m. Tinsley (2009) had recommended soybean to be produced in areas higher than 1600 m so as to avoid low soybean viability issues which are more pronounced in warmer areas. Differences existed among the genotypes for plant height. Paul *et al.,* (2003) had associated high plant height with highest yield while evaluating soybean in different sowing dates. While 73% of the genotypes had no significant difference in the yield, 36% of them had plant heights that were below 55 cm implying, that it is not always the case that high yield correlates to high seed yield. The high yield of the three best yielding genotypes could be attributed to high 100-seed weight and high number of pods $plant^{-1}$ for Gazelle and Nyala while EAI 3600 had higher number of seeds pod^{-1} (Table 2). In soybean, the number of pods $plant^{-1}$, seeds pod^{-1} and seed weight are considered yield forming components (Macak and Candrakova, 2013). Soybean for use in the soybean industry should have seed weight of 13-15 g/100 (Filho *et al.,* 2004). Soybean genotypes in the study had higher seed weight than suggested except DPSB 3 which had a 100-seed weight of 11g. Protein content is considered an important trait when the economic product is protein meal. Although there are no set thresholds for seed protein, Pfeifer *et al.,* (1995) had set a threshold of 34.8% which is lower than the trial mean of 38.4%. This suggests that all the genotypes studied had sufficient levels of seed protein. Selection criteria for the genotypes would then preferably be seed yield.

Genotypes DPSB 19 and DPSB 8 are promiscuous in that they have the capability to nodulate with local rhizobia in Kenyan soils. The yield of Genotype DPSB 8 was not significantly different from that of Gazelle which had the highest yield at the site. Genotype DPSB 19 yielded 1.9 % above the trial mean. The yield observed could either be due genetic factors or presence of free nodulating *rhizobia*. Mugendi *et al.,* (2010) had established the presence of *Bradyrhizobium elkanii*, *Bradyrhizobium japonicum* and *Sinorhizobium fredii* as nodulating bacteria in soils of central highland in Kenya.

Conclusion

Lanet in Nakuru County is a suitable environment for soybean production. There are soybean genotypes adaptable to environmental conditions in this region. Genotypes studied have significant variation in seed yield and protein content. Selection of genotypes in this region should be based on seed yield rather than protein content.

Recommndations

Genotypes Gazelle, Nyala and EAI 3600 may be recommended for production due to their high seed production as well acceptable protein content, attributes required by clients in the soybean industry. Further studies are required to establish presence of indigenous *rhizobia* bacteria for use with promiscuous soybean varieties, a factor that would enhance yield through biological nitrogen fixation and reduce the cost of soybean production by eliminating the need for nitrogen application. Soybean varieties that are not promiscuous would require inoculation with *rhizobia* bacteria at planting.

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The effect of soil nutrient intensification and omission regimes on maize yield in Makueni County in semi-arid eastern Kenya during long rains

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Abstract

The southern rangelands of semi-arid eastern Kenya, which are prone to erratic rainfall, drought, and other vagaries of nature, results to limited smallholder farmers livelihood options in addition to making crop production a risky undertaking resulting in rampant food insecurity and poverty. Unpredictable rainfall and soil variability influenced by large scale inter-seasonal and inter-annual variability resulting in frequent extreme weather events is among the major risk factors affecting agricultural production and food security negatively in the sub region. A study was initiated at Kambi ya Mawe to identify combinations of management practices that can be considered ecological intensification, and to use such practices to improve yields over time at a faster rate than farmer practice, while minimizing adverse environmental impacts. Maize was planted and subjected to four soil amelioration treatments. Results show maize plants grown under 100% agro-ecological intensification (AEI) (Mavuno + ZnSO4 + Urea full rate) produced significantly higher grain yields than those under 50% AEI (Mavuno +Urea ½ rate), nil fertilizer, and DAP + Urea full rate. However, plants grown under 100% AEI (Mavuno + ZnSO4 + Urea full rate), 50% AEI (Mavuno +Urea ½ rate), and nil fertilizer produced significantly higher biomass and harvest index than those produced under DAP + Urea full rate. Maize plants grown under 100% (AEI) (Mavuno + ZnSO4 + Urea full rate), 50% AEI (Mavuno +Urea ½ rate), and DAP + Urea full rate, produced significantly taller plants than those under nil fertilizer. However, plants grown under DAP + Urea full rate produced significantly greater leaf area than those under 100% (AEI) (Mavuno + ZnSO4 + Urea full rate), 50% AEI (Mavuno +Urea ½ rate), and nil fertilizer. Maize plants had similar vigour irrespective of soil amelioration treatment. On the other hand plants supplied with 100% AEI -Mavuno + ZnSO4 + Urea full rate, 50% AEI - Mavuno +Urea ½ rate, and DAP + Urea full rate had significantly higher stay-green ability than those under control (nil fertilizer).

Introduction

In sub-Saharan African, the agricultural sector continues to be confronted with multiple shocks and crises, threatening the returns of the sector and impeding efforts at attaining the millennium development goals (MDGs), and core Comprehensive African Agriculture Development Programme (CAADP) pillars (Chuku and Okoye, 2009; World Development Report, 2009). The southern rangelands of semi-arid eastern Kenya, which are prone to erratic rainfall, drought, and other vagaries of nature, are no exception. This results to limited livelihood options in addition to making crop production a risky undertaking resulting in rampant food insecurity and poverty. In trying to achieve their economic ends communities in the drylands engage in the growing of crops and trees to supplement returns from the main rangeland activities like livestock rearing (GoK, 2004). The major impediment to agricultural production in these areas is low moisture stress characterized by low and erratic rainfall and high transpiration rates. Unpredictable rainfall and soil variability influenced by large scale inter-seasonal and inter-annual variability resulting

in frequent extreme weather events is among the major risk factors affecting agricultural production and food security negatively in the sub region (Christensen *et al*., 2007; Easterling *et al*., 2007; Haile, 2005). Managing rainfall risk is important in agriculture not only for the direct impact that rainfall has on production, but also for the tendency of most farmers to be risk averse (Cabrera *et al*., 2009). Risk aversion implies that farmers do not optimize their farm-plan for an upcoming season with average market and climate condition, instead, they continue to adopt conservative management strategies that reduce negative impacts in poor years, but at the expense of higher average productivity and profitability, inefficient use of resources, and sometimes accelerated natural resource degradation (Rosenzweig and Binswanger, 1993; Zimmerman and Carter, 2003). The importance of organic farming, and soil and water conservation techniques respectively as adaptation strategies to climate variability was demonstrated by Kassie *et al*., (2009) and Kato *et a.l*., (2009). In order to improve crop production in these areas, sustainable on-farm rainwater management techniques are required. Some of the options being upscaled in semi-arid eastern Kenya include proven appropriate water harvesting techniques and integrated nutrients management options. Esilaba *et al.* (2000) has demonstrated the positive benefits of simultaneous application of manure and inorganic fertilizers. The combined application of inorganic fertilizers and manure on maize significantly reduced *Striga* emergence and increased crop yields at Sirinka, Ethiopia, during the second season (Esilaba *et al,* 2000). Other studies by Okalebo *et al*. (1999) and Fritz *et al*. (2001) demonstrated that larger yields were obtained when organic and inorganic inputs were applied to soils, particularly when soil moisture was adequate and the organic inputs were higher in mineralisable nutrients. Jager *et al.* (2001) concluded that both subsistence-oriented farm management systems result in serious N-depletion and that 60-80% of farm income is based upon nutrient mining. Work by Saini *et al.* (2005) suggested that for maximum crop yield only 50% of the required fertilizer might be supplied along with bio-inoculants or manure. In long term experiments in southwestern Nigeria, Vanlauwe *et al.* (2005) reported added benefits due to the combined use of fertilizer nitrogen and organic residue application on maize yields over the years. The principle source of nutrients that is available for the crops of resource poor subsistence farmers in the semi–arid areas of eastern Kenya is farmyard manure produced on their holdings. Itabari *et al.* (2004) demonstrated that higher yields of maize and beans can be achieved when both manure and inorganic fertilizers are combined. In the same study, combinations of farmyard manure and run-off harvesting significantly increased grain yield while application of farmyard manure alone had no significant effect on yield. Most soils in the arid and semi-arid areas of Kenya are fragile and prone to dramatic decline in fertility and as such, good soil fertility management must be accompanied with the use of soil and water conservation practices in order to give the farmer good yields. The challenge for research is therefore to develop practical methods of maintaining soil fertility to enable farmers get the benefits of their soil and water conservation efforts against a backdrop of diversity, vulnerability and transition, to produce sustainable management of arid and semi-arid lands. The immediate objectives of this study were to identify combinations of management practices that can be considered ecological intensification, and to use such practices to improve yields over time at a faster rate than farmer practice, while minimizing adverse environmental impacts

Materials and methods

A long term onstation trial was established at Kenya Agricultural Research Institute (KARI) Katumani sub-centre Kambi ya Mawe at the onset of the 2012 long rains cropping season in April. The trials treatments included 4 integrated nutrient management regimes as shown in Table 1.

The trials were replicated three times at each site. The Katumani Composite B (KCB) maize was planted in each site as the test crop in plots measuring 6m x 6m for each treatment at spacing of 75cm x 50cm. Except for the above treatments; all other farmers' cultural practices were observed. The plants were scored for vigour and stay green ability at the average ages of 1, 2, and 3.5 months

after planting. The stay green ability and vigour were assessed using the method adapted from Ekanayake (1996). For stay-green ability and plant vigour, visual scores were based on colour of the leaf and condition of canopy and appearance of the plant as shown in Tables 2 and 3.

Table 1: Nutrient application rate (kg/ha) and source as per treatment

Treatment	Nutrient application rate (kg/ha) and source
N + P Full rate	N – 60 kg/ha; P – 20 kg/ha (DAP + Urea)
100% AEI N + P + K + S +Zn + B Full rate	N – 60 kg/ha; P – 20 kg/ha K – 18 kg/ha; S – 8 kg/ha Ca – 18 kg/ha; Mg – 7 kg/ha Zn – 3 kg/ha (Mavuno +ZnSO4+Urea)
50% AEI N + P + K + S +Zn + B 50% rate	N – 30 kg/ha; P – 10 kg/ha K – 9 kg/ha; S – 4 kg/ha Ca – 9 kg/ha; Mg – 4 kg/ha Zn – 1 kg/ha (Mavuno +Urea)
Control (nil fertilizer)	

Table 2: Stay green canopy appearance scores

Score	Stay green canopy appearance
1	Brown or yellow leaves with increased drying and loss of leaves
2	Light green with browning, yellowing and slight loss of leaves
3	Normal green
4	Deep green with slight loss of leaves
5	Deep green with no loss of leaves

Table 3: Plant vigour appearance scores

Score	Plant Vigour Appearance
1	Very weak
2	Weak
3	Moderate
4	Vigorous
5	Very vigorous

Plant height, number of leaves, and leaf area were also monitored at 1, 2, and 3.5 months after planting. The maize crop was harvested 3.5 months after planting and yield data collected. Total fresh weight of the unshelled cobs, and stover were taken and the yields sub-sampled where necessary. Total stand counts and number of cobs were counted and recorded per plot. Total fresh weights were taken where the yields were very low; the sub-sample fresh weight was taken. The samples were taken to the KARI Katumani laboratory where the maize were shelled and weighed. The cobs and shelled maize grain samples were weighed. The samples were oven-dried to a constant weight. Constant dry weights of the respective samples were obtained. Plant sample dry matter content was expressed as a percentage. The weights taken were used to extrapolate the yields per hectare in each treatment. Stover, cob, grain yields as t/Ha were obtained. Biomass and harvest index were computed. The data was subjected to analysis of variance using the method

described by Gomez and Gomez (1984) and the treatments means were separated using the Least Significant Difference (LSD) test using the SAS statistical package (SAS 1990). Curves and LSD bars were generated using the Microsoft Excel data processing application.

Results and discussion

Maize plants grown under 100% agro-ecological intensification (AEI) (Mavuno + ZnSO4 + Urea full rate) produced significantly higher grain yields than those under 50% AEI (Mavuno +Urea ½ rate), nil fertilizer, and DAP + Urea full rate (Table 4). This suggests that ZnSO4 and other micronutrients contained in Mavuno contribute significantly towards dry matter assimilation and accumulation in maize grains. On the other hand, maize plants grown under 100% AEI (Mavuno + ZnSO4 + Urea full rate) and 50% AEI (Mavuno +Urea ½ rate) produced significantly higher stover yields than those under, nil fertilizer, and DAP + Urea full rate suggesting that micronutrients could be contributing more significantly towards dry matter accumulation in maize stover than Urea. A similar trend is suggested by cob yield where 100% AEI (Mavuno + ZnSO4 + Urea full rate) produced significantly higher stover yields than those under DAP + Urea full rate. Maize plants grown under 100% AEI (Mavuno + ZnSO4 + Urea full rate), 50% AEI (Mavuno +Urea ½ rate), and nil fertilizer produced significantly higher biomass and harvest index than those produced under DAP + Urea full rate suggesting that DAP might not be having positive effect on dry matter accumulation in the arid and semi-arid areas.

Table 4: The effect of soil nutrient intensification and omission regimes on stover, cobs and grain yield (t/ha), biomass (t/ha) and harvest index of maize planted at Kambi ya Mawe Semi-Arid eastern Kenya during the 2012 long rains

Treatment	Grain yield	Stover yield	Cob yield	Biomass	Harvest Index
Control (nil fertilizer)	0.33	4.0	0.08	4.3	0.05
50% AEI - Mavuno +Urea ½ rate	0.27	5.0	0.08	4.2	0.04
100% AEI -Mavuno + ZnSO4 + Urea full rate	0.58	5.1	0.12	5.5	0.07
DAP + Urea full rate	0.10	3.5	0.02	3.6	0.02
Means	0.32	4.4	0.08	4.4	0.05
LSD	0.20	0.8	0.06	2.4	0.03
S.E.	0.47	2.3	0.09	3.4	0.06
CV (%)	46.40	53.4	35.80	77.0	22.00

According to Table 5, maize plants grown under 100% (AEI) (Mavuno + ZnSO4 + Urea full rate), 50% AEI (Mavuno +Urea ½ rate), and DAP + Urea full rate, produced significantly taller plants than those under nil fertilizer. This suggests that maize plants stems grow rapidly in response to any improvement in soil fertility amelioration. On the other hand, maize plants had similar leaf production rate, suggesting that soil amelioration does not have a significant effect on this parameter. However, plants grown under DAP + Urea full rate produced significantly greater leaf area than those under 100% (AEI) (Mavuno + ZnSO4 + Urea full rate), 50% AEI (Mavuno +Urea ½ rate), and nil fertilizer. This suggests that DAP (Phosphorus) probably contributes towards leaf area increase significantly.

According to Table 6 maize plants had similar vigour irrespective of soil amelioration treatment. On the other hand plants supplied with 100% AEI -Mavuno + ZnSO4 + Urea full rate, 50% AEI - Mavuno +Urea ½ rate, and DAP + Urea full rate had significantly higher stay-green ability than those under control (nil fertilizer). The results suggest that any positive soil amendments confer a positive stay-green ability on maize plants with consequent increase dry matter accumulation.

Table 5: The effect of different soil nutrient intensification and omission regimes on plant height (cm), leaf production, and leaf area (cm^2/plant) of maize planted at Kambi ya Mawe Semi-Arid Eastern Kenya during the 2012 long rains

Treatment	Plant ht (cm/plant)	Number of leaves/plant	Leaf area (cm^2/plant)
Control (nil fertilizer)	139.6	11.01	7483
50% AEI - Mavuno +Urea ½ rate	154.3	10.92	7833
100% AEI -Mavuno + ZnSO4 + Urea full rate	158.5	10.93	765
DAP + Urea full rate	154	11.41	9192
Means	151.8	11.07	8041
LSD	17.48	0.714	1008.2
S.E.	24.55	1.002	1415.9
CV (%)	16.2	9.1	17.6

Table 6: The effect of different soil nutrient intensification and omission regimes on plant vigour and stay-green ability of maize planted at Kambi ya Mawe Semi-Arid Eastern Kenya during the 2012 long rains

Treatment	Plant Vigour		Stay-Green Ability	
Control (nil fertilizer)	3.5	a	2.6	b
50% AEI - Mavuno +Urea ½ rate	4.0	a	3.3	ab
100% AEI -Mavuno + ZnSO4 + Urea full rate	4.0	a	3.5	a
DAP + Urea full rate	3.8	a	3.5	a
Means	3.8		3.3	
LSD	1.1		0.8	
S.E.	0.7		0.5	
CV (%)	17.6		14.5	

Conclusions

ZnSO4 and other micronutrients contained in Mavuno contribute significantly towards dry matter assimilation and accumulation in maize grains. Micronutrients could be contributing more significantly towards dry matter accumulation in maize stover than Urea. DAP might not be having positive effect on dry matter accumulation but probably contributes towards leaf area increase significantly in the arid and semi-arid areas. Maize plants stems grow rapidly in response to any improvement in soil fertility amelioration. However, maize plants leaf production rate, is not affected by soil amelioration does. Any positive soil amendments confer a positive stay-green ability on maize plants with consequent increase dry matter accumulation.

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Basal fertiliser effects on the development of the rhizosphere of rainfed rice in relation with vegetative growth and yield in mid-season drought-prone environment

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Abstract

Annual rain-fall reduction and variability are associated with increasing duration of mid-season drought period under bimodal rainfall pattern in West Africa. This situation limits the success of basic drought management strategies in rainfed rice production that account for about 80% of cultivated rice surface in sub-region. To enhance adaptation of rice to the actual climate, an agronomic trial was conducted in order to improve rice rhizosphere (root depth, root length density, soil exploration rate by root), it vegetative growth (height, tillers, leaf) and the 1000-grain weight and yield. Seven additive fertiliser treatments (K [T1], KP [T2], KN [T3], NPK [T4], NPKCa [T5], NPKCaMg [T6] and NPKCaMgZn [T7]) were laid out in a complete block design on Arenosols of foot slope, in a guinea savanna ecology of Côte d'Ivoire. No fertiliser treatment was the control and the roots were studied by profile method. Data was transformed by RACINE©. No significant difference was observed for leaf number and plant height by treatment at successive development stages. However, treatments K, KP and KN induced faster growth rate of root and deeper root development enhancing the improving effects of P and N on root elongation and ramification, respectively. Meanwhile, decreasing effect of Ca^{++} was observed for these parameters even if combined with Mg and Zn which are also potential root improvers. Applying KN was recommended for highest root length density; soil exploration rate, grain filling and yield in the studied ecology. Supplying soil deficient nutrients was further advised as basic concept for mitigating mid-season drought adverse effect in a given environment.

Key words: rainfed rice, root, drought, soil, guinea savanna, West Africa, Côte d'Ivoire

Introduction

Rice (*Oryza sativa* L.) currently sustains the livelihoods of about 100 million people in sub-Sahara Africa (SSA). It is an important crop in attaining food security and poverty reduction in many low-income, food-deficit African countries. However, the demand for rice far outstrips its production in Africa, which in the last 30 years has increased mainly due to land expansion, with only 30% being attributed to an increase in productivity (Fagade, 2000). To meet the shortfall in production, West Africa region imports more than 6 million tonnes per annum into the sub-region, costing about USD 1 billion in scarce foreign exchange annually (Oikeh *et al.,* 2008). Therefore, it is important to improve rice production in sub-Sahara Africa. However, 80% of cultivated rice surface in West Africa depends on rainfall only (Audebert *et al.,* 1999) whereas the climate change effect is important in this area (CNRS, 2000). The variability and reduction of rainfall in West Africa is associated with prolonged mid-season drought of bimodal raining area (Koné *et al*., 2008). These characteristics of the actual climate are limit the success of traditional mechanisms of drought management including drought escape, drought avoidance, drought tolerance and drought recovery (Fukai and Cooper, 1995; Price *et al.,* 2002). This situation affects rice production

even on the foot slope soil which includes a seasonal water Table. Therefore, rice cultivation needs adaptation to the actual climatic event for sustainable production in West Africa.

The development of rice rhizosphere can improve both water and nutrient absorptions, thereby reinforcing rice tolerance to drought. Indeed, there is positive interactions between fertilisers and soil moisture content (Koné *et al*., 1998). Fertiliser can improve crop rhizosphere and yield (Jeon, 2006). In this context, potassium (K) is known to have an increasing effect on root development (Jia *et al*., 2008). It was assumed that the effect of K can increase by the interaction with the other essential nutrients (N, P, Ca, Mg and Zn) of rice nutrition.

On this basis, an agronomic trial was initiated to explore the possibility to improve upland NERICA 5 rhizosphere (root deep, root length density, root distribution and exploration rate of soil) as well as vegetative growth and yield by applying different combinations of K to N, P, Ca, Mg and Zn fertilisers in a foot slope soil. The aim was to identify the basal fertiliser that can improve rice rhizosphere characteristics and yield in a mid-season drought-prone area.

Materials and methods

Site description

The study was carried out in guinea savanna zone of Côte d'Ivoire at M'be (8º06 N, 6º00 W, 180 m) preceding by one year bush fallow essentially composed of *Imperata cylindica* on a foot slope topographic position. Rainy season started from June followed by drought of 21-45 days from August before a new rainfall season of 2 months. The soil was Arenosols characterised by a pH of 6.7, 3.8 g C kg^{-1}, 0.5 g N kg^{-1}, 10 mg P kg^{-1}, 0.01 cmol K kg^{-1}, 2.5 cmol Ca kg^{-1}, 0.3 cmol Mg kg^{-1} and 2.3 mg Zn kg^{-1}. Seasonal water Table was also observed at the end of rainy season.

Experiment layout and data collection

Seven treatments (K [T1], KP [T2], KN [T3], NPK [T4], NPKCa [T5], NPKCaMg [T6] and NPKCaMgZn [T7]) were applied as basal fertilisers during land preparation. No fertiliser treatment (T0) was the control. NERICA 5 was sown per hill of two grains spaced at 20 cm in a micro-plot of 15 m^2 Nitrogen was applied at 35 kg ha^{-1} at rice tillering and topdressing stages, respectively after manual weeding. At tillering, topdressing and maturity stages, core samples of root were taken using PVC of 10 cm in diameter dimension for determining root depth and growing rate. At maturity, data were taken on plant height, numbers of leaves, tillers and panicles before the harvest in 8 m^2. The grains were sieved and weighed for each treatment in order to calculate the yield. One thousand grains were randomly taken before weighing for estimation of relative grain filling. A profile of 70 × 70 cm was opened at 5 cm from plot border to count root impact in soil using a grille of 30 × 60 cm.

Data management and statistical analysis

The root impact number counted in grille (Ni) was transformed by software named RACINE (Chopart and Christophe, 2004) that can generate root maximum depth, root length density and soil exploration rate. These transformed root data, plant height, numbers of leaves, tillers and panicles. The 1000-grain weight and yield were used for Pearson correlation and ANOVA analysis performed with SAS 10.

Results

Root and above ground development as affected by treatment

Figure 1 shows the development of rice root at different physiological stages and plant weight according to the studied treatments. No significant difference was observed between mean values of height at topdressing and maturity stage in all the treatment whereas significant lower value was observed at tillering. The plant height was two times higher than the root growth regardless to treatments and rice physiological stages.

There was an increase of root depth from tillering to rice maturity. However, only T2 has induced significant difference between the values observed at topdressing and maturity stages. Treatments 1, 2 and 3 have induced deepest root early at tillering.

Table 1 shows significant overall Pearson correlation between root depth and plant vegetative growth with a variance of this relationship: No significant correlation was observed between the root depths and leaves number per square meter in T2 and T3 whereas, they have highest positive significant correlations value with plant height and tiller number, respectively. The highest value of soil exploration rate was observed in T3 among the studied treatments far away from T2 (Figure 2).

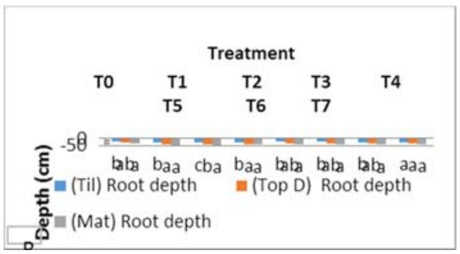

Figure 1: Development of plant height (A) and root depth (B) and tillering, topdressing and maturity stages according to the treatments (T0, T1-T7)

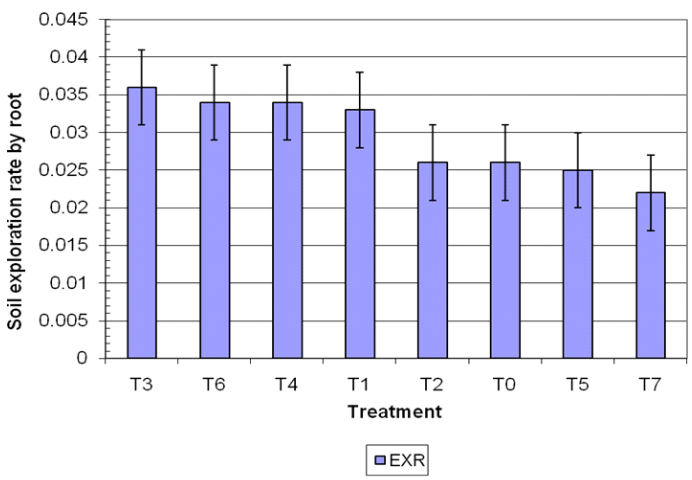

Figure 2 : Soil exploration rate (EXR) by root according to treatment

Table 1: Pearson correlation values calculated between root depth and plant height, numbers of tillers and leaves by square meter

	Root Depth																	
	T0		T1		T2		T3		T4		T5		T6		T7		Mean	
	R^2	Prob.	R^2	Prob.	R^2	Prob.	R^2	Prob.	R^2	Prob.	R^2	Prob.	R^2	Prob.	R^2	Prob.	R^2	Prob.
Height	0.469	0.145	0.684	0.014	0.713	0.009	0.885	0.0001	0.646	0.023	0.617	0.033	0.578	0.049	0.531	0.075	0.601	<.0001
Tillers	0.749	0.008	0.740	0.006	0.771	0.003	0.836	0.0007	0.609	0.036	0.564	0.056	0.761	0.004	0.644	0.024	0.641	<.0001
Leaves	0.111	0.794	0.699	0.054	0.483	0.225	0.580	0.132	0.819	0.013	0.518	0.189	0.574	0.136	0.626	0.097	0.510	<.0001

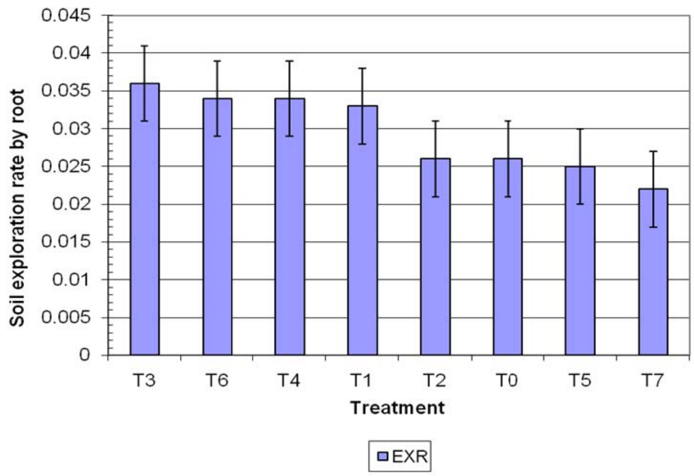

Figure 2: Soil exploration rate (EXR) by root according to treatment

Rice root development and grain production

The grain filling as illustrated by the 1000-grain weight was significantly and positively correlated to the root impact number (Ni), root length density (RLD) and soil exploration rate by root (EXR) (Table 2).

Table 2: Correlation coefficient values between 1000-grain weight and rhizosphere characteristics (Ni, RLD, RD, EXR and MD)

	Root parameters									
	Ni		RLD		RD		EXR		MD	
	R^2	Prob.	R^2	Prob.	R^2	Prob.	R^2	Prob.	R^2	Prob.
Weight for 1000 grains	0.338	0.058	0.354	0.257	0.206	0.257	0.358	0.044	0.079	0.664

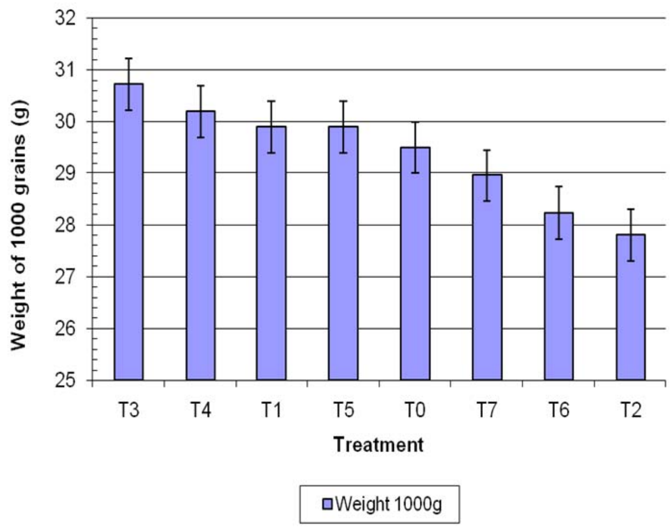

Figure 3: Weighed mean value for 1000-grains per treatment

Although not significantly different, the highest 1000-grain weight was recorded for T3 and the lowest for T2. However, booth treatments have induced higher grain yield than the overall mean value obtained during the experiment (Figure 4).

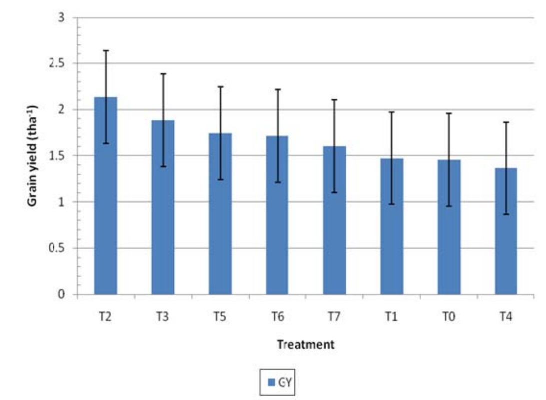

Figure 4: Mean value of grain yield by treatment (horizontal line is grand mean level)

Discussion

Soil and physiological aspects of root development

The Arenosols studied was free of morphological constraint that could have limited rooting depth (Jeon, 2006). However, on foot slope topographic position, the occurrence of seasonal water Table could have restricted root depth especially, in the later development stages, reducing it growth rate between the topdressing and maturity stages. At the end of the rains, there was accumulation of grown water inducing flowing of water Table. This saturation of soil will limit the root depth asphyxiating the meristem (Moormann *et al.,* 1977). However, this constraint could have been mitigated in T2 (PK) that has induced significant root depth between later developments stages underlining positive interaction of P and K on rice rhizosphere. This treatment did not, however, induce high exploration rate of soil by root architecture: Fewer ramifications in rhizosphere can account for this contrasting with the result observed in T3 (KN). Therefore, it is asserted that P can improve rooting depth while N is related to root ramification when they are combined to K, respectively. These characteristics of root are particularly altered by T5 (NPKCa) and T7 (NPKCaMgZn). The effect of T5 can be attributed to the physiological function of Ca^{++} as signal transducer inducing responses to biotic and abiotic stress (Cvetkovska *et al.,* 2005). Therefore, rice in T5 could be more sensitive to mid-season drought, adversely affecting the activity of biosynthesis hormone (Hong-Bo *et al.,* 2008) hence, limiting rooting depth. This result confirms the findings by Koné *et al*. (2008) concerning the tolerance of rice to water stress on Acrisols when Calcium was excluded from basal fertiliser.

In T7, minimising effect of Ca^{++} occurred in spite isomorphic competition with Mg^{++} as in T6 (KNPCaMg). This competition can mitigate Ca^{++} effect on root growth. Furthermore, Zn^{++} in T7 can increase auxin levels in plant, which can enhance root growth (Bennett and Skoog, 2002; Waraich *et al.,* 2011). However, the effect of Zn^{++} was limited because of the excess induced by 10 kg Zn ha^{-1} whereas not deficiency (> 1 mg kg^{-1}) in the studied soil. Thus, a reducing uptake and utilisation of manganese by plant for root development can occur (Ranade-Malvi, 2011; Waraich *et al.,* 2011).

We learn from our finding the existence of some positive and negative interactions between soil nutrients for root growth, whereas they are recommended for rhizosphere development, respectively (Waraich *et al.,* 2011).

Drought stress management

Treatments 2 and 3 are likely to be suitable for root development in mid-season drought-prone area. This is confirmed by their grain yields of about 2 t ha^{-1} that were greater than the grand mean obtained during the experiment. However, the 1000-grain weight was lower in T2 than the observed values for the other treatments, revealing poorest grain filling, contrasting with T3. Therefore, the high yield in T2 could be a consequence of highest number of grains per panicle whereas T3 has higher correlation with plant height and panicles numbers than T2, respectively. The correlations in T3 justify the highest ability of rice grain production and evapotranspiration that is accounting for a water use indicator (Al-Kaisi and Broner, 2009). Rice vegetative growth can increase the evapotranspiration for the improvement of water uptake by root (Koné *et al.,* 2008). The highest soil exploration rate by root in T3 during the experiment is an illustration of this analyse.

There was an unexpected result in treatment T4 including N, P and K, the common ternary fertiliser recommended around the world for most of the crop: despite of positive correlation between root depth and vegetative parameters in T4, it has induced poor root development and lowest grain yield differing with the study of wheat in water stress condition (Baque *et al.,* 2006). The concentrations of these nutrients in the studied soil could contributed for this: K and N was the limiting nutrients for rice cultivation while P was at suitable level (Koné *et al.,* 2009). Therefore, the correction of these deficiencies appears to be rational and was justified by the effects of T3 on the development of rice's rhizosphere development, vegetative growth and grain yield in the studied ecology. It is, thus, from this analyses, necessary to correct soil nutrient deficiency for best fertiliser strategy in mitigating mid-season drought.

Conclusion

This study revealed the ability of basal fertiliser composed of N and K to enhance rice vegetative growth and the root depth in mid-season drought-prone area. The nitrogen was an improver of root ramification for highest root length density and soil exploration rate. The improvement of these morphological traits could have improved the evapotranspiration and water uptake for high grain yield production.

Recommendation

Soil mineral diagnostic is recommended as basic concept for water stress management and a basal fertiliser composed of NK is suitable for foot slope soil in guinea savanna ecology of West Africa.

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Diagnostic 'best-bet' soil fertility management technologies for potato production in Nyandarua County, central Kenya

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Abstract

Irish potato is the second most important food crop in Kenya after maize. However in recent time soil fertility decline has been attributed to be one main cause of decline in potato yields in prominent growing areas comprising the Greater Nyandarua County, Central Kenya. The objective of the study was to test economic viability of existing technologies for improving and sustaining soil fertility in mixed farming system by use of integrated soil fertility approaches. This study was conducted at the KARI Oljo Orok station and in Bahati at Mzee Gakuru's farm sites located within Nyandarua County with potato used as the test crop. The composition of the different treatments that were applied in the trial were: (T1) Mineral fertilizers 17:17:17 at 200 kg ha^{-1} (T2) Mineral fertilizer CAN, TSP, and MOP (T3) Manure alone 10 t/ha (T4) Manure 5 t/ha combined with mineral fertilizer 17:17:17 at 100 kg ha^{-1} and (T5) Unfertilised control. No significant differences in ware potato yield were observe at the KARI Oljo Orok station, but at Mzee Gakuru's farm yield were significant ($p < 0.05$) with yields ranging between 13.7 and 22.3 t ha^{-1} equivalents to 50 and 89 bags per acre, for the control and half manure half fertilizer treatments, respectively. An assessment of economic viability of the tested technologies indicated that since treatment five (T_5) was the control (none use of fertilizers and/or manure), it is can be concluded that the use of manure and fertilizer gives better economic benefits than the none use of fertilizers and/or manure. The highest Marginal Rate of Return (M.R.R = 354%) was obtained from the application of mineral fertilizer 17:17:17 at 200kg/ha, followed by T_4 and T_2 and lastly T_3. It is worth noting that the application of manure alone (T_3) compared to the control, gives an M.R.R of 157%. This further implies that manure application gives better returns than the control. It is also worth noting that the change from either use of fertilizers or manure alone (T_1, T_2 and T_3) to the use of a combination of both (T_4) has positive economic gains, M.R.R of 164, 318 & 438% respectively.

Key words: Irish potato, soil fertility, fertiliser, manure, technology viability marginal rate of return.

Introduction

Irish potato is the second important source of dietary carbohydrate in Kenya with approximately 25 000 to 30 000 hectares being grown annually, granting employment to more than 2.5 million people across the entire production and marketing chain. (Ministry of Agriculture, 2007; Hortfresh Journal, 2012). Despite increased demand of ware potato, production has been experiencing a declining trend Kenya in the past two decades producing 779,190 tons in 1990 to 670,303 in 2000 and 450,000 in 2010 (GeoHive, 2013). Potatoes are produced in the cool highlands mostly by small scale farmers under rain-fed conditions. The soils in these areas have a history of mainly forest origin rich in organic matter which after many years of continuous cultivation become generally acidic and of low fertility (Kiiya *et al*., 2006). The national production is far below the potential, largely due to low application of fertilizers and other organic amendments, limited use of certified seeds, , and low use of fungicides and other production chemicals (Mureiithi and Irungu, 2004). Visits to potato growing areas of the County indicated severe soil degradation. Informal talks with resident farmers also revealed their understanding of the extent and severity in soil fertility decline (Lekasi *et al*, 2010). The main objectives of the project were to test viability of existing technologies for enhancing and sustaining soil fertility in mixed farming system by use of integrated soil fertility approaches. Specifically this project's intend:

- to test and promote existing technologies for improving and sustaining soil fertility in mixed farming system by use of integrated soil fertility approaches for irish potato production in Nyandarua County and
- to assess the economics benefit and viability of the tested technologies

Materials and methods

The study was conducted on-farm during the long rains of 2009 at the KARI Oljoro Orok station and in Bahati at Mzee Gakuru's farm, located within Nyandarua County. Irish potato was used as the test crop. Inorganic fertilisers used were CAN, TSP, MOP and compound 17:17:17. Manure used for the study was obtained from within the respective farms.

The composition of the different treatments that were applied in the demonstrations were as follows:

- Treatment 1(T_1) = Mineral fertilizer 17:17:17 at 200 kg/ha
- Treatment 2(T_2) = Mineral fertilizer CAN, TSP, MOP at 100kg, 100 kg and 50 kg
- Treatment 3(T_3) = Manure alone at 10 t/ha
- Treatment 4(T_4) = Manure 5 t/ha combined with mineral fertilizer 17:17:17 at 100 kg/ha
- Treatment 5(T_5) = Unfertilized control

Study plots were 4 x 6 m per treatment replicated three times. Irish potato variety *Tigoni* was used as the test crop. The choice of the variety was as advised by the frontline extension staff based on local farmers' preferences from the selected sites. Usual agronomic practices were followed till maturity of the crop (Lung'aho and Kabira, 1999). At maturity, harvesting was done in the inner 4 rows from an area of 3 x 3 m and ware potato yield measurements done.

Results and discussions

Some selected soil characteristics are shown in Table 1 for the KARI Oljoro Orok and Mzee Gakuru's sites. Soils from the two sites indicate severe soil acidity. It is worth mentioning that a brief soil survey of the neighboring farms also depicted the soil acidity characteristic some as low as pH 4.39. This observation was not surprising because when we held discussions with the farmer it was evident that the source of this acidity was continuous use of ammonium containing DAP fertilizer, which is known to enhance soil acidity. This condition normally interferes with plant nutrient availability, especially phosphorus and micronutrients. These soils require judicious liming for the individual farms.

Table 1: Some selected soil characteristics of the study sites in Nyandarua district

Analysis	KARI Oljoro Orok site	Mzee Gakuru's farm
Soil pH (1:2.5 0.01M $CaCl_2$)	4.97	4.54
Total OC (%)	1.95	2.1 3
Total nitrogen (%)	0.17	0.24
Available phophorus by Bray P_2	28.4	16.8

Figures 1 and 2 show potato yields obtained from the KARI Oljo Orok station and Mzee Gakuru's farm, respectively. At the KARI Oljoro Orok station the yields ranged between 7.8 and 10.3 t ha^{-1} equivalents to 104 and 139 bags per hectare, for the manure only and inorganic fertilizer only treatments, respectively. However the yields were not significantly different. This could have been attributed to the fact that the field used for this trial had been under continuous cultivation with conventional fertilisation and therefore no response to further soil amendments. This observation is important because it emphasizes the need for proper use of external soil amendments based on proper soil testing and use of recommended sources and rates. In essence, this particular soil needed no fertilization in order to produce optimum yields.

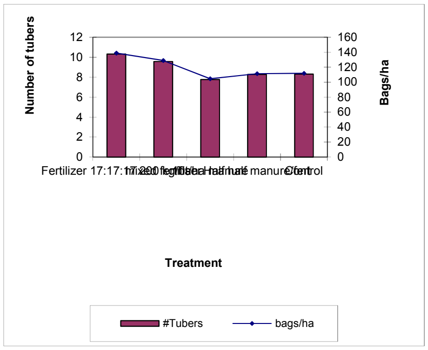

Figure 1: Potato yields at KARI Station

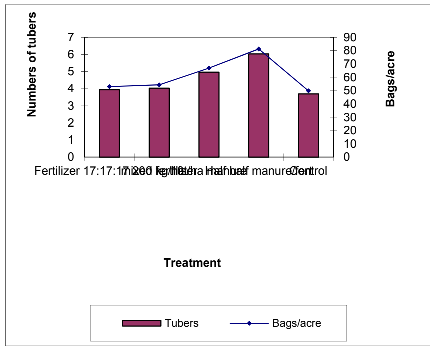

Figure 2: Potato yields at Mr. Gakuru's farm

At Mzee Gakuru's farm, the yield ranged between 13.7 and 22.3 t ha^{-1} equivalents to 50 and 89 bags per acre, for the control and half manure half fertilizer treatments, respectively. The yields were significantly different ($p < 0.05$). Treatments received external nutrients either as organic or inorganic, always produced higher yields than the check, a trend also followed by the number of marketable tubers. Observation shows the need for soil organic matter improvement as well as nutrient replenishment.

Assessment of economic viability of the tested technologies

Table 2 shows the various cost of potato production associated with soil fertility the different soil amendments regimes. These are used in the calculations of benefits of the different treatment for use in deducing economic suitability of technologies applied in the study. Some costs are uniforms with all the treatments since they are associated with agronomics operations of production.

Table 2: Treatments and costs (KES)

Variables	T1	T2	T3	T4	T5
(a) Potato yields (bags/ha)	69	64.2	69.0	76	41.3
(c)Gross field Benefits GB/ha (KES)	99,360	92,448	99,360	109,440	59,040
(d)Costs that Vary					
Cost of seeds/ha (KES)	3,900	3,900	3,900	3,900	3,900
Cost of fertilizer or manure /ha(KES)	7,200	7,200	14,000	10,600	0.00
Cost of labour land prep.,planting,fertilizer appli	1,400	1,400	1,400	1,400	1,400
Cost fungicide /ha (KES)	13,890	13,890	13,890	13,890	13,890
Cost of labour- harvesting/ha (KES)	3,450	3,210	3,450	3,800	2,065
Cost of bags	690	640	690	760	410
Cost labour for weeding, etc	350	350	350	350	350
Total costs that Vary (TCV) i+ii+iii+iv+v+vi+vii	30,880	30,640	37,680	34,700	22,015
Net Benefits (GB-TCV)	68,480	61,808	61,680	74,740	37,025

Price of a 110 kg bag of potatoes was KES 1440 = US$ 20

Table 3 lists the treatments in order of increasing costs that vary. The Table also gives Marginal Net Benefit (M.R.R) of changing from one treatment to the next "better" treatment.

Table 3: Economic analysis (TCV vs NB)

Treatment	Total Costs that Vary (TCV)	Net Benefits (NB)	M.R.R
T_5	22,015	37,025	
T_2	30,640	61,808	287
T_1	30,880	68,480	2,780
T_4	34,700	74,740	161
T_3	37,680	61,680	X

Marginal Rate of Return (M.R.R) is Marginal Net Benefit (change in Net benefits from the control to the next better treatment) divided by the marginal cost (i.e the change in TCV of the respective treatments) expressed as a percentage.

Change in net benefits/change TCV for T_5 to T_4 we have:

$$\frac{(74,740 - 37,025)}{(34,700 - 22,015)} \times 100 = 297\%$$

The M.R.R are calculated as you move from one treatment to the next better treatment as shown above.

The M.R.R marked X in Table 2 indicates that the Net benefits are lower than those of the previous treatment. The M.R.R for changes from none use of fertilizers and/or manure (T_5) to application of fertilizers and/or manure (treatments, T_1, T_2, T_3 and T_4) are summarized in Table 4. The Table also summaries the M.R.R from one treatment to another

Table 4: M.R.R. from T_5 Table

Treatment	M.R.R (%)	M.R.R (%)
T_1	354	(T_1 to T_4) 164
T_2	287	(T_2 to T_4) 318
T_3	157	(T_3 to T_4) 438
T_4	297	
T_5		

The minimum acceptable M.R.R is 50%. The meaning of M.R.R of 50% is that per every extra shilling spend on the "next" treatment compared to the previous treatment you get the shilling plus an additional fifty cents. If the M.R.R is 100% then it means that for every one shilling spend you are getting an extra shilling and so forth.

Since treatment five (T_5) was the control (none use of fertilizers and/or manure), it is can be concluded that the use of manures and fertilizer gives better economic benefits than the none use of fertilizers and/or manure. The highest M.R.R (354%) was obtained from the application of mineral fertilizer 17:17:17 at 200kg/ha, followed by T_4 and T_2 and lastly T_3. It is worthy noting that the application of manure alone (T_3) compared to the control, gives an M.R.R of 157%. This further implies that manure application gives better returns than the control. It is also worthy noting that the change from either use of fertilizers or manure alone (T_1, T_2, & T_3) to the use of a combination of both (T_4) has positive economic gains, M.R.R of 164, 318 & 438% respectively.

Conclusions

Results from this study indicated that in potato growing areas of Nyandarua County, soils require soil organic matter and fertilizer nutrients replenishment if crop yields are to be maintained sustainably. It is

also worth noting that the change from either use of fertilizers or manure alone to a use of a combination of both has better economic returns. Further from the economic analysis it can be recommended that soil fertility improvement through the application of fertilizers and manures is worthy while as it results in increases in the economic benefits. The application manure alone seems to be dominated and leaving the choice between the use of either fertilizer alone (T_1) or a combination of fertilizer and manure (T_4). The decision to use either the combination or fertilizer alone ($T_{1)}$ will depend on whether there are soil physical benefits associated with application of manures. However from the soil characteristics it is inferred, that soil acidifying fertilizers such as DAP should cease to be used in this region and liming should be encouraged upon proper soil testing is done.

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The African Soil Information Service Project on integrated soil fertility management, Kenya

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Abstract

Digital soil fertility mapping is a paramount approach in precision farming. This will enable a farmer to work towards site specific crop management a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. The African Soil Information Service (AFSIS) Project was developed digital soil maps, established soil health surveillance system and provided evidence-based spatially explicit soil management recommendations. Land Degradation Surveillance Framework (LDSF) was used for site selection in sentinel areas where fertilizer validation trials were conducted while legacy data for evidence based soil management activities was obtained through legacy data collection. Digital soil maps and a soil health surveillance system were achieved by setting-up metadata, case definitions, spatial sampling and interpretation standards. Soil legacy data acquired was digitized and spectrally characterized; assembling, processing and interpreting existing national soil maps. Legacy data showed increasing levels of publication especially maize as a test crop under mineral and organic fertilizer application and decreasing soil fertility over time. Validation studies in western, central and eastern Kenya showed that three mineral fertilizers blends (NPK) and higher altitudes recorded higher maize yields compared to NP fertilizer blends and lower altitude zones. Baseline studies to diagnose and characterize the farming systems in western and central Kenya showed that the main crop grown was maize which recorded low yields and the farmer's associated low yields with low soil fertility. The key indicators of low soil fertility were low crop yields, presence of indicator weeds and soil colour.

Key words: soil fertility, soil information, end user, nitrogen, phosphorus

Introduction

The need for improving soil management is particularly acute in sub-Saharan Africa (SSA), where there has been essentially no increase in crop yields or fertilizer use over the last 30 years. Over this same period, Africa's population has more than doubled and is expected to double again within the next 30 years. Many African landscapes are now characterized by a combination of poor soil health, poor crop health, poor water quality and poor livestock health, all major factors contributing to poor human health and low levels of economic development. The poverty traps that African smallholder farmers and pastoralists are locked into are preventing urgently needed investments to maintain soil resources, and are thus likely to result in further losses of agricultural productivity and declining provision of ecosystem services.

In January 2005 the UN Millennium Project released its recommendations on how to attain the Millennium Development Goals by 2015 (Sachs et. al., 2005). A key component was the Hunger Task Force

recommendations to focus on soil health, small-scale water management and use of superior seeds as entry points for drastically increasing agricultural productivity in SSA (Sanchez and Swaminathan 2005). In 2007 the Alliance for a Green Revolution in Africa (AGRA) was launched, including major programs in improved seeds and soil health. The overall vision is the elimination of hunger and absolute poverty in SSA.

Making these or other future plans operational will require reliable up to date information about soil health, including soil maps that are compatible with other natural resource maps, information for better targeting of appropriate management options and agricultural input supplies, and more efficient learning mechanisms about the impacts of soil management interventions and policies. All the above efforts will culminate to site specific crop concept based on observing, measuring and responding to inter and intra-field variability in crops. However, knowledge about African soils is highly fragmented, outdated and there is thus an urgent need for accurate, up-to-date, geo-referenced soil information that will provide for sound decision-making in the implementation of Africa's Green Revolution.

The main objectives were:

- To provide evidence-based, spatially explicit soil management recommendations to national research and extension providers and services.
- To create digital soil maps to aid in precision farming.
- Compare crop performance as affected by agroecological zone and different fertilizer levels of application

Materials and methods

The work was carried out in three Sentinel sites, Kandara District in Muranga County in central Kenya,Wote and Makindu Districts of Makueni County in Eastern Kenya and in Siaya District in Siaya County in western Kenya.

Description of the study sites

Kandara District in Muranga County in central Kenya. It lies across four agro-ecological zones namely LH, UM1, UM2 and UM3 (Jaetzold *et al*. 2006). Due to the south eastern trade winds, the larger Muranga County has a climate that is typical for increasing altitudes in the area.

Average annual rainfall is variable and ranges from slightly more than 800 mm in the lower south east (UM and LM 4) to more than 2600 mm in the north-west zone. The rainfall pattern is bimodal and rainy seasons are clearly separated with the first rain starting at about the end of March, with their peaks in April and May while the second rains start from October with the peak in November. The district has medium to long (155-174 days) and medium to short (115-134 days) cropping season with a mean annual temperature of 18-21^{0}C. The soils are largely presented as Humic Nitisols, which are well drained, extremely deep, dusky red to dark reddish brown, of friable clay and with high inherent fertility and acidic humic topsoil. The soils have very high moisture storage capacity. Kandara District covers an area of 235 km^2 of which 193 km^2 has been put under agricultural production. Maize is the main staple food crop, which is produced at subsistence level by small-scale farmers in zones UM1, UM2 and UM3.

Wote and Makindu Districts of Makueni County in eastern Kenya

This site is in the Wote/Makindu District areas in Makueni County. The climate is semi-arid to arid with the mean annual ranging between about 600 and 750 mm as opposed to potential evaporation of 2100-2150 mm (Achieng and Muchena, 1979). The altitude lies between 150 and 1000 m. The natural vegetation is dominated by wooded bush-land consisting of *Euteropogon macrostachus* and *Chloris roxburghiana* (30% of grasses) with *Acacia brevispica, Combretum exallatum*, *Camiphora* spp. and grasses such as *Premma holstii*, *Ocinum bassilium* and *Grewia spp* plus other wooded species. All soils in the district are developed on sandstones rich in ferro-magnesium minerals. They have well drained, deep to very deep, red to dusky red and are sandy clay to clay (Ekirapa and Muya, 1991). These are represented around Kiboko and west of Kibwezi by *chromic* Luvisols and interfluves of *orthic* and *xanthic* Ferralsols (Ministry of Agriculture, 1987).

Soils are variable in depth depending on parent material, slope and are generally low in organic matter and deficient in nitrogen, phosphorus and potassium (van Wifngaarden and van Englen, 1994). Makueni County population consists of some 43,377 households with a density of 10-150 people per square kilometre and farm sizes averaging 3.5 hectares (ha) per household (De Jager *et al*, 2006). Of the total farmland an average of 48.5% is under cultivation and up to 71% of the households live below poverty line. Farm sizes are on average of 3.3 ha per household of which about 1.8 ha are utilized to grow crops with the rest of the land under pasture. Apart from rain fed agriculture there are extensive areas where irrigation is practiced.

Siaya District in Siaya County in western Kenya

Siaya County (0° 26′ to 0° 18′ N; 33° 58′ East and 34° 33′ W) and covers 1520 km^2 with a population 480,184 persons. It has different relief, soils and land use.. It is located in ecological zone LM1 – LM3 with a small area under UM1. The attitude ranges from 1140 to 1500 metres above sea level (m.a.s.l). The area has two rainy seasons with the average annual rainfall ranging from 800mm to 1600 mm per annum, the minimum temperatures is 15° C and a maximum of 30° C. In this region, poverty is still a challenge and most families live on less than a dollar a day (Republic of Kenya, 2010). The fertility of the soils in Siaya range from moderate to low, and levels of nitrogen (N) and phosphorus (P) are particularly low. Vertisols and Ferralsols are the most common soils in the three villages studied. Most soils are underlain by plinthite (Murram) at a shallow depth, resulting in low moisture retention.

Methodologies

Developing digital soil maps and establishing a soil health surveillance system

The development of digital soil maps and establishment of soil health surveillance system in Kenya was done by setting-up data, metadata, case definitions, spatial sampling and interpretation standards, acquiring, digitizing and spectrally characterizing soil legacy data; assembling, processing and interpreting remote sensing data and existing national soil maps. Collecting and analyzing soil health data from representative sentinel sites, and generating high resolution digital maps of soil functional properties in Kenya, including soil degradation status and biophysical and socioeconomic risk factors were done.

Provision of evidence-based, spatially explicit soil management recommendations involved development of: norms and standards for locally appropriate soil management practices; protocols for demonstrations and testing best-bet soil management practices at sentinel sites in eastern, central and western Kenya. This entailed collection, assembly and interpretation of data related to field trials, evaluation of appropriate management practices, and ISFM technologies. The development of evidence-based soil management recommendations involved derivation of descriptive and quantitative models to predict the performance of specific ISFM recommendations under varied, soil, climatic and socio-economic conditions. ISFM technologies refer to fertilizer application rates, soil organic matter management, use of legumes, and tillage operations in cropping systems. Additionally, socio-economic factors like labor availability, access to input and output markets, access to credit, and other factors related to the social and cultural characteristics and the farming systems were considered. Both quantitative and qualitative techniques were used to determine how these factors (environmental and socioeconomic) were rated. The decision framework was flexible and allowed for comparisons of the different ISFM options under different and changing socio-economic and policy scenarios and ratings to be adjusted accordingly. Field trials were established in the above sentinel sites within the first two years of the project. The project conducted multi-locational, on- farm, controlled standard trials. Farmers were involved in the participatory monitoring and evaluation. The teams responsible for the implementing this activity worked closely with the AFSIS mapping team to determine where to locate the trials based on the prevailing soil conditions and farming systems. All of the sites had a standard nutrient response trial that linked to the soil spectral characterization of the sentinel sites. The trials involved a range of fertilizer application rates, application of organic matter in different forms and quantities and with the integration of legume crops in the crop rotation or cropping systems that are acceptable to farmers and that serve a dual purpose (i.e. provide economic benefits as well as benefits to soil productivity). There was also collection and meta-analysis of literature and case-based soil management practices; installation and monitoring of additional field trials

at sentinel sites, modelling all of the above, including expert systems that assisted in the development of soil management recommendations in Kenya.

For capacity building, legacy data was collected was carried in KARI libraries (Headquarters, Muguga, Kabete and Katumani stations) to ascertain the extend ISFM research work done in Kenya. This involved literature search of all ISFM related publications of research work done in Kenya. The collected literature was entered into Filemaker software and later extracted to Ms excel and exported to SPSS where meta-analysis was done. A questionnaire was developed to capture the end users awareness of ISFM. End users included Africa Green Revolution Alliance (AGRA), national research organizations and extension providers, CGIAR centres, UN organizations, NARS, NGO's, donor agencies, private sector companies, other research projects and Government of Kenya (GoK). The feedback was analyzed using SPSS.

Results and discussions

Application of cluster techniques for soil fertility trial site selection and characterization in central and eastern Kenya

The Land Degradation Surveillance Framework (LDSF) was used while selecting the sites. Soil sampling was done according to a structured sampling design (Kamoni *et al.*, 2012a and 2012b). Farms were selected from farmer's fields and from secondary schools. Thirty six farms (sites) in Kandara and 30 sites in Makueni were selected from which composite soil fertility samples were collected using the LDSF Y scheme and analysed at KARI Kabete Laboratories. The purpose of the analysis was to get baseline fertility levels of the sites before starting the experimentation. Out of the 36 sites selected in Kandara19.4% of the sites had a pH of 4.32-5.0, 30.6% had pH of 5.0-5.5, 38.9% had pH of 5.5-5.94 and 11.25 had near neutral pH of 6.1-6.7 (Table 1). The results in Table 1 indicate that the selected sites in Kandara had suitable soil characteristics for use as fertilizer trial sites. Most of the sites were however deficient in nitrogen and phosphorus and had low levels of organic matter and therefore would respond to N, P and manure applications. Management measures that aim at raising the soil pH, improving soil N and P levels as well as organic matter content would be the most appropriate in the Kandara area.

In Kiboko District, Makueni County in eastern Kenya the site was selected by a Global maize project which aims at assessing and promoting nutrient management practices that optimize and improve maize productivity. Out of the 30 selected sites, eighty one percent of the sites had a pH of 6.5-7.0, all other sites had a pH greater than or equal to 6.0. All sites were deficient in total nitrogen (< 0.2%). Ninety six percent of the sites had low levels of total organic carbon (<1.33% OC). Ninety four percent of the sites had excessive levels of phosphorus (> 80 ppm Mehlich or Olsen P). Ninety six percent of the sites had adequate levels of potassium (>0.24-1.50 me %) (Table 1).

Table 1: Soil fertility pH, total nitrogen, total carbon, phosphorus and potassium in Kandara and Makueni

Site	Kandara			Makueni	Remarks
Soil chemical characteristic	Range/ level	Total (%) (n=36)	Remarks	Range/level total (n=26)	
pH	4.32-4.98	19.4	Best management require carefully chosen combination of manure and fertilizers. Liming is necessary		acidic
	5.05-5.46	30.6	Best management require carefully chosen combination of manure and fertilizers		
	5.5-5.94	38.9			
	6.0-6.5	5.6		11.5	Slightly acid
	6.5-7.00	5.6		80.8	Slight acid to near neutral
	< 0.2	66.7	Deficient	100	Deficient

Total nitrogen (%)	0.2-0.5	23.3	Adequate-highest value was 0.27%	0	Adequate
Total organic carbon (%)	< 1.33	8.3	Deficient	96.2	Deficient
	1.33-2.65	72.2	Moderate	3.8	Moderate
	2.66-5.32	11.1	Adequate	0	Adequate
Phosphorus (ppm)	< 30	66.7	Deficient	3.1	Deficient
	30-80	30.6	Adequate	3.1	Adequate
	> 80	2.8	Excessive	93.8	Excessive
Potassium (me%)	< 0.24	2.8	Deficient	0	Deficient
	0.24-1.50	94.4	Adequate	3.8	Adequate
	> 1.5	2.8	Excessive	96.2	Excessive

Response of maize to different soil nutrient intensification and omission regimes in the southern rangelands of semi-arid eastern Kenya

Thirty on-farm soil nutrient agroecological intensification and omission trials were established at Makindu in Makueni County in the southern rangelands of semi-arid eastern Kenya to evaluate and promote site-specific nutrient management recommendations in eastern Kenya. The results of soil analysis showed that the soil reaction (pH) varies from slightly acidic to near neutral. Nitrogen and zinc were deficient. Phosphorus was deficient in some cluster fields. Therefore, the most appropriate management measures in the area should focus on improving soil N, Zinc and P levels as well as the organic matter content. Crop growth and development data was collected at 1, 2, and 3.5 months after planting. In Table 2, the results of data collected are presented. Maize plants supplied with NPK, NPK + Lime (1T/ha) and NPK + Manure (10T/ha) were significantly ($P \leq 0.05$) more vigorous than plants under the other treatments one month after planting. At 3.5 months after planting, maize grown under the NPK, KP, and NPK + Lime (1T/ha) were significantly taller than those under other treatments. The results suggest that treatments with KP had positive effect on plant height. The maize crop was harvested 3.5 months after planting. Results indicate that treatments NPK + Mavuno and NPK + Lime (1T/ha) had highly positive effects on the performance of the maize crop.

Higher stover yield and biomass were obtained from maize treatments supplied with NPK + Mavuno and NPK + Lime (1T/ha). Consequently, due to the high coefficients of variation, the cob and grain yields did not show significant differences between the different treatments (nutrient regimes). Thus application of fertilizers alone without addressing issues to do with water supply and conservation in the arid and semi-arid areas is not sufficient. Micronutrients (Mavuno) and lime had similar positive effects on performance of maize. On the other hand, the maize supplied with NPK and with nothing (control- nil fertilizer) had significantly higher harvest index than the other treatments. These highly contrasting results between yield and harvest index suggest this parameter is not a good selection criteria. Maize plants supplied with NPK, NPK + Lime (1T/Ha), and NPK + Manure (10 T/Ha) were significantly ($P \leq 0.05$) more vigorous than plants under the other treatments one month after planting. At 2 and 3.5 months after planting all maize plants under all eight treatments ranged between weak and moderately vigorous plants. Plants grown under NPK, NPK + Lime (1T/Ha), NPK + Manure (10 T/Ha), and NPK + Mavuno had a significantly higher stay-green ability than those under the other four treatments. It seems that plants under intensive multiple plant nutrients regimes had significantly higher stay-green ability than those without. Addition of manure, micronutrients (Mavuno), and lime had a positive effect on plants performance. Plants with a high stay-green ability tend to have a longer photosynthetic period and hence higher dry matter accumulation than those with lower stay green ability. This concurs with the results obtained where plants grown under NPK + Mavuno, and NPK + Lime (1T/ha) which had the highest biomass yield.

Table 2: The effect of INM and plant age on biomass yield (t/ha) and harvest index of maize at Kiboko/Makindu semi-arid eastern Kenya during the 2012 LR

Treatment	Stover yield	Cob yield	Grain yield	Biomass	Harvest Index
Control (0)	0.53	0.05	0.20	0.70	0.35
NPK	0.73	0.06	0.24	0.92	0.37
NP	0.48	0.06	0.28	0.82	0.29
NK	0.66	0.01	0.09	0.76	0.31
NPK + Mavuno	1.01	0.02	0.09	1.11	0.27
NPK + Lime (1 t/ha)	0.96	0.04	0.22	1.22	0.35
NPK + Manure (10 t/ha))	0.63	0.03	0.22	0.88	0.22
KP	0.72	0.02	0.07	0.81	0.18
Means	0.72	0.03	0.18	0.90	0.29
LSD	0.39	0.05	0.24	0.49	0.16
CV (%)	54.0	143.3	135.9	54.2	54.3

A similar study was carried out in Central Kenya. Eight diagnostic fertilizer treatments (NPK, NPK+lime, NP, PK, NK, Mavuno, NPK+manure and control) were tested in 32 farms selected from sixteen clusters of Kandara sentinel site. Soil samples at 0-20cm depth were taken from each farm for evaluating soil fertility while the eight fertilizer treatments were laid out in 10 plots in each farm for the September-January 2011-2012 season. Thereafter harvest and fertility data from each treatment and farms were analyzed to determine difference between farmers and treatments on dry matter and grains yield. Results obtained indicated that there was a significant difference in soil fertility management between farmers ($p<0.001$) in relation to dry matter yield and a significant difference in grain yield between treatments ($p<0.01$). Treatments; NPK+Lime, NPK+manure and Mavuno showed higher stover and grain yield. The intial soil fertility results indicated that soils of the farms selected for the trials were variable and differ from one farm to another(Table 3) . This difference was significant ($p<0.001$) when the soil nutrients from each farm were compared . Soil pH, exchangeable acidity and total N were identified by principal component analysis (PCA) as the contibuting factors to the difference in soil fertility since they contribute 74% of the variabilty observed with an eigen value of >1. Soil pH varied from 4.3 to 6.7 and the difference determines the availability of most nutrients. Farms with low soil pH were characterised by low calcium and magnesium content implying an excess removal of bases with crop harvests. The results also showed 20 out of the 32 farms had exchangeable acidity that requires liming. C: N ratio was 1:4 implying poor management in most of the farms that results in lowering of Soil organic carbon (SOC). The SOC has been shown to be affected by the wealth of individual farmer and it varied with location and resource endowment of farmers (Cobo, *et al*, 2009). The difference in soil fertility of farms was further observed when the mean grain yields of maize from each farm were compared irrespective of treatments.

Table 3: Soil variability in initial soil fertility of the top soil samples of farms in Kandara in central Kenya

				mean		
	N	Minimum	maximum	statistic	Std error	Std dev
Soil pH	32	4.32	6.72	5.46	0.10	0.57
Exch. acidity(mg/kg)	20	0.10	0.40	0.22	0.21	0.09
Total N (%)	32	0.10	2.06	0.39	0.10	0.57
SOC (%)	32	0.20	2.90	1.54	0.90	0.53
P(ppm)	32	1.00	156	31.00	5.05	28.57
K^+(mg/kg)	32	0.16	10.70	1.65	0.40	2.29
Ca^{2+}(mg/kg)	32	0.60	18.60	5.71	0.60	3.39
Mg^{2+}(mg/Kg)	32	1.31	11.70	4.68	0.43	2.44
Mn^{2+}(ppm)	32	0.56	16.80	2.51	0.65	3.65
Cu(ppm)	32	1.50	92.60	14.57	3.80	21.51
Fe^{2+}(ppm)	32	5.20	90.80	40.69	3.40	19.23
Zn^{2+}(ppm)	32	0.50	65.60	19.60	3.55	20.08
Na^+(mg/kg)	32	0.10	1.50	0.53	0.05	0.28

NPK+lime, NPK +manure , Mavuno and NP treatments had the highest grain yields and the difference was significant($p<0.001$) when compared to the control. The observed increase in dry matter and grain yield in each diagnostic treatment indicate that the soils of the area are depleted of nutrients and there is a response in each intergrated fertility management intervention approach(Table 4). The response to treatments varied between farmers ($p<0.001$) and were consistent with the observed soil fertility variability. Farms with high inherent soil fertility had better response to the treatments than those with low fertility. These results are consistent with those found on smaller holder farms in Zimbabwe where maize yield increased with the wealth of the farm (Cobo *et al*,2009). There was an increase of over 1.0 ton/ha in dry matter yield in each fertilizer intervention despite the unfavourable rainfall conditions of the season. The increase implys that even under low moisture conditions farmer can harvest adequate stovers for dairy cow feeding, a common charactersitic of majority of the farms in Kandara area. Results obtained from these diagnostic trials show that various treatments will improve maize yields in Central Kenya. However, the approaches to improve these yields must incorporate the inherent soil fertility condition of each farm and the resource endowment of the farmer. Soil pH, exchangeable acidity and N capital must be improved to obtain increased yields. A stepwise approach is proposed that seeks first to increase the inherent soil fertility of each farm by investing in farmyard manure application together with NPK applications and secondly, increase maize yield by using NPK+manure or Mavuno that have shown promising results. These approaches should be coupled with fertilizer subsidies that have been shown in Malawi to improve food security of farmers. More research needs to be done to determine the thresholds of the proposed fertlizer treatments for intervention in these small holder farms.

Table 4: Maize dry matter, grain and total biomass yield in Kandara in central Kenya

Treatment	Stover (t/ha)	Grain (t/ha)	Total biomass (t/ha)
NPK +lime	2.08	3.07	5.16
NPK +manure	2.48	3.18	5.67
NP	1.92	3.48	5.4
Mavuno	2.15	3.90	6.04
PK	1.66	1.97	3.63
NK	1.88	2.91	4.88
NPK	2.26	3.47	5.73
Control	1.17	1.76	2.96

Maize response to macro and micro nutrient fertilizer combinations across nutrient deficient smallholder fields in western Kenya

Thirty-two field experiments were established during 2010 short rains in Gem and Ugenya districts of Western Kenya with similar treatments as was in eastern and central Kenya. Within each field, 8 partially replicated treatments were established. Maize grain yields and dry matter production were evaluated for their response to the application of N, P; N, P, K and multi-nutrient (macro and micronutrients) fertilizer combinations under different altitudes, moisture regimes, striga prevalence, seasons and farm management conditions.

The results indicated that treatments located in higher altitudes (above 1350 m.a.s.l) resulted in higher (62-72 %) grain yields compared to treatments established in lower altitudes (below 1349 m.a.s.l) with 3-mineral fertilizer blend giving higher yields relative to 2-mineral blends across both altitudes ranges. Similar treatment's trends were observed in fields located in areas with higher mean monthly rainfall (41.7 mm-rainfall regime1) compared to those located in areas with lower mean monthly rainfall (< 20 mm-rainfall regime3). Multi-purpose (N, P, K and micro nutrients) treatment produced 37-86 % higher grain and DM yields compared to two-mineral fertilizer combination across in-fields, mid-fields and outfields categories in experimental fields. The results indicated the impact of omitting any of the nutrients as compared to the application of all the three macro nutrients (nitrogen, phosphorous and potassium). Generally, the application of all the three mineral nutrients (i.e., nitrogen, phosphorus and potassium- NPK) fertilizer combined with either lime or dosed with micro-nutrients calcium, magnesium and sulphur resulted in significant maize grain and biomass yield increases compared to application of either two-mineral (NP, NK, PN) fertilizer or no input control. The yield gap from application of NPK + lime fertilizer compared to no-input control (102%) and the best performing two mineral NP fertilizer combination (29%) further confirms the effectiveness of combining lime with modest recommended amounts of NPK fertilizer for improving maize productivity in nutrient depleted, low pH smallholder farms of western Kenya. Moisture is critical for dissolution of applied mineral fertilizer in the soil for plant uptake, with delays expected in dry soils or where moisture conditions are limiting. Little variations in rainfall patterns within the 10 x 10 km experimental site are reflected by low yield gaps to sole inorganic and combined inorganic and organic soil fertility amendments. The slightly higher total precipitation in rainfall regime 2 compared to either of the remaining two regimes in short rains likely accounts for the slight and insignificant total maize yield increment (Table 5) observed for the rainfall regime. Low grain yield differences either resulted from application of sole NPK fertilizers or when combined with lime, manure or multi-nutrient fertilizer. However, application of three-mineral fertilizers resulted in higher (between, 0.6 - 1.7 t ha^{-1}) and significant maize grain increases compared to application of two-mineral fertilizers.

Table 5: Effects of different rainfall patterns on maize grain yields (Kg ha^{-1}) under inorganic and organic fertilizer inputs in Siaya in western Kenya

	Rainfall regime			
Treatment	1	2	3	Means
NPK	3.3	3.0	3.0	3.1
NPK + Lime	3.6	3.6	3.0	3.4
NPK + Manure	3.3	3.3	2.9	3.2
NPK + Micro-Nutrients	3.3	3.3	3.3	3.3
Control	1.9	1.7	1.5	1.7
NK	1.9	2.1	2.0	2.0
NP	2.7	3.1	2.9	2.9
PK	2.3	2.4	2.2	2.3
Mean	2.7	2.8	2.5	2.7
CV	51.12	41.40	47.38	46.44
LSD $_{(0.05\ \%)}$	9.4	7.0	7.7	4.6

Altitude effects on maize grain yield and biomass production responses to applied treatments

Altitude effects on applied inorganic and organic fertilizer treatments were observed from increased canopy vigor in fields within and beyond 1400 m. Established crop had a dark green color, larger stem girdle and height when compared to crops in cluster lying in lower altitudes. Cluster analysis along altitude show a yield gap close to 0.5 t/ha in fields lying above 1350 m compared to fields lying below this range. Additionally, all treatments lying above 1350 m fared consistently better, underpinning the importance of altitude considerations not only in maize breeding but also in recommending strategies for soil fertility replenishment in western Kenya. NPK + Lime treatment performed best with yield 94 % and 107 % increase in grain yield when compared to no input control at both altitudes (below and above 1350 m) ranges respectively. Addition of manure, lime or micro-nutrients had a net positive effect on NPK fertilizer combination and resulted in the highest grain yield increases. Result from this study indicate that repeated additions of manure, lime or multi-nutrient fertilizer may have important beneficial effects on the physical and chemical soil properties, either as a soil conditioner or a source of plant available nutrients. Further, most soils in the study area were of low pH making some of the nutrients such as P be fixed by the aluminum of hydrogen ions. Acidity in soils comes from H^+ and Al^{3+} ions in the soil solution and sorbed to soil surfaces. While pH is the measure of H^+ in solution, Al^{3+} is important in acid soils because between pH 4 and 6, Al^{3+} reacts with water (H_2O) forming $AlOH^{2+}$, and $Al(OH)_2^+$, releasing extra H^+ ions. Every Al^{3+} ion can create 3 H^+ ions. Many other processes contribute to the formation of acid soils including rainfall, fertilizer use, plant root activity and the weathering of primary and secondary soil minerals. Applied organic and inorganic treatments tested in this study exhibited a definite response trend and, according to their effect on maize grain and dry matter production can be grouped into three broad categories; Top performers: NPK + Lime; NPK + Manure; NPK + Multi-nutrient fertilizer; Moderate performers: NPK, NP and Low performers: PK, NK (Table 6).

For Integrated soil fertility management research legacy data collection in Kenya, the results showed that 57% of the materials were published in conference proceedings, 21% scientific journals and 14% thesis, which may not be accessible to all end users or may not contain all the necessary information needed or the information could be in a format that is difficult for end users to interpret. Still there remained 1% of the data which was still not published (Table 7).

Table 6: Altitude influence on maize grain yield (t ha^{-1}) to applied fertilizer treatments in Siaya in western Kenya

Fertilizer type	1250-1349 m	1350-1450 m	Overall mean
NPK	2.90	3.30	3.40
NPK + lime	3.00	4.00	4.10
NPK + manure	3.10	3.30	3.30
NPK + micronutrients	3.20	3.40	3.70
Control	1.50	1.90	2.00
NK	1.80	2.30	2.10
NP	2.70	3.20	3.20
PK	2.20	2.50	2.60
Mean	2.50	3.00	3.00
CV	39.51	53.22	43.12
LSC (0.05%)	4.60	9.40	7.00

Table 7: Type and level of publication

Publication type	Frequency	Percentage
Book	14	11.1
Conference proceedings	57	45.2
Master thesis	1	0.8
PhD thesis	8	6.3
Scientific Journal	27	21.4
Technical report	18	14.3
Unpublished	1	0.8
Total	126	100

The main nutrient management intervention was use of combined organic and inorganic resource inputs (72%) followed by inorganic resource inputs (16%) (Table 8). The nutrients inputs focused mainly on organic and inorganic resource inputs, with few studies focusing on liming, tillage, drainage and water harvesting. Drainage, tillage and water harvesting was done together with nutrient interventions in the studies recorded

Table 8: Type of soil amendment intervention

Type of intervention	Frequency	Percentage
Liming	1	1.1
Organic and inorganic resource inputs	68	72.3
Resource inputs (Inorganic)	16	17.1
Resource inputs (Organic)	7	7.4
Resource inputs (Rock phosphate)	1	1.1
Tillage operations	1	1.1
Total	94	100

This study concluded that there is need to consolidate ISFM findings into an easy to understand format and make it available to end users

Soil information user needs assessment

A Soil Information User Needs Assessment survey carried out within Nairobi and its environs and Western revealed that accessing soil information was difficult among the end users and the information accessed was scanty; and thus there is need forsetting up an up-to date soil information source. Soil information was mainly acquired in the form of hard copies including soil profile descriptions. The soil information acquired was used in advising farmers on the fertility status of their soils including potential for specific crops and integrated soil fertility management.

Conclusions and recommendations

About three quarters of the sites tested were deficient in nitrogen, low levels of organic matter and therefore responded to N and manure applications. Soil fertility management recommendations targeting these environments must strive to identify the criterion or 'factors' that improve the efficiency per unit of input applied for optimized cereal crop production.

The influence of different rainfall regimes on maize grain yield response to applied fertilizer were varied, suggesting that rainfall may not be a reliable localized parameter on which to anchor fertilizer recommendations in western Kenya. In contrast, higher grain yields achieved by mid-field and outfields and at higher altitudes ranges from application of organic and inorganic inputs indicate both parameters have a significant influence on crop fertilizer responses and are preferable indicators for tailoring fertilizer use options in nutrient depleted smallholder systems of western Kenya. From the study, the following conclusions are made;

- Application of 3-nutrients fertilizer NPK and its combination with manure, lime and micro-nutrients at applied rates is favourable for maize production compared to application of 2-nutrients fertilizer combination (NP, NK or PN).
- Application of NP fertilizer a preferable alternative when NPK fertilizers are scarce or not available.
- Field management category and altitude ranges are stable parameters in tailoring fertilizer use options for Siaya and Gem districts in western Kenya.
- There is need to investigate and incorporate other covariates (soil types, soil physical, chemical and biological characteristics), farmer tastes and preferences and household socio-economic conditions in further studies for a more comprehensive fertilizer recommendation assessment for the region

Soil pH, exchangeable acidity and N capital must be improved to obtain higher yields. We thus propose a stepwise approach that seeks first to increase the inherent soil fertility of each farm by investing in farmyard manure application together with NPK applications and secondly, increase maize yield by using NPK+manure or Mavuno that have shown promising results. More research needs to be done to determine the thresholds of the proposed fertlizer treatments for intervention in these small holder farms.

There is need to demonstrate to farmers the need to adopt an integrated natural resource management approach in crop production and train farmers on appropriate soil and water management options in the semi-arid areas. Scaling up ISFM should consist of simple practical processes that farmers can understand, adapt and share with others while interacting with researchers. The process needs long-term farmer empowerment and dialogue that leads to demystification of science from "known certainties and facts" to continuous processes that generate better opportunities. A proper information base is a precondition for improved soil fertility management and hence increased food production and sustainable natural resource management. Adequate data on soil types and properties, fertilizer types and their suitability for different crops and soil types, available basket of technologies for soil fertility management, fertilizer traders and stockists, institutions involved in research on soil fertility and service providers need to be available at all levels for decision-making at farm, local and national levels. Thus farmers need to be educated on the right maize varieties; proper maize spacing; the right fertilizers and quantities to use during planting and top dressing; be encouraged to continue using manure and to increase input to 5 t ha^{-1} per season (50 wheel barrows) or 12 bags ha^{-1}or more in combination with the fertilizers and besides high dose of manure, liming

is recommended for those farms with pH below 5.0 A combination of NP, FYM and liming will give best results.

Way forward for ISFM in Kenya

An essential condition for integrated soil fertility management (ISFM) adoption is access to farm inputs, produce markets, and financial resources. To a large extent, adoption is market-driven as commodity sales provide incentives and cash to invest in soil fertility management technologies, providing opportunities for community-based savings and credit schemes. Policies towards sustainable land use intensification and the necessary institutions and mechanisms to implement and evaluate these also facilitate the uptake of ISFM. Policies favoring the importation of fertilizer, its blending and packaging, or smart subsidies are needed to stimulate the supply of fertilizer as well. Specific policies addressing the rehabilitation of degraded, non-responsive soils are required since investments to achieve this may be too large to be supported by farm families alone. While dissemination and adoption of complete ISFM is the ultimate goal, substantial improvements in production can be made by promoting the greater use of farm inputs and germplasm within market-oriented farm enterprises. Such dissemination strategies should include ways to facilitate access to the required inputs, simple information fliers, spread through extension networks, and knowledge on how to avoid less-responsive soils. To support productivity gains and income generation, novel soil- and crop specific technologies should be developed, pilot-tested and transferred in a relatively short time frame. Issues such as increasing fertilizer use efficiency, balanced nutrition, identification and development of crop germplasm with superior resource use efficiency and adaptation to harsh environments, improved crop rotations and cropping systems and efficient water use practices need to be investigated. One of the main challenges would be to identify appropriate integrated management practices best suited for a particular agro-ecosystem, considering the availability of the inputs and socio-economic conditions. Research on inorganic fertilizers should consider its effect on aspects of climate change such as green gas emissions and carbon sequestration, water quality and interaction with pests and diseases. The challenge is to establish and quantify the global benefits resulting from sustainable land management. The use of decision-support tools can help predict and unravel some of these challenges facing integrated sustainable management of resources.

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Grain yield of selected crops at four climate analogue locations in Zimbabwe

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Abstract

Predicted warmer climates are likely to negatively affect production systems and expose smallholder farmers in sub-Saharan Africa, whose adaptive capacity is limited mainly due to poverty, to food insecurity. We studied the performance of selected varieties representing short, medium and long duration growth periods of four crops (maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* L.) at two pairs (wet and dry) of 2050s climate analogue sites. Climate analogues, based on 30 years metereological data, were identified in smallholder areas of Zimbabwe. The sites were Kadoma (722 mm annual mean rainfall; 21.8°C annual mean temperature) which was the higher-temperature analogue site for Mazowe (842 mm annual mean rainfall; 18.2°C annual mean temperature) for wetter areas, and Chiredzi (541 mm annual mean rainfall; 21.3°C annual mean temperature) which was the higher-temperature analogue site for Matobo (567 mm annual mean rainfall: 18.4°C annual mean temperature) for drier areas. First season (2011/12) results showed that for the wetter pair, maize and groundnut grain yields were significantly higher at the cooler site (Mazowe). Sorghum yields were not significantly different between the sites and there was no grain yield for cowpea at the cooler site due to a fungal disease. Varietal yield differences were only significantly higher ($P<0.05$) at the cooler site for groundnut where the short duration variety had the highest yield (3809 kg/ha) and the medium duration variety the lowest yield (1420 kg/ha), compared with 140-355 kg/ha at the hotter site where growth was poor for all varieties. For the drier sites, maize, sorghum and cowpea grain yields were higher at the cooler site (Matobo) compared with the hotter sites (Chiredzi) but varietal differences were not significant. Results for the second season (2012/13) will be presented.

Introduction

Crop productivity and food systems are predicted to be affected by changing climate which is likely to affect crop variety preferences by farmers across varying agro-ecological regions in future (Gregory *et al.,* 2005). In Zimbabwe, conditions for growing early low yielding maize varieties are projected to shift more into currently wetter regions experiencing changing conditions suitable for growing long duration high yielding varieties (Nyabako and Manzungu, 2012). Reduction of crop yields is likely to effect a fall in crop revenue by as much as 90% (Carter *et al.,* 2007). The changes in crop production patterns is more likely to affect the marginalised smallholder farmers, who already experience low productivity due to current socio-economic and biophysical challenges characterising the drier areas of sub-Saharan Africa thereby impacting negatively on food security (Matarira *et al.,* 1995). These changes call for a focus on adaptive cropping strategies that will serve as mitigation measures against drastic changes in peoples' livelihoods (Eriksen *et al.,* 2011).

Exposing communities to various crop variety options than those they traditionally grow might be a way forward in preparing these farmers for the future. Crop breeding has to be in tandem with changing climate. As the conditions in the wetter areas get drier and warmer, it is important for farmers to realise that they can no longer continue with high yielding crop varieties that take long to mature but rather move to shorter duration varieties to ensure food security is maintained. It is against this background that

different crops and their varieties were grown on climate analogues and their reference sites. The crops were selected based on farmer preferences and suitability to different climatic conditions whilst the varieties were selected based on the number of days to maturity. The days to maturity vary from crop to crop and is influenced by crop genotype, climatic and environmental factors (Bruns, 2009). As these factors change, it is important that research informs on climate risk mitigation varietal cropping options, which farmers can adopt to minimise climate change shocks such as total crop failure due to droughts. The dilemma for farmers is to ascertain whether crop varieties will still perform to expected yield potential given the anticipated climatic changes. A study was carried out to assess the performance of selected crops and their varieties under different climatic regimes. It was hypothesized that as temperatures increase with climate change, short duration crop varieties will be better adapted to these climates.

Materials and methods

Site description

The study was conducted at two climate analogue sites; wet and dry and their respective reference sites classified as cool and hot. The hot/wet analogue site was Kadoma (722 mm annual mean rainfall; 21.8^{o}C annual mean temperature) which represented the 2050s climate in the cool/wet reference site Mazowe (842 mm annual mean rainfall; 18.2^{o}C annual mean temperature). The hot/dry analogue site was Chiredzi (541 mm annual mean rainfall; 21.3^{o}Cannual mean temperature) which represented the 2050s climate in the cool/dry reference site Matobo (567 mm annual mean rainfall: 18.4^{o}C annual mean temperature). The 2011/12 season rainfall totals (Table 1) were recorded.

Table 1: 2011/12 seasonal rainfall cumulative totals for selected sites

Site	Rainfall (mm)
Matobo	278
Chiredzi	462.8
Mazowe	673.6
Kadoma	577.5

Soil samples were collected at the beginning of the first season (2011/12) from three sites for site characterization. A summary of soil chemical properties from the top 15 cm from the two study sites is given in Table 2.

Table 2: Soil characterization on analogue and reference sites

Site	pH	Olsen- P (mg kg^{-1})	Total P (%)	Mineral N (mg kg^{-1})	Total N (%)	Organic C (%)
Matopos	5.3	0.1	0.01	3.7	0.04	0.8
Mazowe	5.6	0.5	0.1	2.4	0.1	1.6
Kadoma	6.1	0.5	0.04	3.7	0.1	1.3

Experimental design and management

The experiment on crop varieties was set up as a completely randomised block design with four crops (Table 3), each with three varieties replicated three times in 30-54 m^2 plots.

Table 3: Crop varieties

Crop	Early maturing variety	Medium maturing variety	Late maturing variety
Maize	SC403	SC513	SC727
Sorghum	Macia	SDSL89473	Pato
Groundnut	Nyanda	Natal common	Makhulu red
Cowpea	CBC1	CBC2	Landrace

Land preparation was done using a SC6 tractor drawn disc plough and planting furrows were opened using hand hoes. The plant spacing used was based on national extension recommendations for each crop. Maize was planted at 90cm (between rows) x 30cm (in-row) giving an approximate 37037 plants per hectare, sorghum 75cm x 20cm (approximately 66 666 plants per hectare) whilst groundnut and cowpea were planted at 45cm x 15cm (approximately 148 148plants per hectare). Compound D (7N:6P:6K) fertilizer was applied as basal at planting at a rate of 286 kg ha^{-1} for all crops at the dry sites and at 300 kg ha^{-1} at the wet sites. The experiment was managed under rain-fed conditions at all sites.

Thinning was performed two weeks after emergence for all crops. Ammonium nitrate was applied (above ground) to maize and sorghum plots as top dressing fertilizer at a rate of 58 kg ha^{-1} at the dry sites and 150 kg ha^{-1} at wet sites six weeks after planting. The fertilizer was placed 5cm away from the plants and left uncovered. Gypsum was applied to groundnuts at flowering at a rate of 250kg ha^{-1}. All the plots were hand hoe weeded three times using hand-hoes with the first weeding performed two weeks after planting. Armyworm (*Spodoptera exempta*) and other leaf eaters were controlled by spraying carbryl (1-naphthyl methylcarbamate) 85% WP. Aphids were controlled several times in cowpea by spraying diamethoate (O,O-Dimethyl S-(N methylcarbamoylmethyl) phosphorodithioate).

Data collection

Net plots of 3 x 4 m were marked within the experimental plot. Grain yields were determined by harvesting crop in the net plots at physiological maturity. Grain sub samples for maize and sorghum were collected and oven dried to 12.5% moisture. The net plot grain weights were then corrected to 12.5% moisture and yield calculated. For groundnut and cowpeas net plots of 11 rows x 4 running metres were harvested at physiological maturity (cowpea; dry pods and groundnut after browning of leaves). The harvested crops were cleaned and sun dried for three days and then shelled. The grain was weighed and corrected to 10% content and resultant yields were calculated.

Statistical analysis

Grain yields were analyzed using analysis of variance (ANOVA) in GenStat 14th edition (VSN, 2011). The standard error of differences (SED) of the means ($P < 0.05$) was used to separate site and variety means.

Results

Grain yields at wet sites

At the wet sites, maize (Table 4) and groundnut (Table 5) yields were significantly different between the cool and hot sites ($P < 0.05$). Varietal differences were only observed for groundnuts. For maize, yields were higher at the cooler sites for all varieties. The late duration variety gave the highest yields (5937 kg ha^{-1} at Mazowe, 3979 kg ha^{-1}at Kadoma), followed by the early duration (5083 t ha^{-1} at Mazowe, 3373 kg ha^{-1} at Kadoma) and lastly the medium duration (4857 kg ha^{-1} at Mazowe, 2529 kg ha^{-1} at Kadoma), although differences were not significant across varieties ($P > 0.05$). Sorghum yields ranged from 2000-5500 kg ha^{-1} at both sites; however, the yields were neither affected by site nor variety.

Groundnut varieties were significantly different ($P>0.05$) between the two wet sites with higher yields recorded on the wetter site, Mazowe (1420-3809 kg ha^{-1}). (Table 5). The yields were low at the hot site, Kadoma (140-158 kg ha^{-1}) due to poor establishment of the crop. The cowpea yields were obtained at

Kadoma, a comparison between sites was not made as the crop was affected by a fungal disease at the cool site (Mazowe) and hence no grain yields were obtained.

Table 4: Maize and sorghum grain yields at Kadoma (hot/wet) and Mazowe (cool/wet), Zimbabwe in the 2011/12 season

	Maize				Sorghum	
	SC403	SC513	SC727	Macia	SDSL89473	Pato
Kadoma	3373	2529	3979	3121	5468	3928
Mazowe	5083	4857	5937	5223	2007	3861
P values						
Site		0.005			0.088	
Variety		0.198			0.396	
Interaction		0.902			< 0.001	
SED						
Site		547.1			251.7	
Variety		672.0			308.2	
Interaction		952.3			435.9	
LSD						
Site		1238			560.8	
Variety		1520			686.8	
Interaction		2154			971.3	

Table 5: Groundnut and cowpea grain yields at Kadoma (hot/wet) and Mazowe (cool/wet), Zimbabwe in the 2011/12 season

	Groundnut			Cowpea		
	Nyanda	Natal common	Makhulu red	CBC1	CBC2	Landrace
Kadoma	158	355	140	1250	1546	976
Mazowe	3809	1420	2094	-	-	-
P values						
Site		< 0.001			-	
Variety		0.015			0.138	
Interaction		0.007			-	
SED						
Site		259.0			-	
Variety		317.2				
Interaction		448.6			-	
LSD						
Site		577.1			-	
Variety		706.9			671.7	
Interaction		999.6			-	

Grain yields at dry sites

At the dry sites, maize, sorghum (Table 6) and cowpea (Table 7) yields were significantly different between the cool and hot sites ($P < 0.05$). The cool site (Matobo) had the highest crop yields for all crops and across all varieties although varietal differences were not significantly different. Crops and their varieties established well at Chiredzi; however a series of dry spells ranging between 9 to 15 days with no rainfall during the months of January and February affected crop growth and ultimately the crop yields.

Table 6: Maize and sorghum grain yields at Chiredzi (hot/dry) and Matobo (cool/dry), Zimbabwe in the 2011/12 season

	Maize			Sorghum		
	SC403	SC513	SC727	Macia	SDSL89473	Pato
Chiredzi	75	150	245	26	185	15
Matobo	2523	2152	3450	2374	2337	1781
P values						
Site		< 0.001			< 0.001	
Variety		0.435			0.235	
Interaction		0.556			0.412	
SED						
Site		445.4			173.5	
Variety		545.6			212.5	
Interaction		771.5			300.5	
LSD						
Site		992.5			386.6	
Variety		1216			473.5	
Interaction		1719			669.6	

Table 7: Groundnut and cowpea grain yields at Chiredzi (hot/dry) and Matopos (cool/dry), Zimbabwe in the 2011/12 season

	Groundnut			Cowpea		
	Nyanda	Natal common	Makhulu red	CBC1	CBC2	Landrace
Chiredzi	169.8	431.0	298.1	254.6	93.9	27.0
Matopos	409.9	431.9	415.8	856.8	1167.0	1153.0
P values						
Site		0.303			< 0.001	
Variety0.593	0.927					
Interaction		0.685			0.358	
SED						
Site		110.2			156.0	
Variety		135.0			191.1	
Interaction		190.9			270.2	
LSD						
Site		245.6			347.6	
Variety		300.7			425.7	
Interaction		425.3			602.0	

Table 8: Crop grain yields averaged by site for the 2011/12 season

Site	Maize	Sorghum	Groundnut	Cowpea
Kadoma	3289	4172	218	1257
Mazowe	5305	3697	2441	-
P value	0.005	0.088	< 0.001	
Chiredzi	157	75	299.6	125.2
Matobo	2708	2164	419.2	1058.9
P value	< 0.001	< 0.001	0.303	< 0.001

Discussion

At the wet sites, the reference site which was cooler (Mazowe) had higher maize and groundnut yields. Maize yields were higher in the wet areas with late maturing varieties (SC727) giving higher yields averaging 3.9-5.9 t ha^{-1} in wet/hot and wet/cool areas respectively. The higher grain yields at cooler sites might be explained by more available water for crop use. The late maturing maize variety SC727 gave the highest yields at both the reference and analogue sites. The cowpea was affected by a fungal disease at the cool/wet site as it tends not to do well in poorly drained and cool areas (Davis *et al*., 2007).

At the dry sites, all crop yields were highest at the cooler site, with maize yields of yields ranging from 0.07t/ha to 0.2t/ha in dry/hot and 2.5t/ha to 3.4t/ha dry/cool areas respectively. This was attributed to low, poorly distributed rainfall and several dry spells during the planting season (2011/12). Maize crop production varies with variation in spatial and temporal patterns of both total annual and planting season rainfall (Oseni and Masarirambi, 2011). The future climate for Matobo (current conditions at Chiredzi) may not favour crop production as yields were all lower than 0.5t ha^{-1} (Table 9).

All the three maize varieties (SC403, SC513 and SC727) yield performances were below the potential yield performances (SeedCo, 2011). This might have been attributed to the poor in-season rainfall distribution that prevailed at the sites. The maize varieties performed as expected in yield differences between the early (low yielding) compared to the late (high yielding) varieties as they are characterised by the production seed house SeedCo. Farmers currently producing high maize yields on wet cool sites (Mazowe) are likely to experience a decline in crop productivity as is currently occurring in the wet hot site (Kadoma). This might prompt the farmers to shift to short duration varieties that are, however, low yielding to adjust to the changes in climatic conditions. This is likely to affect household food security since maize is the staple food. Given this decline in maize yields, it will be of interest to look at the adaptation strategies employed by the rural poor in resolving food insecurity challenges. The decline in maize yields will not only affect food security but livelihoods in general as most farmers in wetter areas of Zimbabwe depend on maize production as a livelihood strategy.

Sorghum is mostly grown in the drier parts of Zimbabwe (Rao and Mushonga, 1987) and with the wetter regions expected to experience reduced rainfall and frequent droughts the crop might be a preference for the wetter regions in the future. Macia matured early and was not affected by in-season dry spells therefore giving yields ranging from 2.3t ha^{-1} in dry sites to 5.2t ha^{-1} in wet sites a performance that is consistent with the observations made by Saadan *et al.* (2000) except for Chiredzi site where the yields were severely affected by end of season dry spell. The medium duration sorghum variety SDSL 89473 showed some consistency in yields across dry and wet sites. Sorghum is one among the few resilient crops that can adapt well to future climate change conditions, particularly the increasing drought, soil salinity and high temperatures (http://www.icrisat.org/crop-sorghum.htm); however its preference by farmers might be hampered by labour involved in processing, taste and bird scaring. Though sorghum displayed consistently high yields its promotion might mean a lot of work has to be done on food product improvement, for farmers to take it up as an alternative cereal crop.

The performance of legumes in this trial shows some promising results especially for cowpea; however a shift to legume production will not be a likely solution considering suppressed markets similarly observed as a constraint in Malawi (Brand, 2011). This calls for genotypic improvement of maize varieties that are of both short duration and high yielding characteristics to ensure food security is achieved.

Cautious climate change adaptive measures have to be gradually introduced to avoid shocks associated with a future decline in crop productivity in the climate analogue sites. In dry sites some considerations have to be made on alternative livelihood options other than crop production as yields obtained from reference site (Chiredzi) for all test crops and their varieties were too low to sustain household cereal and legume food requirements. Livestock farming might be considered an option supported by supplementary fodder production to complement feed requirements during critical month of animal feed shortages.

Conclusions

We conclude that as temperatures increase with climate change, short duration varieties of maize will be better suited for the currently wet-cool environment. All sorghum and cowpea varieties may continue to give high yields however groundnut yields will decline significantly. At the currently cool-dry sites, we conclude that even the short duration varieties will give low yields and as such, lead to food insecurity.

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Enhancing food production in semi-arid coastal lowlands Kenya through water harvesting technologies

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Abstract

About 35% of coastal lowland Kenya is classified as semi-arid lands, and food production in these areas is constrained by low soil moisture. To address the constraint, two studies were conducted during the 2010 long rains, 2011 long rains and, both 2011 and 2012 short rains seasons to evaluate the performance of drought tolerant maize (Zea mays L.) varieties under different water harvesting technologies (Zai pits, tied ridges and conventional). The treatments were laid out in a split plot design with water harvesting methods as the main plots and maize varieties as the sub-plots. Four maize varieties (DK8031, DUMA 43, KDV1 and PH4) were evaluated under the three water harvesting technologies for the first experiment. For the second experiment, four maize plant population treatments of 3 (P3), 5 (P5), 7 (P7) and 9 (P9) plants per pit were used. Maize variety DUMA 43 was used alongside the four plant populations. The results for both experiments indicated that the maize yields in zai pits and tied ridges treatments were significantly ($P<0.05$) higher than for conventional treatment and the population of 5 plants per pit had significantly ($P<0.05$) higher grain yield than the rest of treatments.

Introduction

The coastal region of Kenya is a food deficit area with households purchasing one third of their food requirements, mainly because of insufficient food production on the farms (Saha *et al*., 1993). Maize is the most important food stable and constitutes a major component of the diet in the region (Wekesa *et al*., 2003; Waiyaki *et al*. 2006). More than 70% of maize area is cultivated by farmers in small holder units of less than 20 hectares of land (Doss *et al*. 2003). The crop is grown in all agro-ecological zones of the province including arid and semi-arid lands more suited for sorghum and millet (KARI, 2005; Wekesa *et al*., 2003). Although maize is the most important food crop in the region, the area produces 1.56 million bags, while the demand is 3.80 million bags leaving a shortfall of 2.24 million bags (MoA, 2012). The deficit has to be imported from abroad or other parts of the country. Over 75% of the coastal area is either arid or semi-arid (Jaetzold and Schmidt, 2006). Rapid population growth in the high and medium potential areas has forced farmers to immigrate to the marginal areas. In ASAL areas farmers grow local maize varieties recommended for the medium to high rainfall zones for lack of suitable varieties. This has in most cases resulted in crop failures since the drought sets in at the most critical stage of crop growth. Maize grown in plots demonstrating zai pits technology in semi-arid lands showed some yield advantage compared to tied ridges and flat planting (Sanginga and Woomer, 2009). However, zai pit construction was observed to be laborious and very expensive for farmers without adequate family labour or appropriate equipment (Kabore and Reij, 2004). This study was therefore carried out to determine the most adaptable drought tolerant maize variety under the various water harvesting methods, for high maize grain yield in semi-arid lands of Kilifi County. The objectives of the study were to determine the most suitable water harvesting technology for high maize yield in coastal lowland Kenya. Another study to determine the optimum plant population per zai pit was also carried out.

Materials and methods

The studies were conducted at the Kenya Agricultural Research Institute (KARI) testing site of Bamba in Ganze district which is described as a livestock-millet zone in Agroecological zone (AEZ) Coastal Lowland (CL) 5 (Jaetzold and Schmidt, 2006). They were carried out during the long rains of 2010and 2011 and theboth short rains seasons of 2011 and 2012. The Bamba site is characterized by unreliable and erratic

rainfall. The soils are rich in nutrients but crop productivity is limited by high ambient temperatures and low soil moisture. The natural vegetation consists of grass and thickets which is primarily utilized by cattle, sheep and goats. Eighty percent of the land is communally owned; communal grazing is practiced while the feeding system for livestock is free range grazing (Ramadhan *et al*., 2008). The major food crops grown in the area are maize, green gram, cowpea and cassava.

For experiment 1, four commercial drought tolerant maize varieties were evaluated under three water harvesting methods. The four varieties were DUMA 43, DK8031, KDV1 and Pwani hybrid (PH) 4. Pwani hybrid 4 was used as the local check. The three water harvesting methods included; Zai pits, tied ridges and conventional (flat). Zai pits are holes measuring 60 cm long, 60 cm wide and 60 cm deep. The pits were spaced 60 cm apart within the row and were 90 cm between the rows.

The treatments were laid out in a split plot design with water harvesting methods assigned to main plots and maize varieties assigned to sub-plots. Plots consisted of three rows of zai pits and one row comprised of four pits. At the time of excavation, soil from the first 30 cm was placed separately from that of the next 30 cm (31-60) cm. Before filling up the zai pits, dry grass was laid at the bottom up to about 15 cm and then compacted and the remaining portion of the hole was filled with a mixture of top soil and manure at the ratio of 2:1 up to a depth of 5 cm. Two seeds were planted at 9 equidistant spots within the zai pit and were thinned to one plant per hill resulting in 9 plants per pit.

Ridges were spaced at 90 cm. Crop spacing at the ridges and conventional method treatments were 90 x 60 cm. Three seeds were planted per hill and later thinned to two plants per hill. Farm yard manure was applied at the rate of 5 t ha-1 during planting to both tied ridges and the conventional treatments. Additional nitrogen fertilizer was applied as a topdress at a rate of 60 kg N ha-1 four weeks after planting. To control maize stalk-borer, 'Buddock' (0.05 GR 0.5 g/kg beta cyfluthrin) was applied at the rate of 8 kg ha-1 three weeks after planting. The crop in zai pits and tied ridges was weeded once while a second weeding was carried out at the conventional treatment plots.

Data was collected on: stand count, plant height, ear height, ear weight, grain moisture content, stover weight and grain weight. Agronomic data were subjected to analysis of variance and differences among treatment means compared using Fischer's Protected LSD test at $P < 0.05$.

For experiment 2, four maize plant population treatments of 3 (P3), 5 (P5), 7 (P7) and 9(P9) plants per pit were used. The density of 9 plants per pit was used as a check. Maize variety DUMA 43 was used alongside the four plant populations. More seeds were planted per hill and were later thinned to required plants per pit. Plots comprised of 3 rows of zai pits and each row comprised of 4 zai pits. Phosphatic basal fertilizer was not applied since farm yard manure had been applied to the zai pits during the 2011 long rains season. Nitrogen fertilizer was applied as a topdress at a rate of 60 kg N ha-1 four weeks after planting. To control maize stalk-borer, 'Buddock' (0.05 GR 0.5 g kg-1 beta cyfluthrin) was applied at the rate of 8 kg ha-1 three weeks after planting. Two weedings were carried out during the crop's growth. Data was collected on: stand count, plant height, ear height, ear length, field weight and moisture content. Maize was also shelled and grain weight recorded.

Results and discussion

Only the results for the effect of water harvesting technologies on maize performance are going to be presented in this paper. Water harvesting methods significantly influenced all the measured parameters (Table 1). Plants in the Zai pits treatment were significantly taller than those in tied ridges and the conventional tillage method. Though not quantified, it observed that the zai pits remained relatively moist for a longer time than the other treaments. This was attributed to enhanced water retention in Zai pits compared to the other treatments. However, the plants in zai pits were thinner than those for tied ridges and conventional treatments probably due to plant competition for light in zai pits. There were no significant differences in plant height between the tied ridges and conventional method. A similar trend was observed for ear height. Zai pits and tied ridges treatments indicated significantly ($P<0.05$) higher maize grain yield than the conventional method (Table 1). However, there was no significant ($P<0.05$) yield

difference between the Zai pits and the tied ridges. For maize stover, significant (P<0.05) differences were observed among all the water harvesting methods. The Zai pit method had significantly higher stover yield than both the tied ridges and conventional method. This was also attributed to enhanced water retention in zai pits. The maize stover yield from tied ridges was significantly (P<0.05) higher than from the conventional method. This was because plants in conventional treatments were stunted during the early stages of growth.

Table 1: Effect of method of water harvesting on plant height, ear height, grain and stover yield

Water harvesting method	Parameters			
	Plant ht (cm)	Ear ht (cm)	Grain yield (t ha-1)	Stover yield (t ha-1)
Zai pits	187.3a	97.7a	2.4a	7.8a
Tied ridges	159.2b	76.3b	2.3a	5.1b
Conventional method	155.2b	74.9b	0.9b	3.5c
LSD	15.9	9.3	0.4	1.5

Means within a column followed by the same superscript are not significantly different (P≤0.05)

Results for experiment two showed differences in plant height but significant (P<0.05) differences existed for only P5 and P7. There was no significant (P<0.05) plant population effect on ear height. However, significant (P<0.05) differences were observed for both ear length and grain yield as indicated in table 11. The populations of 3 plants per pit showed significantly (P<0.05) longer ears than both P7 and the check treatment (P9). However, there was no significant difference between P3 and P5. The longer ear size for P3 was expected because of less competition for nutrients amongst the plants due to lower density than the rest of treatments.

Grain yield was 2.72-4.97 t ha-1 for the populations of 9 and 5 respectively (Table 2). The population of 5 plants per pit showed significantly (P<0.05) higher grain yield than the rest of treatments. The population of 3 plants per pit was too low for the plants to compensate through ear size where as the population of 9 plants was too high hence presenting high competition for scarce resources. Though we used plant population to reduce competition, other workers have maintained the recommended population of 9 plants per pit while widening the pit from 60 x 60 cm to 75 x 75 cm (Njiru, 2012)

Table 2. Effect of plant population on plant height, ear height, ear length and grain yield

Plant population	Parameters			
	Plant ht (cm)	Ear ht (cm)	Ear length (cm)	Grain yield (t ha-1)
P7	200.7a	85.3a	13.3b	3.53b
P9	195.7ab	77.0a	13.0b	2.72b
P3	184.0ab	75.6a	16.6a	3.07b
P5	169.6b	69.7a	14.7ab	4.97a
LSD	28.47	20.38	2.80	0.94

abcMeans followed by the same superscript are not significantly different (P≤0.05) within the column

Conclusion

Both Zai pits and tied ridges methods of water harvesting are superior to conventional method of maize production and the two technologies would fit well in overcoming the adversaries of climate change in semi-arid lands. The plant population of 5 plants per pit was found to be optimum under the conditions of the current study area. Based on the findings this study Zai pit technology should be promoted in coastal ASALS with the emphasis of 5 plants per pit instead of 9 plants.

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Upland rice response to fertilizer in Uganda

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Abstract

Upland rice (Oryza spp.) yields are low in Uganda, partly because of inadequate fertilizer use. Yield response to nitrogen, phosphorus, and potassium application and economically optimal nutrient rates (EOR) were determined. Three on-station trials and two clusters of on-farm trials were conducted in Uganda at about 1000 m. Mean grain yield, with hulls, was 1.3 and 3.7 t ha-1 with 0 and 100 kg ha-1 N applied, respectively. Grain yield response to applied P compared with N was less, and mean yield was not increased with K application. Depending on fertilizer cost relative to grain price (CP), mean EOR ranged from 54 to 92 kg ha-1 N and 17 to 30 kg ha-1 P. Equations were determined for yield response, estimation of EOR, and the benefit:cost ratio (BC) for fertilizer N and P use. Grain N concentration and N harvest index at EOR were 1.55 and 55%, respectively. Mean recovery efficiency, partial factor productivity, and agronomic efficiency declined with increasing N rate and were 75%, 41 kg kg–1, and 28 kg kg–1, respectively, at the EOR. Fertilizer N and P use can be highly and moderately profitable, respectively, for upland rice production in Uganda. Maximizing net return on finance-constrained investment in fertilizer use needs to consider CP and smallholder investment capacity rather than net return ha-1.

Key words: economic, fertilizer use, nitrogen, phosphorus, potassium, use efficiency.

Introduction

Upland rice production is of less importance in Uganda compared with maize (Zea mays L.) and sorghum (Sorghum bicolor L. Moench), but production has increased substantially during the past decade due to high market value. The increased production has been achieved more through expansion of area sown than increased yields. Rice production in Uganda equals about 75% of consumption (Government of the Republic of Uganda, 2009). Smallholders are more likely to apply fertilizer to rice compared with other cereals because of the high market value of rice. However, levels of nutrient application are low and mean grain yield in Uganda is estimated to be 1.5 Mg ha-1 (FAOSTAT, 2011). Inadequate control of numerous constraints may contribute to the low yield as found in Tanzania with biotic constraints, low input use, and low availability of soil N and P constraining productivity (Mghase *et al*., 2010). Little, if any, fertilizer is applied for upland rice production in Uganda, as in other sub-Saharan African countries, because of high costs of fertilizer use relative to the price of rice (Otsuka and Kalirajan, 2006). Yet soil nutrient depletion is high and a major cause of land degradation with estimated mean depletion rates for nitrogen (N), phosphorus (P) and potassium (K) of -21, -8 and -43 kg ha-1 year-1, respectively, in Uganda (Wortmann and Kaizzi, 1998).

Currently there are no fertilizer recommendations for upland rice production in Uganda. Research findings from elsewhere are that nutrient application needs are highly variable and situation specific. Research in Uganda found that upland rice grain yield can often be increased by more than 100% with application of N and P, and the crop is responsive to Azolla spp. and to a preceding green manure crop of Mucuna pruriens L. (Kaizzi, 2002; Kaizzi *et al*., 2007). Yield increases of 2.1 – 5.2 Mg ha-1 in response to 80 – 120 kg ha-1 of applied N were reported in Uganda (Onaga *et al*., 2012). Miyamoto *et al*. (2012) found that paddy yield could be increased by 46 kg ha-1 per 1 kg ha-1 of applied N. In the Ivory Coast, yield was maximized with just 50 kg ha-1 of NPK fertilizer 12:24:18 or with 12 kg ha-1 urea-N applied with the low responsiveness attributed to soil water deficit stress during grain fill (Galabi *et al*., 2011). Kone *et al*. (2011)

encountered situations of reduced grain yield and root development with N application which was attributed to mid-season soil water deficits. In Benin, yields were less with no N compared with N applied in diagnostic trials (Kone *et al*., 2009). On the dry savannah land of northern Nigeria, grain yield increased linearly with N rates up to 90 kg ha-1 (Kamara *et al*., 2010). Upland rice yields were increased from 1.7 to 2.3 t ha-1 with a Bray-1 soil test P of 4 mg kg-1 with P application (Oikeh *et al*., 2010), and from 0.98 to 1.27 Mg ha-1 with Bray-1 of 2 to 3 mg kg-1 (Sahrawat, 2000) with 45 kg ha-1 P applied. Oikeh *et al*. (2008) determined 60 and 26 kg ha-1 to be the optimal rates of N and P application, respectively, for upland rice production by smallholders in Nigerian forest agro-ecosystems.

The objectives of this research were to quantify the yield response of upland rice to N, P, and K, to determine economically optimal nutrient rates for N, P, and K (EONR, EOPR, and EOKR) at different CP, and to evaluate efficiency of applied N use by upland rice in Uganda.

Materials and methods

Site characteristics and experimental design

Fertilizer response trials were conducted at five site-seasons in western Uganda across three cropping seasons from 2009 to 2010 (Table 1). Three site-seasons were on the Bulindi research station and two site-seasons were clusters of single sets of treatments evaluated on-farm with three farms per cluster providing replication. The research area was in the Western Mid-Altitude Farmlands Agroecological Zone (Wortmann and Eledu, 1999).

Table 1: Characteristics for research sites at Bulindi for three seasons, and for clusters of on-farm trials conducted at Kwera and Kiziranfumbi, to determine upland rice response to applied N, P, and K in Uganda

	Soil properties						Previous crop	Sowing date	Harvest date
Site-seasona	Sand	Clay	OM	pH	P	K			
	g kg-1				mg kg-1				
Bulindi 2009B	154	506	46	5.9	4.9	418	FL‡	Sept. 18 -20	Jan. 12 -15
Bulindi 2010A	326	505	44	5.9	4.6	235	CR	Mar. 17 - 19	June 8 - 21
Bulindi 2010B	168	550	49	6.1	7.9	385	CR	Aug. 23 - 25	Jan. 9 - 11
Kwera	405	406	36	6.0	6.2	231	CR	Sept. 1 - 10	Jan 15 - 30
Kiziranfumbi	503	298	54	7.1	3.7	132	CR	Sept. 1 - 10	Jan 15 - 30

a The rainfall is bimodal, with planting for season A and B occurring in March and April and in late August and September, respectively; ‡ The latitude, longitude, and elevation of the research locations, respectively, were: Bulindi, 1o30'N, 31o29'E, 1021 m, Acric Ferralsol; Kwera, 1o49'N, 32o58'E, Petric Plinthsol; and Kiziranfumbi, 1o21'N, 31o12'E, Acric Ferralsol. CR = cereal, FL = fallow

All Bulindi trial sites received >50 mm rainfall in the two weeks before sowing and received 430 mm or more of rainfall by 100 days after sowing (Fig. 1). Rainfall was less in season 2010B compared with other seasons with only 55 mm from 23 to 55 days after sowing. The rainfall and soils of the site-seasons were considered representative of the niches within agroecological zones where upland rice production occurs in Uganda.

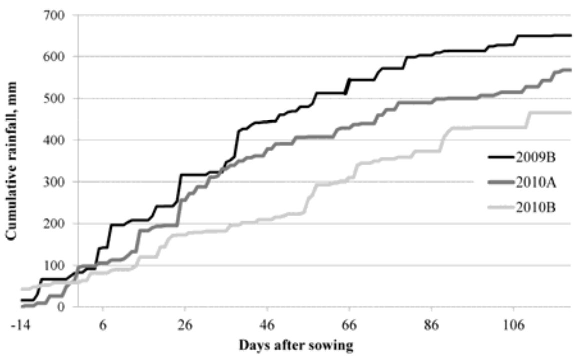

Figure 1**: Cumulative rainfall for three cropping seasons at Bulindi, Uganda**

The soils were Acric Ferralsols except for pre-dominantly Petric Plinthsol at the Kwera on-farm location (Table 1). The soils at all site-seasons had rooting depths greater than 1.0 m. Surface soil samples for the 0- to 20-cm depth consisting of 10 cores per site-season were collected before planting and fertilizer application to determine basic soil properties. Sand, clay, and soil organic matter content ranged from 154 to 503, 298 to 506 (Bouyoucos, 1936), and 36 to 54 (Walkley and Black, 1934) g kg-1 soil, respectively. Mehlich-3 P (Mehlich, 1984) ranged from 3.7 to 7.9 mg kg-1 soil.

The experimental design was a randomized complete block design of three replications for the Bulindi trials, and with five or six single replication trials per on-farm cluster. The nutrient rates evaluated were: 0 (N0), 50, 100, and 150 kg N ha–1; 0, 12.5, 25.0, and 37.5 kg P ha–1; and 0, 30, 60, and 90 kg K ha–1 (Table 2). The incomplete factorial arrangement limited the treatment number in consideration of Liebig's law of the minimum, proposed by J. von Liebig in 1840, expecting N and K to be the most and least limiting of the three nutrient deficiencies. The N0 treatment occurred only with no P and K applied, and P and K effects were tested only with N applied. Similarly, no K was applied for the zero-P treatment. There was confounding of P and K treatments. The K effect was determined in the statistical analysis by subtracting at the plot level the K-minus treatments from the corresponding K-plus treatments after verifying that the P × K interaction was not significant; K level effect on these differences was determined.

Table 2 **The N-P-K rates (kg ha-1) of fertilizer trials conducted for upland rice in Uganda.**

0-0-0						
50-0-0	50-12.5-0	50-25-0	50-37.5-0	50-12.5-30	50-25-60	50-37.5-90
100-0-0	100-12.5-0	100-25-0	100-37.5-0	100-12.5-30	100-25-60	100-37.5-90
150-0-0	150-12.5-0	150-25-0	150-37.5-0	150-12.5-30	150-25-60	150-37.5-90

Varieties were a sub-plot factor including Nerica4 and Superica. Nerica-4 is a genotype derived from the interspecific hybridization of WAB 56-104 (Oryza sativa, tropical japonica type) and CG 14 [Oryza glaberrima]). Superica-1 (O. sativa) is a Ugandan release. Each variety has a maturity period of 120 days. The plot size was 4 by 6 m.

The N, P, and K sources were urea, triple super phosphate, and potassium chloride, respectively. Fertilizer P was applied pre-plant. Fertilizer N and K were applied with 25% pre-plant, 25% at tiller formation, and 50% at panicle initiation. The fertilizers were surface broadcast applied at planting and incorporated. The side dress application of N and K was band-applied to the side of the row and covered.

Crop management and data collected

Site preparation included disk plowing at 15 to 20 cm depth followed by secondary disk tillage at 10 cm depth. The previous crop and sowing dates varied (Table 1). Seeding rates were selected to achieve final plant populations of 50 plants m–2, with spacing of 20 cm by 20 cm. In-season weed control was by weeding with hand hoes twice or thrice depending on weed intensity. During the season, chloropyrifos 5% (DursbanTM) was applied for control of the stem borer complex and the African rice gall midge (Orseolia oryzivora Harris and Gagné (Diptera: Cecidomyiidae).

The plants were cut at ground-level from the inner rows in a 1.5 x 2.0 m area and air dried for at least 3 d. The panicles were threshed and the harvested grain weight was determined. After adding the panicle remnants, the straw was weighed to determine the straw yield. The harvested grain was weighed, and grain yield calculated. Grain yield was adjusted to 140 g kg-1 water content. Oven-dried plant samples were ground to pass a 0.5-mm sieve and analyzed for total N in a single digest by a wet-ashing technique with colorimetric determination (Anderson and Ingram, 1993; Okalebo *et al*., 2002). The harvest index (HI) was calculated. Straw and grain N concentrations were used in the calculation of N uptake in grain and total biomass, the N harvest index (NHI), and other N use efficiency (NUE) values.

Data analysis

The data analyses were done by site-season and combined across site-seasons using Statistix 9 (Analytical Software, Tallahassee, FL) with site-seasons and replications as random variables and varieties and nutrient rates as fixed variables. When significant nutrient rate effects occurred, an asymptotic yield function was determined: Yield (Mg ha-1) = a – bcN, where a was near maximum yield, b was the gain in yield due to nutrient application, and cN determined the shape of the curvilinear response where c was a curvature coefficient and N was the nutrient rate. The regression analyses by site-season and combined across site-seasons were done with plot data. Upland rice response to applied N was determined across all P levels after verifying a lack of N x P rate interaction, and response to applied P was determined with the zero N treatment omitted from the analysis. There were no grain yield increases due to applied K.

The EONR and EOPR, or the nutrient application rates that gave the greatest net return ha-1 to fertilizer use, were calculated for a range of CP. A grain price of US$0.40 kg–1 (Uganda Sh. 2400 US$-1) was used for the economic analysis. Equations were developed using non-linear regression analysis to relate EOR to CP. Benefit:cost ratio was considered to be the value of increased yield relative to cost of fertilizer use for the given application rate. Polynomial functions were determined for each crop-nutrient combination to estimate BC with application rate and CP as independent variables. Differences and relationships were considered significant at $P \leq 0.05$.

Nonlinear functions that related total N in the aboveground biomass at harvest (UN) to the N rate and grain yield were determined. Asymptotic regression analysis, using individual plot data, related NUE parameters to N rate. Exceptions were for straw N concentration and uptake which had linear and quadratic relationships to N rate, respectively, and for RE and agronomic efficiency of N use (AE) which had linear and quadratic relationships to N rate, respectively. The NUE parameters included grain N concentration and content, HI, NHI, internal efficiency (IE) of total plant N taken up from soil and fertilizer, partial factor productivity (PFP), and physiological efficiency (PE), recovery efficiency (RE), and (AE) for fertilizer N use (Cassman *et al*. 2002). The NUE components were calculated as: IE = Y/UN (kg kg–1) where Y is grain yield (kg ha–1); PFP = Y/N rate; NHI = grain N/UN; RE = (UN+N – UNN0)/N rate; PE = (Y+N – YN0)/(UN+N – UNN0); and AE = (Y+N – YN0)/N rate. The units for IE, PE, AE, and PFP were kg grain kg-1 N, and kg N kg-1 N for NHI.

Results

Yield response to N, P and K

The mean upland rice paddy grain yield at N0 was 1.42 Mg ha–1 and was more in on-farm trials than at Bulindi (Table 3). The predicted mean maximum grain yield was 3.67 t ha–1 (Table 4), with no significant yield increase for >100 kg ha–1 N applied.

Table 3: **Nitrogen application effect on upland rice grain and straw yield in Uganda. The results are the means of two varieties as there was no variety by N rate or P x N rate interaction**

Site-season	N rate, kg ha-1					N rate, kg ha-1				
	0	50	100	150	Pr	0	50	100	150	Pr
	Grain yield, t ha-1					Straw yield, t ha-1				
Bulindi 2009B	0.75cb	2.19b	2.45ab	2.48a	*	2.74c	5.26b	6.06b	7.04a	***
Bulindi 2010A	1.00b	2.56a	2.55a	2.62a	*	3.37b	5.98a	5.99a	5.78a	**
Bulindi 2010B	0.99b	3.27a	3.56a	3.36a	***	4.01c	7.20b	8.25a	8.20a	**
Kwera	1.79c	4.59b	5.02ab	5.18a	***					
Kiziranfumbi	1.87b	4.32a	4.97a	4.45a	***					
Meana	1.42b	3.39a	3.71a	3.62a	***	3.37c	6.15b	6.77a	7.01a	***
SE	0.26	0.53	0.63	0.59		0.49	0.17	0.18	0.17	

aThe N rate x site-season interaction was significant for straw yield due to a relatively greater increase in straw yield in season 2010B compared with the other seasons; bDifferent letters in a row under grain or straw yield indicate statistically significant differences at α ≤ 0.05

The N x P rate and N rate site-season interactions were not significant for grain yield but there was a relatively greater increase in straw yield in Season 2010B due to N application compared with the other seasons.

Table 4: **The coefficients for the upland rice grain yield response functions to applied N and the economically optimal N rates (EONR) for different cost of fertilizer N use to grain value ratios (CP)**

Site-season	Response coefficients			EONR at five N:grain price ratios				
	t ha-1			kg ha-1				
	a	b	C	2	4	6	8	10
Bulindi, 2009B	2.65	1.90	0.971	113	96	76	66	58
Bulindi, 2010A	2.59	1.56	0.945	67	55	47	43	38
Bulindi, 2010B	3.57	2.40	0.971	118	95	81	71	64
Kwera	5.59	3.44	0.979	113	106	92	85	80
Kiziranfumbi	4.85	2.81	0.956	150	132	114	101	91
Combined	3.67	2.40	0.958	92	76	66	60	54
SE	0.36	0.59	0.054					

Upland rice grain yield increased in response to N for all site-seasons (Table 3, 4). The predicted overall mean grain yield increase was 2.40 t ha–1. Grain yield was significantly increased by application of >50 kg ha-1 N for only two of the five site-seasons but this was not sufficient to result in a N rate x site-season interaction. Combined across all site-seasons, the grain yield response to applied N was

$$Y = 3.67 - 2.40(0.958^{N}) \quad \text{Eq. 1}$$

$$Y = 3.39 - 2.12(0.968^{N}) \text{ with no P or K applied} \quad \text{Eq. 2}$$

The b and c coefficients of equations 1 and 2 were not significantly different at α = 0.05 using a z-test. Upland rice straw yield was increased by 50 kg ha-1 N application for the three site-seasons where measured, with an additional increase by applying more N at two of the site-seasons.

Nitrogen was profitable for all site-seasons and all CPs, and the site-season EONR ranged from 38 to 150 kg ha–1 depending on the CP (Table 4). The mean EONRs determined from the analysis combined across all site-seasons ranged from 54 and 92 kg ha–1 with CPs of 10 and 2, respectively (Fig. 2).

Net returns to applied N were more sensitive to the N rate as the CP increased. The mean EONR can be estimated from the CP according to

$$EONR, kg\, ha^{-1} = 107.2 - 8.78CP + 0.339CP^2 \quad \text{Eq. 3}$$

The P x K rate interaction was not significant but the P rate □ site-season interaction was significant for grain yield with P, in the presence of N, resulting in increased upland rice grain yield for three of the five site-seasons (Table 5).

Table 5: Phosphorus application effect on upland rice grain and straw yield in Uganda. The results are the means of two varieties as there was no variety by N rate or P x N rate interaction

Site-seasons	P rate, kg ha-1					P rate, kg ha-1				
	0	12.5	25	37.5	Pr	0	12.5	25	37.5	Pr
	Grain yield, t ha-1					Straw yield, t ha-1				
Bulindi, 2009B	2.21b	2.25	2.41	2.55	Ns	5.81	6.04	6.22	6.23	ns
Bulindi, 2010A	2.36b	2.53b	2.50ab	2.80a	*	5.68	5.92	5.86	6.09	ns
Bulindi, 2010B	3.03b	3.29b	3.34ab	3.70a	*	7.14b	7.62ab	8.18ab	8.55a	*
Kwera	4.53	4.73	4.94	5.22	Ns					
Kiziranfumbi	4.44b	5.66a	4.51b	4.75ab	*					
Meana	3.31c	3.69ab	3.67bc	3.88a	**	6.21	6.53	6.75	6.97	ns
SE	0.50	0.65	0.51	0.52						

aThe P rate x site-season interaction was significant for grain yield with greater response to P rate for some site-seasons compared with others. The grain yield response function to applied P was: Yield = 3.79 – 0.556*0.947P.

bDifferent letters in a row under grain or straw yield indicate statistically significant differences at α ≤ 0.05

Yield increased with up to 25 kg ha–1 P for two site-seasons. In the combined analysis, grain yield was increased by 0.38 t ha–1 with 12.5 kg ha–1 P. The yield response function from the combined analysis was

$$Y = 3.79 - 0.556(0.947^P) \quad \text{Eq. 4}$$

Applying Eq.4, EOPR was determined to be related to CP, with CP for fertilizer P at 4-12, as

$$EOPR, kg\, ha^{-1} = 53.4 - 4.69CP + 0.134CP^2 \quad \text{Eq. 5}$$

Straw yield was increased with P at Bulindi in the 2010B season only with no additional increase with >12.5 kg ha–1 P applied. Mehlich-3 P was low at 4-8 mg kg-1, but there was no indication of relationship between soil test P and grain yield response to P. Grain and straw yield were not affected by K for any site-season.

The BC of fertilizer use was greater with N than P, and decreased as CP increased. The BC was related to nutrient application rate and CP for N applied at ≤100 kg ha-1 and P at ≤50 kg ha-1 as follows:

$$N\, rate \le 100\, kg\, ha^{-1} : BC_N = 56.52 - 0.541N - 9.983CP + 1.83E10^{-4}N^2 + 0.425CP^2 + 0.0326NCP \quad \text{Eq. 6}$$

$$P\, rate \le 40\, kg\, ha^{-1} : BC_P = 10.67 - 0.172P - 0.383CP + 1.01E10^{-3}P^2 + 0.0513CP^2 + 8.54E10^{-3}PCP \quad \text{Eq. 7}$$

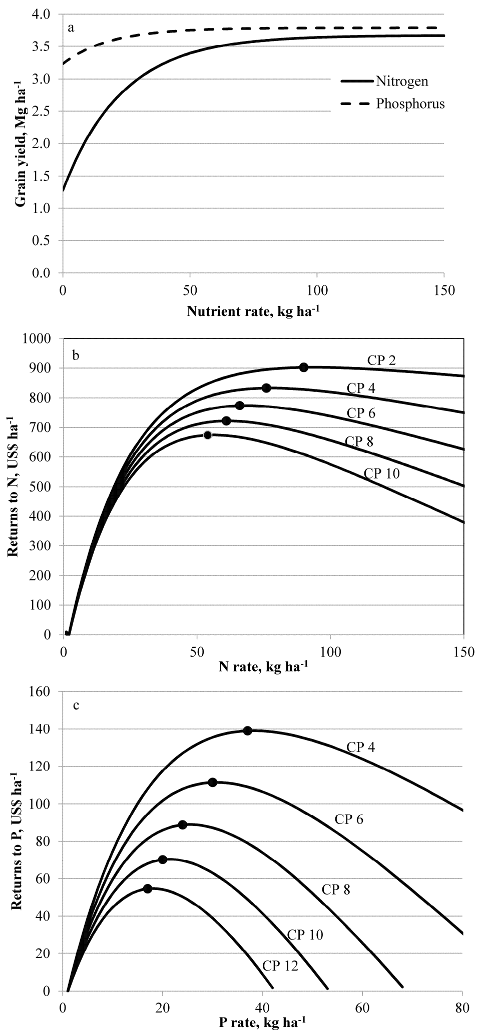

Figure 2: **Upland rice yield response to applied N and P, and economically optimal N and P rates for different ratios of fertilizer use cost to grain price ratios (CP)**

Nitrogen use efficiency

Plant UN ranged from 31 to 89 kg ha-1 for N0 and with 150 kg ha-1 N applied and was 79 kg ha-1 at EONR (Table 6). Variation in UN accounted for 82 and 74% of the variation in biomass and grain yield, respectively. Grain yield increased by a mean of 14.7 kg (kg UN)-1 for N0 and by 27.6 kg kg-1 UN across all N rates.

Table 6: Mean effect of N rate on components of N use efficiency by upland rice averaged for 5 site-seasons in Uganda

		N rate (kg ha-1)					
Component	Units	0	50	100	150	Pr	EONRa
Grain N concentration	g kg-1	14.2	15.6	16.1	16.8	***	15.5
Straw N concentration	g kg-1	5.60	5.32	6.08	6.05	***	5.6
Grain N content	kg ha-1	13.2	41.4	46.7	47.9	***	43.6
Straw N content	kg ha-1	18.0	32.3	41.6	41.2	***	35.6
Plant N content	kg ha-1	31.2	73.7	88.3	89.2	***	78.7
Harvest index	kg kg-1	0.24	0.31	0.30	0.30	***	0.30
N harvest index	kg kg-1	0.44	0.57	0.54	0.54	***	0.55
Recovery efficiency	kg kg-1		0.85	0.57	0.38	***	0.75
Agronomic efficiency	kg kg-1		34.4	19.7	12.7	***	28.1
Internal efficiency	kg kg-1	31.0	36.5	33.6	32.6	***	35.4
Partial factor productivity	kg kg-1		52.8	28.9	18.9	***	41.4
Physiological efficiency	kg kg-1		40.3	37.5	32.6	ns	

aThe EONR was 66 kg ha-1 for a fertilizer N use cost to farm-gate grain price ratio of 6; ns, no significant effect at $\alpha \leq 0.05$; *** Significant effect at $\alpha \leq 0.001$

Internal efficiency (IE), or the efficiency of converting UN to grain yield, is a function of NHI and grain N concentration. The linear effect of NHI and grain N concentration accounted for 72 and 11% of the variation in IE, respectively. Grain N concentration, NHI, and IE at an EONR = 66 kg ha-1 for CP = 6 were 15.5 g kg-1, 55% and 35.4 kg grain (kg UN)-1, respectively, which were higher than for the 0N rate (Table 6). The IE decreased with increased N rates. Mean NHI was high in comparison to HI. Upland rice NHI was similar and less than NHI reported for sorghum and maize, respectively, at EONR in Uganda, although EONR was higher for upland rice compared with sorghum and maize (Kaizzi *et al*. 2012 a,b).

Mean PFP declined with increased N rate and was 41 kg kg-1 at EONR compared with 79 and 83 kg kg-1 for sorghum and maize, respectively, although EONR was calculated for relatively low grain values for maize and sorghum compared with rice which is typical in Uganda (Kaizzi *et al*. 2012 a,b). Mean AE decreased with N rate and was estimated to be 28 kg kg-1 at EONR compared with 52 and 64 kg kg-1 for sorghum and maize, respectively. Mean PE of fertilizer N was not affected by N rate which is consistent with the results of the sorghum and maize studies. The following equations, determined from plot data of the three site-seasons at Bulindi, represent the N rate effect on various components of NUE for upland rice in Uganda.

$$UN, kg\ ha^{-1} = 91.82 - 60.89(0.977^{N})$$ Eq. 8

$$Grain\ N\ concentration, kg\ kg^{-1} = 17.50 - 3.47(0.992^{N})$$ Eq. 9

$$GrainUN, kg\ ha^{-1} = 47.60 - 34.42(0.968^{N})$$ Eq. 10

$$Stover\ N\ concentration, kg\ kg^{-1} = 5.32 - 0.0060N$$ Eq. 11

$$StoverUN, kg\ ha^{-1} = 17.73 - 0.356N - 0.00129N^{2}$$ Eq. 12

$$HI, kg\ kg^{-1} = 0.303 - 0.691(0.613^{N})$$ Eq. 13

$$NHI, kg\ kg^{-1} = 0.547 + 0.106 - 0.106(0.609^{N})$$ Eq. 14

$$IE, kg\ kg^{-1} = 23.63 + 0.0797N - 0.000570N^{2}$$ Eq. 15

$$AE, kg\ kg^{-1} = 57.6 - 0.564N + 0.00177N^{2}$$ Eq. 16

$$RE, kg\ kg^{-1} = 104.7 - 0.446N$$ Eq. 17

$$PFP, kg\ kg^{-1} = 12.9 + 101(0.981^{N})$$ Eq. 18

Discussion

Inadequate rainfall was not an apparent constraint to grain yield in the Bulindi trials as yield was highest in the 2010B season when rainfall was least and less well-distributed compared with 2009B and 2010A. The indigenous soil N supply was apparently low as indicated by a mean grain yield of 1.46 t ha-1 and 31 kg ha-1 UN with N0, even though SOM was always >36 g kg-1. In comparison, UN with N0 was 31 and 46 kg ha-1 by sorghum and maize, respectively, in Uganda with generally less SOM concentration (Kaizzi *et al*. 2012 a,b). In contrast, UN by irrigated maize in Nebraska at N0 averaged 175 kg ha-1 with similar or lower SOM levels (Wortmann *et al*. 2011). The difference in UN at N0 for Uganda compared with irrigated maize in Nebraska indicates greater recalcitrance of the SOM in Uganda with lower soil organic N mineralization rates, possibly associated with older soil surfaces and less annual return of organic material to the soil in Uganda compared with irrigated maize production areas in Nebraska. The organic matter of Uganda soils is probably valuable for enhanced soil physical properties including wet soil aggregate stability, water infiltration and percolation, water holding capacity, and cation exchange capacity (Tisdall and Oades 1982; Woomer *et al*. 1994), but apparently has low organic nutrient mineralization rates.

The large response of upland rice grain yield to N application was consistent with earlier results from Uganda (Kaizzi 2002; Kaizzi *et al*. 2007; Onaga *et al*. 2012), and with the responses of maize and sorghum in Uganda (Fig. 3; Kaizzi *et al*. 2012 a,b). Yield with N applied and at N0 was more and less for maize and sorghum compared with upland rice. The coefficient values for b of 2.14 and 2.40 and for c of 0.94 and 0.96 for maize and upland rice, respectively, were not significantly different resulting in similar curve shape although with the plateau reached with a higher N rate for upland rice compared with maize.

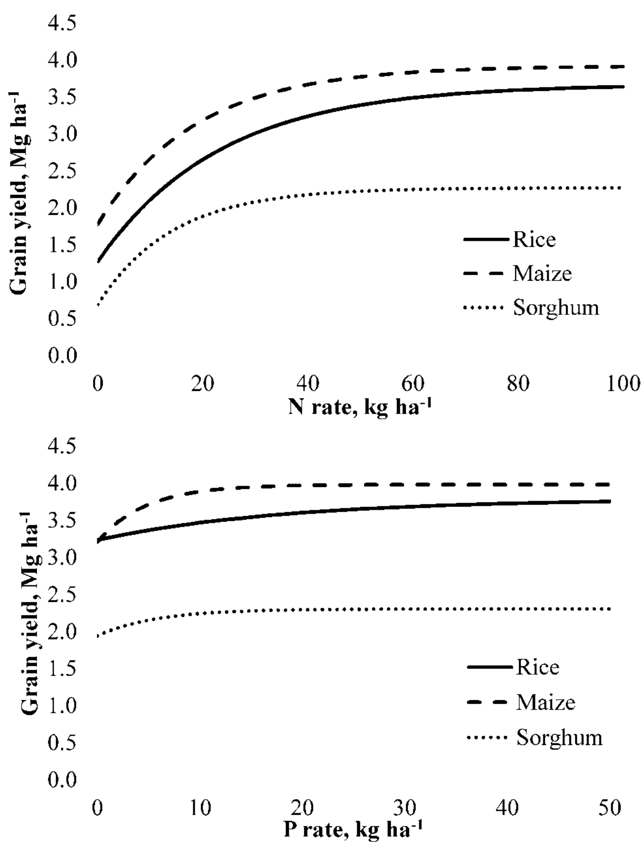

Figure 3: **The N and P grain yield response functions of upland rice compared with maize and grain sorghum in Uganda (Kaizzi *et al*. 2012 a,b)**

The high market value of upland rice compared with maize and sorghum results in relatively lower CPs and higher EONRs for upland rice. Upland rice response to applied P, with N applied, was more gradual and to a higher P rate compared with maize and sorghum which had little response beyond 10 kg ha-1 P. The significant but small increase in upland rice yield to P application, with N applied, was generally consistent with the responses reported by Oikeh *et al*. (2008) and Sahrawat (2000).

Depending on CP, the mean EONR and EOPR for upland rice ranged from 54 to 92 and 17 to 37 kg ha-1, respectively. In reality, the CP of fertilizer use must include fertilizer procurement and application costs, the interest rate or opportunity cost of the money used for fertilizer purchase, and the nutrient price. These added costs can be very high when fertilizer is not easily available. Opportunity cost for resource-poor people with little access to money is often 100% of the actual value due to other high priority uses of available funds and other investment opportunities (CIMMYT 1988). A BC ≥1 is therefore required for such an investment to be attractive to such finance-constrained farmers (Wortmann and Ssali 2001). The value

of grain used in determining CP, whether used for consumption by the producers or marketed, must consider the added costs of harvesting, processing, storage, and marketing the increased production.

Finance-constrained farmers commonly do not have enough money to apply fertilizer at EOR to maximize net returns ha-1. Fertilizer application at less than EOR to more land is expected to give more total production and higher net returns compared with applying at EOR to less land. Optimizing the choice of crop-nutrient-rate combinations, in consideration of CPs, is needed to maximize net returns on their constrained investment.

Considering 12 other crop nutrient combinations in Uganda using common CP values, Kaizzi *et al*. (2012c) found that the decreasing order of BC for fertilizer nutrients applied at EOR was groundnut (Arachis hypogaea L.) P > bean (Phaseolus vulgaris L.) N, maize N > soybean (Glycine max L.) P > sorghum N > groundnut K > maize P > bean P > soybean K, and > K applied to maize or sorghum. The BC for N applied to upland rice at EOR is greater than for any of the above and the BC for applied P to upland rice is less than for soybean P but greater than for sorghum N. This ordering could change with changes in relative CP due to changed grain values or nutrient costs. The upland rice EONR allows for BC >2, but BC >2 at EOPR only if CP ≤4. The results demonstrate that N application to upland rice can increase farm productivity with high profitability, and N application to upland rice should have priority over the 14 other crop-nutrient response function evaluated here and in Kaizzi *et al*. (2012 a,b,c). Phosphorus application for upland rice can be profitable when CP is not too high and/or when applied at less than EOPR. Improved input supply and marketing efficiency, fertilizer subsidies, and improved access to credit could greatly affect CP and therefore the BC of fertilizer use for upland rice production.

Recovery of applied N in the aboveground upland rice biomass was 75% at EONR which is a good recovery rate and intermediate between the RE reported for maize and sorghum (Kaizzi *et al*. 2012 a,b). The RE of sorghum was >100% as sorghum performance was poor at N0 and applied N apparently boosted plant vigor and root growth to recover nitrate-N that was otherwise lost to leaching beyond the root zone. Other fertilizer N use efficiency components were low at EONR for upland rice compared to maize and sorghum including AE and PFP, but this is largely due to the higher EONR of upland rice associated with its higher market value compared with maize and sorghum.

Conclusion

Upland rice increased by 178% with N applied at the EONR for a CP of 6. Yield can be further increased with P application but the results demonstrate that N deficiency is much more limiting than P or K deficiency. The yield response to applied N indicates that N application for upland rice production is highly profitable and a priority fertilizer application option relative to other crop-nutrient options of finance-constrained smallholder farmers of Uganda. The recovery of applied N is high if properly applied at EONR or less, implying little residual effect for the following crop but also little lost to the environment.

Acknowledgement

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The effects of application of integrated soil fertility management technologies on yields and economic benefits of maize in Kagera region, Tanzania

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Abstract

The production of maize in many parts of Kagera region is increasing rapidly due to declining production and yields of banana. However, maize yields from farmers' fields are low. The low maize yield is due to declining soil fertility aggravated by extensive weathering of the soils, low organic matter content in the soils and continuous crop removal of the nutrients from the soils without replenishment, use of poor germplasm and poor agronomic practices by farmers. Demonstration fields were established during 2010-2011 season in Biharamulo, Bukoba and Muleba districts of Kagera region to explore the effect of using ISFM technologies on maze yields and economic benefit. The treatments tested were Urea alone, Urea and Minjingu granular, Urea and Minjingu powder, Urea and Minjingu mazao, Urea and triple superphosphate and the control (no fertilizer). Urea was applied at the rate of 60 kg Nha-1 while TSP and Minjingu fertilizers were applied at the rate of 20 kg Pha-1. Demonstration fields were laid out using randomized complete block design (RCBD) in three replications. Before planting soil samples were collected and analyzed for texture, total N, Available P, organic carbon, pH, and CEC. Agronomic and economic data were collected and analyzed using GENSTAT and excel statistical software respectively. The soils were acidic to moderate acidic, with very low to low organic carbon, low to medium total N, low to medium extractable P, low to medium exchangeable K, low to medium exchangeable Ca, and low to high exchangeable Mg. The results showed significant ($P \leq 0.001$) difference in maize yields among the tested treatments but not across the districts. Application of fertilizers increased maize grain and biomass yields from 0.86 to 3.25 tha-1 and biomass yields from 0.76 to 1.45 tha-1. Likewise, application of fertilizers gave net profit ranging from 116.7 to 378.7 $ compared to net loss of $ 278 when fertilizers were not applied. The study showed that it was uneconomical to plant maize without application of fertilizers.

Key words: yields, benefits, fertilizers, germplasm

Introduction

Application of fertilizers is of great importance so as to increase maize yield. In order to increase the available P content of soils with low native P fertilizer, materials that contain P should be added to such soils. Sanchez 1976 pointed out that P was known to be the second most limiting nutrient element after nitrogen (N) in crop production in tropical soils, particularly the highly weathered soils. It is, therefore, of greater importance to apply P fertilizer materials, which will ameliorate the problem of insufficient P in such soils. Usually, most P fertilizers applied to agricultural land contain water-soluble components. The common sources of water-soluble phosphate fertilizers applied to field crops are triple super phosphate (TSP), single super phosphate (SSP), and mono or di-ammonium phosphate (MAP or DAP). However, there is little use of inorganic P fertilizers by resource-poor farmers due to high prices of these inputs. The resource poor farmers can benefit by use of less expensive but equally effective alternative P sources such as phosphate rock (PR) (Hammond *et al*., 1986). Therefore, research has been focused on possible use of agro mineral deposits, namely phosphate rocks, as an alternative to the more expensive water-soluble fertilizers (Khasawneh and Doll, 1978) to improve agricultural production

Phosphate rocks have received attention as low cost P fertilizers for acid soils (Khasawneh and Doll, 1978; Chien and Menon, 1995). In Tanzania phosphate rocks occur in different locations including Minjingu in

Arusha region, Chali hills in Dodoma region, Sangu-Ikolla, Panda hill, Mbalizi, Njelenje, Songwe and Nguala in Mbeya region (Patel, 1975; Mchihiyo, 1991; Mwambete, 1991) and Bachuba and Ichwandini in Muleba district in Kagera region (Mkamba, 1988). Significant deposits occur at Panda hill, Mbeya (igneous origin) and Minjingu, Arusha (sedimentary origin). Mnkeni *et al*. (1991) working with four different soils observed varied effects of Minjingu Phosphate Rock (MPR) on maize yields. In their studies, they observed that the rates of 80 kg and 240 kg P/ha significantly increased maize yield on Magadu and Mzumbe soils in Morogoro region, both of which had <6.5 mg P/kg soil and pH value <5.2. Semoka *et al*. (1992) observed that MPR applied at the rate of 40 mg P/kg soil was as effective as TSP with relative agronomic effective value of 92 % and 111 % in an Ultisols and an Oxisols, respectively.

In Tanzania 80 percent of the population depends on agriculture for their survival. Agriculture is the main source of food which account for about 26 percent of the national GDP and 30 percent of the foreign exchange gain. However, agriculture in the country is dominated by smallholder farmers having average farm sizes of between 0.9 hectares and 3.0 hectares (NBS, 2002). Kagera region is one of the 27 regions in Tanzania found in the Northwest part of the country at latitude 1o-3o S and longitude 30o-32o E. The region supports a population of 2.1 million people, of whom 90 percent live in rural areas (NBS, 2002). The rural economy relies on agriculture and 85% of people are involved in farming. Human population density varies from 250 people km2 in the dry areas to more than 510 people km2 in wetter areas (NBS, 2002). The region is endowed with high rainfall (above 1800 mm) with short and long rain cropping seasons yet it is one of the most food-insecure in the country. The smallholder production system that dominates the region and which is largely banana/coffee-based has low and declining productivity.

Production of maize in many parts of Kagera region is increasing rapidly due to declining production of banana. Fifteen years ago, maize was sparsely planted in the Kibanja (homestead garden where different crops are grown in a mixture), but after realizing that the crop is not suited for shaded conditions, the crop is now planted in Kikamba (open field far from or near to home), the land use type where normally no fertilizers or manure is applied. The average yields of maize is <1.1 t/ha (ARI Maruku, 2011).The major factors contributing to low maize yields in most parts of Kagera region are the low fertility status of the soils, use of local maize seeds and poor agronomic practices such as un-recommended spacing by farmers (Baijukya and Folmer, 1999). Low fertility status of the soil has been attributed to the extensive loss of nutrients through leaching especially in high rainfall zone (above 1800 mm), extensive weathering of the soils, low organic matter content in the soils and continuous crop removal of the nutrients from the soils without replenishment (Baijukya and Folmer, 1999. This suggests the need to apply fertilizers in these soils in order to improve the soil fertility status in the region for increased crop yields. This research study aimed to explore the effect of application integrated soil fertility management technologies (fertilizers, improved germplasm and agronomic practices) on maize yields and economic benefits.

Material and methods

Location of study area

Maize mother demonstration fields were established during 2010-2011 cropping season in three districts of Kagera region namely Biharamulo, Bukoba and Muleba. In Biharamulo district five demonstration fields were established at Mazigera (2.82786oS; 31.45742oE), Kagondo (2.72628oS; 31.49497oE), and (2.73453oS; 31.49109oE), Runazi (3.10336oS; 31.11683oE) and Nyamahanga (2.80019oS; 31.33289oE) villages, in Nyabusozi, Kabindi, Runazi and Nyamahanga wards. In Bukoba district four demonstration fields were established at Izimbya (1.54972oS; 31.44722oE), Missenyi (1.52333oS; 31.57083oE) Kaibanja (1.39917oS; 31.53833oE) and Kasharu villages in Izimbya, Butelankuzi, Kaibanja and Kasharu, wards. In Muleba district one demonstration field was established at Kyamunyorwa (2.09408oS; 31.57256oE) village in Kasharunga ward. The number of demonstration fields differs from district to district depending on the potentiality of the crop and availability of land during the respective cropping season.

Experimental design, treatments and treatment application

Demonstration establishment sites were selected by extension officers of respective wards/village in collaboration with researchers followed by land prepared by farmers. Demonstration fields were designed

and laid out by researchers with the assistance of extension officers using randomized complete block design (RCBD) in three replications. Plot size was 10 m x 10 m and the net plot was 43.2 m2. Three seeds of improved maize (Situka variety) were planted in each hole in a flat land at a spacing of 0.9 m x 0.6 m followed by thinning to two seeds per hole after 3-4 weeks of planting.The treatments tested were:

Control

Urea at the rate of 60 kg N ha-1

Minjingu granular at the rate of 20 kg P ha-1 + Urea at the rate of 60 kg N ha-1

Minjingu powder at the rate of 20 kg P ha-1 + Urea at the rate of 60 kg N ha-1

Minjingu Mazao at the rate of 20 kg P ha-1 + Urea at the rate of 60 kg N ha-1

TSP at the rate of 20 kg P ha-1 + Urea at the rate of 60 kg N ha-1

Soil sampling

Before planting, soil samples were randomly taken using soil auger at a depth of 0-30 cm. At least ten spots sampling was done, mixed thoroughly for composite soil sample, packed in a plastic bags and labelled in the field. The composite soil samples were air-dried, ground and sieved through 2 mm wire-mesh, packed labelled and sent at Ukiriguru Agricultural Research institute laboratory in Missungwi Mwanza for analysis.

Fertilizer application

Phosphorus fertilizers (TSP and Minjingu) were applied at planting. Nitrogen fertilizer (urea) was applied in two splits, half dose (30 kg N/ha) at planting and the second half dose (30 kg N/ha) at active growing (tasselling) stage of maize crop.

Demonstration fields management, data collection and harvesting

Demonstration fields were managed by farmers under the supervision of extension officers of the respective wards/villages. However, researchers and district extension officers visited the demonstration fields at least once per month for monitoring, collecting data and technical backstopping whenever required. After crops maturity, harvesting was done from a net plot of 43.2 m2. After harvesting, sub samples were taken for oven drying at Maruku station to get sub sample oven dry weights that were used to calculate yield in t/ha. Agronomic data including date of planting, weeding and harvesting, GPS readings and yields were taken during crop management and harvesting period. Harvesting was done after five months. Moreover, economic data including cost of inputs, farm management and prices of produces were collected during the whole period of maize growth.

Data analysis

Composite soil samples were analyzed for soil texture, pH, organic carbon, total nitrogen, available phosphorus, and exchangeable cations (calcium, magnesium, potassium and sodium) at Ukiriguru Agricultural Research Institute soil laboratory, in Mwanza region using standard by the National Soil Service, 1990 and Moberg, 2000. The collected agronomic data were processed and entered into GENSTAT statistic program and analysed using ANOVA. The means were compared using LSD at 5%. Economic data were processed and analysed using Excel spreadsheet program. Tables of mean yields and net profit for the treatments are presented in the results and discussion section.

Results and discussion

Fertility status of soils in the project area

Some of the chemical and physical characteristics of soils in the project area are presented in table 1. Soil analysis results showed that texture of the soils in the study area ranged from clay, to sandy clay loam. Soil

pH (in water) range from 4.26 to 6.30, soil organic carbon range from 1.06 to 3.36, total N range from 0.04 to 0.26 %, Bray 1 extractable P range from 12 to 25 mg/kg and exchangeable cations range from 0.01 to 0.92 meq/100g, 0.42 to 5.30 meq/100g and 0.08 to1.85 meq/100 g for K, Ca and Mg, respectively.

Table 1: Some chemical and physical characteristics of soils in the study area

District	Depth (cm)	Soil texture	Soil pH-H20 (1:2.5)	Soil OC (%)	Total N (%)	Available P –Bray 1 (mg/kg)	Exchangeable cation (meg/100g)		
							K	Ca	Mg
Bukoba	0-30	Clay, sandy clay and sandy clay loam	4.26-5.88	1.76-3.36	0.18-0.26	12-15	0.05-0.92	0.54-5.30	0.1-0.94
B'mulo	0-30	Clay, sandy clay, sandy loam and sandy clay loam	4.67-5.90	1.06-2.0	0.04-0.17	11-13	0.01-0.11	1.05-2.88	0.19-0.44
Muleba	0-30	Clay, sandy clay, sandy loam and sandy clay loam	4.48-6.30	1.44-3.22	0.13-0.25	12-14	0.05-0.30	0.41-10.51	0.08-1.85

Based on these laboratory soil results it showed that the soils in all sites were acidic to moderate acidic, with very low to low organic carbon, low to medium total N, low to medium extractable P, low to medium exchangeable K, low to medium exchangeable Ca, and low to high exchangeable Mg (Landon 1999). However, soil properties indicated slight differences between districts. These results generally indicated that inherent soil fertility status for soils in all the sites was low. This calls the need for external inputs for fertilizing the soil during crop production. Hence, the use of ISFM technologies is among other solutions to improve the fertility status of the poor soils in the project districts.

Maize grain and biomass yields due to application of nitrogen and phosphorus fertilizers

The mean grain and biomass yields of improved maize varieties planted using different type of fertilizers are presented in the tables 2. The results showed significant ($P<0.001$) difference in maize grain and biomass yields among the tested treatments fertilizers and districts. Interaction between districts and fertilizer did not show significant ($P < 0.0981$) difference in grain and biomass yields. Fertilizer application resulted into significant ($P < 0.001$) increase in grain and biomass yields as compared to control treatment. Application of triple super phosphate (TSP) and Urea gave the highest mean maize grain yield (3.25 t ha-1) followed by Minjingu Mazao and Urea (3.25 t ha-1) and Minjingu Powder and Urea (2.94 t ha-1). No significant ($P < 0.0981$) difference in maize grain yield was recorded between Minjingu granular + Urea (2.84 t ha-1) and Minjingu Powder + Urea (2.94 t ha-1) indicating that Minjingu powder and Minjingu granular gave equal maize response when applied with N–fertilizer (Urea in this case). Among the fertilizer treatments, the lower maize grain yield was observed from Urea alone (2.28 tha-1). This justified the need to apply both P and N fertilizers during maize production. Moreover, the districts differed significantly ($P < 0.001$) in maize grain yields. The highest maize yields were recorded in Bukoba district (2.63 t ha-1) and the least (2.12 t ha-1) was recorded in Muleba district. The same trend was observed in maize biomass yields (Table 2). The higher maize grain yields in Bukoba could be attributed to availability of enough soil moisture as compared to the other districts having low rainfall since Bukoba is located the in the high rain fall zone with annual rainfall of >1800 mm based on agro-ecological zones of Kagera region. Application of fertilizers increased maize grain and biomass yields to about 4 and 2 folds, respectively as compared to when fertilizer was not applied.

The results generally, showed that farmers in the study area need to apply the combination of both P and N fertilizers for higher maize yields.

Table 2: Maize grain and biomass yields due to application of nitrogen and phosphorus fertilizer

District	Treatments						
	Control	Minjingu Granular + Urea	Minjingu Mazao + Urea	Minjingu powder + Urea	TSP + Urea	Urea	Mean
Grain yield (t ha-1)							
Biharamulo	0.95	2.80	3.11	2.81	3.31	2.35	2.56
Bukoba	0.84	2.93	3.30	3.16	3.30	2.56	2.63
Muleba	0.49	2.53	2.57	2.40	2.67	2.06	2.12
Mean	0.86	2.84	3.15	2.94	3.25	2.28	
CV (%)	17.96						
LSD (5%)	0.49						
Biomass yield (t ha-1)							
Biharamulo	0.92	150	1.57	1.62	191	1.27	1.46
Bukoba	0.83	1.02	1.25	1.30	1.11	1.11	1.11
Muleba	0.71	0.70	0.84	0.88	0.87	0.79	0.79
Mean	0.86	1.21	1.36	1.41	1.45	1.15	
CV (%)	32.02						
LSD (5%)	0.43						

Economic benefits of maize due to the application of nitrogen and phosphorus fertilizers

The economic analysis for the tested treatments is presented in Table 3. The results showed that the control treatment (no fertilizer) gave negative net profit as compared to fertilizer treatments.

Table 3. The economic benefit of maize due to the application of nitrogen and phosphorus fertilizers

Item	Control	Minjingu granular + Urea	Minjingu Mazao + Urea	Minjingu powder + Urea	TSP + Urea	Urea
Grain yield kg ha-1	860	2,840	3,150	2,940	3,250	2,280
Price: $ Kg-1	0.4	0.4	0.4	0.4	0.4	0.4
Revenue: $ ha-1	344	1,136	1,260	1,176	1,300	912
Production cost: $ ha-1	622	925.3	935.3	925.3	921.3	795.3
Net profit: $ ha-1	-278	210.7	324.7	250.7	378.7	116.7
Breakeven price: $ Kg-1	0.72	0.33	0.30	0.32	0.29	0.41
Beak even yield: Kg ha-1	1.04	1.54	1.56	1.54	1.54	1.57

For the fertilizer treatments, the result showed that combined application of TSP at the rate of 20 kg P ha-1 and Urea at the rate of 60 kg N ha-1gave the higher net profit ($ 378.67) than Minjingu fertilizers and Urea at the same rates. It also showed combined application of Minjingu Mazao at the rate of 20 kg P ha-1 and Urea at the rate of 60 kg N ha-1 gave higher net benefit ($ 324.67) than Minjingu powder and urea ($ 250.67) and Minjingu granular and Urea ($ 210.67) at the same rates. Among the fertilizer treatments the lowest net profit was recorded from the application of Urea alone at the rate of 60 kg N/ha. These results revealed that farmers in Kagera region who were not apply any type of fertilizer during maize production were losing $ 278 from one hectare regardless using other recommended farm management practices.

Conclusion and recommendations

There was significant difference ($P<0.001$) in maize yields due to the application of different types of fertilizers among the applied treatments but not across the districts. This meant that the effectiveness of applied fertilizers to the performance of maize was different within the district but equal from one district to another. Thus, the recommendation of a particular type of fertilizer in one district could be applied to another district and bring the same response and all P source fertilizers tested in combination with Urea could be applied during maize production depending on which type is available. However, more benefits can be obtained by farmers when P fertilizer (s) (in this case TSP at the rate of 20 kg P ha-1) in combination with N fertilizer(s) (in this case Urea at the rate of 60 kg N kg-1) are to be applied followed by the combination of Minjingu mazao and Urea. Generally, the results showed increased maize grain and biomass yields of about 4 and 2 folds, respectively due to the application of fertilizers as compared to when fertilizers were not applied (control). It also showed that it was uneconomical to cultivate maize without application of fertilizers.

The research suggests more investigation on the rate(s) of fertilizers to be applied for optimum maize yields and economic benefit with in depth economic analysis based on return to labour and investment.

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Evaluation of soils in south western Nigeria for response to single super phosphate fertilizer under screen-house conditions

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Abstract

Application of Single Super Phosphate (SSP) fertilizer in soils with inadequate phosphorus (P) should elicit crop response. However, there is an indication of inconsistent response behavior to SSP fertilizer in some Nigeria soils despite their low available P. This study identified major soil types in south western Nigeria that are un-responsive to P fertilizer application under screen-house and soil properties that are related to this un-responsiveness behavior condition were determined. Maize seeds were sown in 3.0 kg soils treated with phosphorus fertilizer rates at 0, 30, 60 90 and 120 kg P2O5 ha-1 arranged in a complete randomized block design and replicated three times. Most of the locations responded to initial P application except for Fashola 2 which produced significantly higher maize shoot yield in control soils. There were five other locations where no-response was observed. Multiple regression analysis showed that PSI was influenced by the sand, clay and organic matter contents of the soils. Phosphorus response behavior can be explained by the available P levels, PSI and soil texture.

Key words: un-responsive soils, phosphorus, single super phosphate, available P and soil properties.

Introduction

Increasing demand for food crop production for the ever rising human population still remains a challenge of modern agriculture. However, Integrated Soil Fertility Management (ISFM) remains a key to sustainable production under tropical conditions (Iyamuremye *et al*., 1996; Zhenoy and Kalagudi, 2005). Studies have also shown that many Nigeria soils have available phosphorus levels below critical level of < 8 mgkg-1 hence, require phosphorus fertilizer application (Agbenin, 2003; Egwu *et al*., 2010). However, soils with high available phosphorus levels are mainly associated with high soil organic matter due to cropping system and management practices (Potarzycki *et al*., 2004). The application of phosphorus fertilizer has been shown to have tremendous effect on the soil especially the highly weathered tropical soils (Cottenie, 1980; Brady and Weil, 2008) and the use single super phosphate has also produced significant crop response in Nigeria soils albeit with cases of inconsistent response (Enwezor, 1977, Kang and Osiname, 1979; Osodeke *et al*., (2004). However, in some south eastern Nigeria soils, Osodeke *et al*. (2004) attributed no response to high soil P levels in the locations studied while other locations with low soil P content, required unusually higher P application rates to elicit response to P fertilizer (Enwezor, 1977). Similarly, pockets of soils with this inconsistent soil behavior have been observed in some western Nigeria savanna and forest soils (Adepetu and Corey, 1977, Kang and Osiname, 1979; Ayodele, 1980).

It is therefore, believed that these soils with inconsistent behavior constitute a significant part of cropland in Nigeria. Hence, identifying these soils with no response would elicit suggestions on how to improve phosphorus nutrition in crops and phosphorus release in such soils. Information provided from this study, will also improve existing phosphorus calibration and fertilizer recommendations.

The aim of this study therefore, was to identify some major soil series in southwestern Nigeria that are un-responsive to phosphorus (P) fertilizer and to determine soil properties that are related to these un-responsive soils under screen-house conditions with maize as a test crop.

Materials and methods

Soil sample collection

Twenty soil samples of different soil series from varous parent materials vegetation and soil management practices were collected from various locations in Lagos, Oyo, Ogun, Osun, Edo and Ondo states of Nigeria for cropping and laboratory studies (Table 1). They were air-dried, sieved through 2-mm sieve. The selected soils were from farmer's fields which have been cropped for 2-8 years. Other soils were from fallow fields and some national Agricultural Research Institute (ARI) fields.

Routine soil analysis

Routine laboratory analysis for the soil samples were carried out as described in the Department of Agronomy, University of Ibadan, Nigeria, laboratory manual for the analysis of soil, plant and water by Udo and Ogunwale (1986).

Determination of free Fe and Al oxides

The extraction method proposed by Blakemore *et al*., (1987) using the 0.2 M ammonium oxalate acid and oxalic acid solution was used to extract ammonium oxalate extractable iron and aluminium (Feo and Alo) in the extracts and they were determined with inductively coupled plasma - atomic emission spectrum at wavelength 258.8 and 396.1 nm respectively.

For dithionite citrate bicarbonate extraction (DCB), the extraction method proposed by Holmgren (1967) adapted from Blakemore *et al*. (1987) was used. Dithionite citrate bicarbonate extractable iron and aluminium (Fed and Ald) in the extracts were also determined with inductively coupled plasma - atomic emission spectrum.

Determination of the Phosphorus Sorption Index (PSI)

A Single Point Adsorption (SPA) procedure by Bauche and Williams (1971) as modified by Sims (2000) was carried out to provide a quick estimate of the phosphorus sorption capacity of the screened soils and provide information on the Phosphorus Sorption Index (PSI) of the soils. The amount of P sorbed (x) was calculated by subtracting the amount of P in the equilibrium solution from the amount added.

PSI was calculated as: (P sorbed)/(Log c) 1

where c = P concentration at 75 mgP/l

Screen-house studies with Single Super Phosphate (SSP)

Single Super Phosphate (SSP) fertilizer rates were applied to selected soils in three kg plastic pots of 6 cm diameter at the rate of 0, 30, 60, 90 and 120 kg P2O5 ha-1with the soils drainage holes and arranged in completely randomized design with three replications. A total of three hundred experimental pots were used for all the soils. Urea was applied at the rate of 120 kg N ha-1 to supply adequate N to the maize crop in addition to SSP rates and thoroughly mixed with the selected soils. The soils were sown with four maize seeds (TZE comp 3DT) after watering to field capacity. Maize plants were thinned to 2 seedlings 5 days after sowing and subsequently grown for 6 weeks. The harvesting of maize shoots was done after six weeks of growth and oven dried at 650C until constant shoot dry weight was obtained and stored in labeled envelopes. The second cropping of maize was carried out after removal of the roots from the selected soil samples. Data was subsequently analyzed statistically using Genstat statistical package (Genstat, 2008).

Table 1: **Chemical and soil texture properties of the experimental soil (0-20 cm depth)**

Soil location	Soil series	Soil classification (USDA)	Fine sand	Silt	Clay	Textural class (USDA)	pH (H_2O)	pH (KCl)	OC	Total N	Ca	Mg	K	Exch acidity	ECEC
			g kg-1				gkg-								
NIFOR 1	Alagba NIFOR	Typic paleudult	892	34	74	sand	5.0	3.7	18	1.26	1.1	0.9	1.7	1.0	4.9
NIFOR 2	Ahiara NIFOR	Typic paleudult	912	34	54	sand	5.3	4.3	20	0.80	1.7	1.2	1.6	0.6	5.4
Fashola 1	Fashola	Typic kanhaplustalf	852	74	74	Sand	5.4	4.4	18	0.38	0.4	0.7	1.8	0.2	3.3
Fashola 2	Oyo	Typic kanhaplustalf	892	54	54	sand	5.8	4.9	21	0.24	1.9	0.6	1.5	0.6	4.8
Ikoyi	Shante	Typic ustipsamment	792	114	94	Loamy sand	5.8	4,8	14	0.49	0.9	0.7	1.5	0.6	3.9
Iwo 1	Iwo	Typic paleudalf	792	114	94	Loamy sand	5.6	4.6	22	0.42	1.2	0.7	1.6	0.6	4.2
Iwo 2	Ibadan	Typic paleudalf	852	94	54	Loamy sand	6.2	5.0	20	0.10	2.1	0.7	1.7	0.4	5.1
Auchi	Ahiara	Typic paleudult	852	74	74	Sand	5.8	5.1	10	0.21	1.4	0.8	1.8	0.2	4.4
Ikenne 1	Alagba	Oxic paleustalf	872	54	74	Loamy sand	5.8	5.0	6	0.38	2.4	0.8	1.8	0.4	5.6
Ikenne 2	Agege	Oxic paleustalf	832	94	74	Loamy sand	5.2	4.4	20	0.28	3.3	0.8	1.8	0.6	6.7
Ikenne 3	Owode	Oxic paleustalf	692	194	114	Sandy loam	5.7	4.7	17	0.28	4.1	0.6	1.5	0.2	6.6
Ilaro	Ilaro	Oxic paleustalf	732	134	134	Sandy loam	6.4	5.4	10	0.42	1.7	0.7	1.6	0.6	4.8
Owo 1	Owo	Oxic tropulstaf	732	134	134	Sandy loam	6.0	5.1	19	0.42	4.4	0.7	1.7	0.4	7.4
Owo 2	Ondo	Oxic tropulstaf	692	154	154	Sandy Loam	6.4	5.8	54	0.17	1.8	0.8	1.9	0.2	4.9
Owena 1	Itagunmodi	Udic rhodustalf	932	34	34	Sand	5.4	4.8	17	0.28	6.0	1.0	1.5	0.4	9.1

Owena 2	Owena	Udic rhodustalf	752	154	114	Sandy loam	6.0	5.1	11	0.28	3.2	0.7	1.8	0.2	6.1
Badagry	Iweke	Iweke	832	74	94	Loamy sand	5.1	3.4	15	0.21	17	1.1	1.5	1.4	21.2
Egbeda 1	Egbeda	Udic rhodustalf	746	114	140	Sandy loam	5.7	4.9	21	0.84	5.8	1.4	1.0	0.4	8.8
Egbeda 2	Olorunda	Udic rhodustalf	726	114	160	Sandy loam	6.1	5.1	25	1.04	3.5	1.3	1.3	0.4	6.7
Epe	Iweke	Iweke	920	40	40	Sand	4.1	3.4	28	0.98	0.9	1.0	1.4	1.4	4.9

Results and discussion

The physical and chemical characteristics of the soils studied

Pre-cropping analysis results indicates that except for Total Nitrogen (N) which was below critical limit of 1.5 gkg-1 K, Ca and Mg were above critical limit of 0.15, 0.2 and 0.2 cmolkg-1 respectively (FFD, 2012).The texture and chemical characteristics of the experimental soil (0-20 cm) are shown in Table 1. The soil properties varied with soil type. The soil pH (H2O) ranged from 4.1 to 6.4 with an average of 5.6+ 0.54 soil while pH (KCl) ranged from 3.4 to 5.4 with an average of 4.7+0.62. The soils therefore ranged from strongly acid to slightly acid. Organic carbon gave an average value of 19+9.6 gkg-1 and ranged from 11 to 54 gkg-1 while the total N varied from 0.1 to 1.26 gkg-1 with an average value of 0.47+0.3 gkg-1. The trend of exchangeable bases in the order of abundance is Ca>Mg>K>Na for and mean values for K, Ca, Na and Mg were 0.2+0.02, 3.26+3.6, 1.2+0.02 and 0.85+0.24 cmolkg-1. The ECEC ranged from 3.3 to 20.2 cmolkg-1with a mean of 6.4+3.7 cmolkg-1 while the total exchangeable acidity ranged from 0.2 to 1.4 cmolkg-1 with a mean of 0.54.

The sand fraction was dominant in all soils and had a mean value of 815+78 gkg-1 with a range of 692 to 920 gkg-1. The silt fraction, ranged from 34 to 194 gkg-1with a mean of 93+45 while the clay fraction had a mean value of 92+38 gkg-1 and the corresponding range values of 40 to 154 gkg-1. The soils broadly were generally in the class of sand, loamy sand and sandy loam texture.

Phosphorus Sorption Index (PSI) and soil properties

The PSI value was 43-80% with an average value of 61%. According to Wolf and Slaton (2007) established soil critical level for PSI is 25-30%. When this is applied to the soils of this study, 12 (NIFOR 1, NIFOR 2, Fashola 1, Fashola 2, Ikoyi, Iwo 1, Iwo 2, Auchi, Ilaro and Epe) with PSI values greater than 60 % could be regarded as high P sorbing soils. It was observed that there was negative correlation between PSI and Feo, Fed and Ald (Table 2). When this occurs, free Fe oxides may exist as coatings on sand soils (Bolland *et al*., 1996) and as such P is not directly sorbed onto Fe and Al oxide in the soils. Earlier results of Ojanuga *et al*. (1975) and Uyovbisere and Chude (1995) have also reported negative relationship between sorption parameters and free Fe oxides in some Nigerian soils. There was however, positive relationship with exchangeable acidity and sand suggesting its influence on the P availability of the experimental soils.

Table 2**: Correlation between PSI and some soil properties**

	PSI (0-20 cm)
Exchangeable acidity	0.52
pH (H2O)	0.30
Clay	-0.30
OM	0.45
Feo	-0.77
Alo	-0.84
Fed	-0.60*
Ald	-0.46
ECEC	-0.62*
Sand	0.84*
Total N	0.51
Al saturation	0.52
Cu	0.66

* Significant at 5 %

Screen-house experiment

There is high significant difference in maize shoot dry matter response to different P levels (p=<0.001), soil types (p=<0.001) and P levels x soil types interaction (p= <0.001) (Fig. 1). Initial P application at 90 and 120 kg P2O5 ha-1 produced significant increase in maize shoot dry matter for all the soils except at NIFOR 2 soil. Corresponding lower values were obtained at Ikoyi and Fashola 2 soil in the second cropping (Fig 2). It was observed that residual effect of previously applied P at 90 and 120 kg P2O5 ha-1 resulted in significant maize shoot dry matter above control soils at NIFOR 1, NIFOR 2, Iwo 2, Ilaro, Owo 1, Owena 1 and Owena 2. However, maize shoot dry matter produced at 120 kg P2O5 ha-1 differed significantly from 90 kg P2O5 ha-1 only at NIFOR 1 and Ilaro. It will be recalled that PSI values for these soils were greater than 60 % (Table 2) and PSI was positively related with exchangeable acidity. This may suggest that high P application may be required for these soils and may be related to the appreciable amount of exchangeable acidity present in these soils (Table 1). However, for NIFOR 1, the high PSI of 73 % may be associated with soils derived from coastal plain sand parent material which is common with soils in that agro-ecology (NIFOR 1, NIFOR 2 and Auchi soils) and this indicate high buffer capacity (Bolland *et al*., 1996).

Consistent response to increasing rate of P application was observed at Owena 1 and Owena 2. The PSI for Owena 1 (51 %) and Owena 2 (52 %) did not differ thus; same P requirement may apply to both.

The soils with no P application produced lower maize shoot dry matter compared to higher P rates except at Fashola 2 which had consistently and significantly higher maize shoot dry matter in both first and second cropping. This may attributed to the moderate available P levels (FFD, 2012) and high PSI. The high maize shoot dry matter from soils with no SSP addition for Fashola 2 confirms previous observation (Sanginga *et al*., 1995; Sanginga *et al*., 2000) of no-response in Fashola soils. Higher maize dry matter from no P soils was also observed in Ikenne 2 soils in the first cropping. This trend was also observed at Epe which is predominantly sand textured soil in the second cropping. Other soils which did not respond to P fertilizer in the second cropping are Owo 2, Egbeda 2, Iwo 1 and Ikenne 1. Previous study (Adepetu and Corey, 1977) has observed no response behavior at Iwo 1 (Iwo soil series).

Multiple regression analysis performed to test the contribution of soil properties to phosphorus sorption index indicated that sand fraction, organic matter and clay content were the most associated variables (r = 0.88)*** used to determine the relationship between maize shoot yield and soil properties. Criteria used was based on the F probability of each individual variable (soil properties) added to the model.

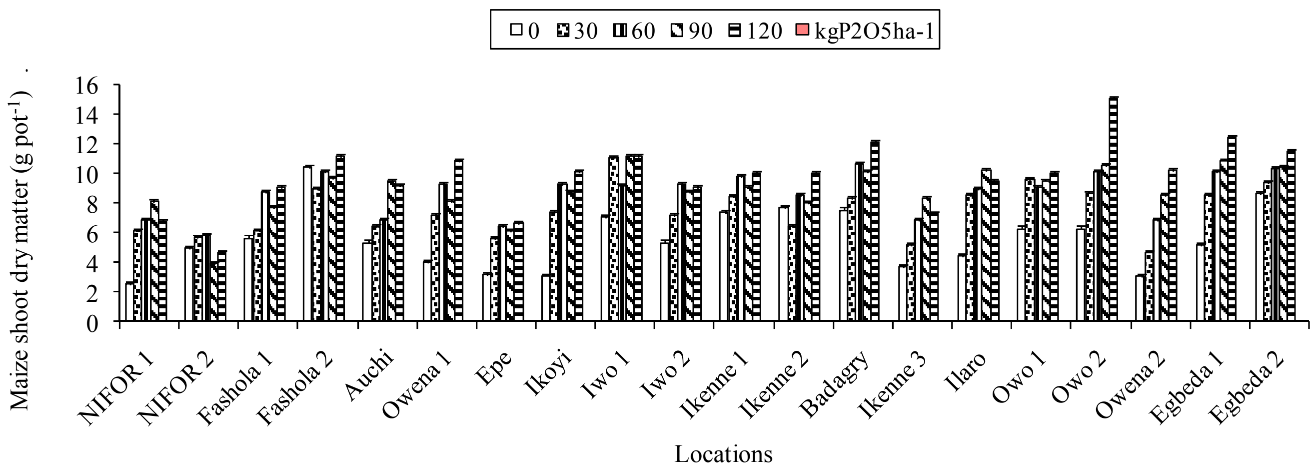

Figure 1**: Effects of different levels of phosphorus on maize shoot dry matter of twenty different locations under screen-house conditions for first cropping**

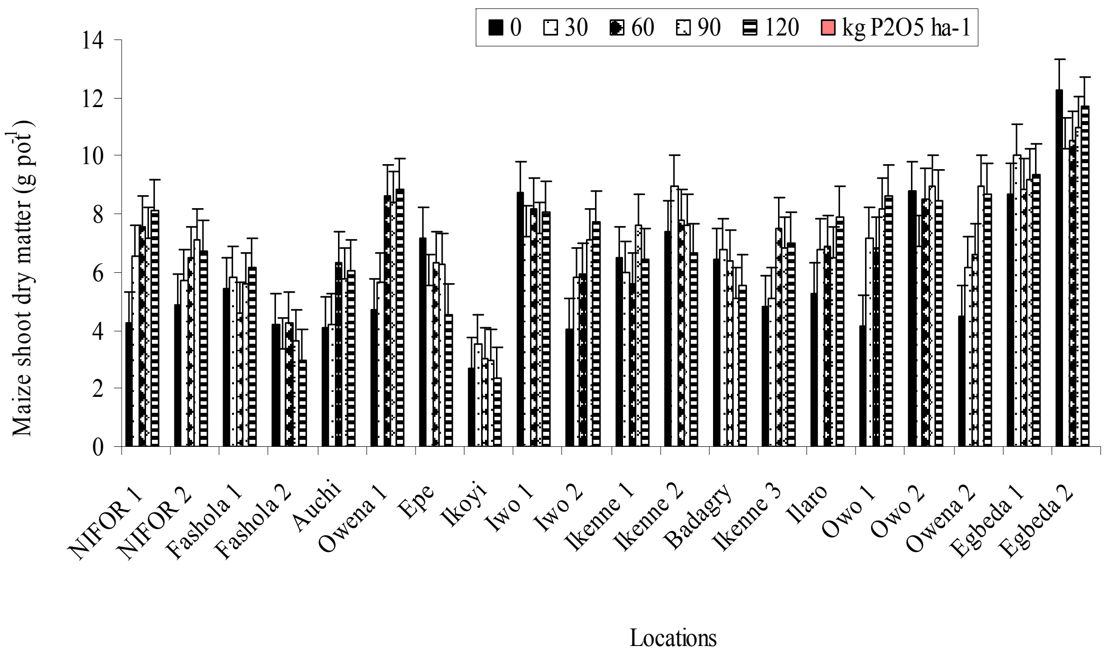

Figure 2: Effects of different levels of phosphorus on maize shoot dry matter of twenty different locations under screen-house conditions for second cropping

Conclusion

The above results indicate that moderate available P levels and residual SSP availability influence un-responsive P behavior in the selected soils. Phosphorus sorption is enhanced by the soil texture, organic matter and exchangeable acidity in these soils. There is need for detailed study of these un-responsive soils so as to understand the phosphorus chemistry of these soils.

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Adapting resource use efficient methods into integrated soil fertility management for maize production in Tabora, Tanzania

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Abstract

Assessment of resource use-efficient is an important tool for establishing sound Integrated Soil Fertility Management practices in a given socio-economic community. We studied different sources of locally available organic fertilizers. Animal manures, ashes of different origin, tobacco leaf residues and oil palm processing residues to a large extent can for a base for ISFM establishment. The use of high quality NPK with Ca,Mg S and Zn will have a big role to pray in improving crop productivity. The characteristics of particular farming systems provide the potentials and challenges of ISFM establishment. Locally available gypsum should be used in soil amelioration to improve soil health. Enhancement of locally available organic and inorganic resources should be promoted with support of field experiments to formulate the base for ISFM practices. There was a highly significant difference at (P=0.001) on maize grain yield following application of inorganic and organic fertilizers. Results show that modest rates of organic manures, ash and gypsum application have a positive effect on the soil.Recomendations are given on the importance of parallel assessment of local resources for ISFM practices establishment.

Key words: maize, soil fertility, indigenous methods

Introduction

Resource efficient methods of farming are based on a principle of maximizing organic matter recycling into soil which sustains soil health and productivity (Rodale, 1983).In the past four decades use of organic sources of soil fertility improvement in Tanzania was strongly based on the importance of substituting expensive inorganic fertilizers to help farmers maintain agricultural production (Kasembe *et al*., 1987).In recent agriculture soil fertility degradation has emerged as the most challenge in spite of the effort being put in place for increasing the use of inorganic fertilizers in Tanzania. The Tanzanian Government has established policies for promoting use of inorganic fertilizers among smallholder farmers through subsidy system and free marketing of inorganic fertilizers by national and international investors in the fertilizer sector.The establishment of Tanzania Fertilizer Regulatory Agency in 2012 is considered as the country's move towards increased use of inorganic fertilizers. Soil nutrient depletion is high in Tanzania; the loss of nutrients is a product of many interactive factors (Stoorvogel *et al*., 1993).Soil fertility and soil health promotion are addressed through adoption of the Integrated Soil Fertility Management (ISFM). This is the application of soil fertility management practices, and knowledge to adapt to local conditions, which maximize fertilizer use and organic resource efficiency and crop production (Sanginga and Woomer, 2009). Development of the sound (ISFM) should be established on assessment of local available resources that will enhance soil nutrient recycling, soil productivity and farmers income. This study focused on two aspects of resource-efficient methods in Western Tanzania. The first aspect was to assess the available resources and the second aspect was to test the field performance of using organic and inorganic resources and mineral inorganic fertilizers to improve soil productivity. Agricultural by-products are part of crop harvests that are not directly used by man or are the product of harvest processing with fewer utilities which could be used as soil amendments to improve soil fertility. Palm oil processing residues (POPR) are common in the oil palm-based farming system in western Tanzania. Studies in the humid rain forest in Nigeria (Nwoko and Sola, 2010; Okwute and Isu, 2007) and in Malaysia (Yeap and Poop, 1983, Chan *et al*.,

1980; Shamshuddin *et al*., 1992) show significant yield increments and soil health in response to application of palm oil processing effluents into soil. Organic animal manures application into sandy textured soil at rates of 12-26 t/ha was found to effectively impact the long-term effect for maize production in (Waddington and Karingwindi, 2001).Tobacco leaf residues and tobacco kiln ashes are some of local available organic resources which could be used to develop ISFM practices in the tobacco based farming system in Western Tanzania. According to the study by Rizvi *et al*., (2006) nicotine stimulated the growth of maize plants and it was thought that rotating maize with tobacco could improve maize grain yield Attention is given also on the potential of using locally available green manures for improving soil health and crop productivity. The main focus of the paper is to promote resource-efficient methods as part of ISFM in smallholder settings.

Materials and methods

A combined study with on-farm surveys for assessment of locally available resources with the potential for establishing ISFM was conducted in Tabora and Kigoma regions in Tanzania in 2009 through 2010.The survey involved collection of secondary livestock production data and discussions with targeted livestock keepers.Field and pot experiments were later carried out at Tumbi Agricultural Research Institute to test the effect of locally available resources on crop production. Locally available agricultural by-products tested included tobacco leaves residues, palm oil processing residues (POME) from Kigoma region. The overall treatments were(A) Control(B) NPK20:20:23 + 30 kg N(Urea), (C) Cow manure 5 tons/ha (D) POME 5 tons/ha, (E) Tobacco residues 5 tons/ha, (F)Manure of Procavian carpensis (PIMBI) 5 tons/ha. Maize was planted on 15 December 2010. Sidedressing of mineral fertilizers was carried out 20days after planting.

Maize was harvested, threshed and weighed. Maize yield data has been analyzed using GENSTAT Discovery 2006.

Results

Assessment of locally available organic animal manure is shown in Tables 1-4).

Table 1: Estimated livestock number spicies in Kigoma region

Livestock species	Kigoma municipality	Kigoma Rural District	Kasulu District	Kibondo District	Total
Indigenous cattle	902	29031	50506	2550	105959
Improved milk cattle	1349	615	1009	948	3921
Indigenous goats	3404	298238	65785	26428	360813
Milk goats	-	-	125	-	125
Sheep	1336	24143	8275	11212	44966
Pigs	1916	929	1394	890	5129
Indigenous chicken	69066	201332	247311	221826	739535
Egg laying improved breeds(Layers)	9569	227	649	2214	12659
Meat chicken(Broires)	512	-	395	-	907
Total Livestock units	79147	201559	248455	224040	752879

Source:National animal census 2010

Table 2: Estimated Annual Cattle Manure Production, Nitrogen, Phosphorus and Potassium in Kigoma region (Tons/dry matter basis)

Nutrient content	Kigoma/Ujiji	Kigoma rural District	Kibondo District	Kasulu District	Total
Cattle manure	439.27	5480.08	4863.74	9447.09	20230.24
Nitrogen content (N, 1.5%)	6.58	82.20	72.95	141.70	303.43
Phosphorus as (P2O5, 0.275%)	1.20	15.07	13.37	25.97	55.61
Potassium as (K=1.275%)	5.60	69.87	62.01	120.45	257.93

Source:Methodology(Kasembe *et al*.1987).

Table 3: Estimated Animal Manure production in Nzega district Tabora,region

Manure source	Manure produced per day per animal (kg)	Manure produced per year per animal (kg)	Total No of animals in Nzega	Total manure produced/year in Kraals (Mt)	Total N produced/year in kraals (Mt)
Cow beef (180 kg)	2.5	912.5	325,141	296,691	1186.7
Goat (20 kg)	0.9	328.5	185,172	60,829	334.5
Sheep(25 kg)	0.9	328.5	42,118	13,836	103.8
Pig (67.5 kg)	3.0	1,095	1,800	1971	10.8
Chicken 250=1.8 kg per unit	1.8	657	496,490	1304	14.3
Donkey	1.9	701.1	1197	839	4
Total Amount of Manure and N Produced per year				375,470	1654.1

Table 4: Estimated animal manure production in Igunga district,Tabora region

Manure source	Manure produced per day per animal (kg)	Manure produced per year per animal (kg)	Total No of animals in Igunga	Total manure produced/year in Kraals (Mt)	Total N produced/year in kraals (Mt)
Cow beef (180 kg)	2.5	912.5	466,892	325,920	1303.7
Goat (20 kg)	0.9	328.5	234,077	76,894	422.9
Sheep(25 kg)	0.9	328.5	101,570	33,366	250.2
Pig (67.5 kg)	3.0	1,095	100	109.5	0.60
Chicken 250=1.8 Kg per unit	1.8	657	366,284	962.6	10.6
Donkey	1.9	693.5	11,055	7,666.6	38.3
Total Amount of Manure and N Produced per year				444,919	2026.3

Discussion

Animal manures have a big role to play for enhancing soil health and crop productivity in developing countries like Tanzania. Assessment of locally available animal manure resources is essential for establishment of the sound ISFM under given local and socio-economic conditions (Tables 1, 2, 3 and 4).The existing climate conditions and agricultural production conditions is important for promoting the adoption of organic manures into ISFM practices (Sanginga and Woomer, 2009). In this study organic manures are widely adopted in the humid farming systems in Kigoma regions and Nzega district.But, Igunga district which is relatively dry produce more and non-used organic manure which could be processed to the neighboring district of Nzega.The farming systems were critically studied and it was found that there exist alternative sources of organic manure potential for integration in ISFM.Tobacco leaf residues can improve the soil productivity as shown in this study(Table,5).Tobacco leaf residues are not produced in large

quantities however they should not be ignored for application in small fields. The use of tobacco leaf residues is important in nutrient recycling because tobacco production utilizes high input demand for nitrogen, phosphorus and potassium. Farmers are aware of the importance of other locally available resources such as Procavian carpensis manure.Procavian carpensis are rock habiting animals whose manure is considered of value in crop production. Increasing soil productivity and development of ISFM should consider the use of high analyze inorganic fertilizers. In this study it was found that using NPK with rich in secondary and micronutrients can increase yield tremendously high(Table,6) and that the use of Urea alone on sandy soil was limiting maize production on sandy soil deficient in secondary and micronutrients. Use of locally available fertilizer resources can be used to ameliorate soil. In the study the growth of Amaranthus spp., on the sub-soil of the Ferric Acrisol in the pot experiment indicated that application of Gypsum local mineral can improve crop yield performance (Table 7).

Table 5: The response of maize on organic and inorganic fertilizers on a sandy textured soil in Tabora, Tanzania

Treatrements	Season 2009/2010		Season 2010/2011	
	Mean maize grain yield(kg/ha)	Mean stover weight kg/ha	Mean maize grain yield(kg/ha)	Mean stover weight kg/ha
Control(60 kg N)	2222	2222	3059	4046
POME	4500	4333	3927	4053
NPK+Urea	4407	4407	3691	3552
Cow manure	3926	3926	4000	4142
Procavian carpensis manure	4685	4685	3157	3511
Tobacco leaves residues	4333	4500	3190	3333
F Test	**	**	NS	NS
CV%	16.7	22.1	16.9	19.6
LSD 0.05	1167.7	1615.4		

Table 6: Maize performance on high inorganic fertilizers input fertilizer system

Treatments	Maize grain yield(kg/ha)
Control(60kg N/ha Urea)	3347
N23:P20:K20(100 kg/ha)+ 60 kg N/ha Calcium Nitrate)	8639
N23:P20:K20(100kg/ha)+60 kg N/ha Urea)	7319
N23:P20:K20(100kg/ha)+30 kg N/ha(urea)+30 kg N/ha Calcium nitrate)	7515
LSD (0.05)	2247.9
Fvalue<0.001)	***
CV%	21.0

Table 7: The effect of tobacco leaf residues and tobacco kiln ash on maize yield on a sandy textured soil at Tumbi, Tabora

Treatments	Mean maize grain yield (kg/ha)	Mean Maize stover wt (kg/ha)
Minjingu Rock Phosphate(MRP) 100kg/ha	693a	691a
Flue-tobacco kiln Ash(TFKA) one ton/hectare	1039a	654a
Dry tobacco leaf residues (two tons/ha)	1734b	1432a
Dry tobacco leaf residues (2 tons/ha +1ton/ha(TFKA)	1627b	835a
LSD0.05%	740.1	744.6
CV%	27.7	41.3

Means followed by same letter are not statistically significant at 5% probability

Table 8: The effect of ash and calcium amendments on Amaranthus yield (gm/pot) in a pot experiment

Treatments	Amaranthus spp. dry weight per pot(gm)
Control	12.8a
Calcium carbonate(10gm/2kgsoil)	19.0a
Groundnut haulm ash	61.4c
Miombo woodland ash	26.9a
Rice husk ash	27.1a
Grounded gypsum local mineral	43.3b
LSD 0.05	16.29
CV%	28.8

Means followed by same letter are not statistically significant at 5% probability

Conclusion

Assessment of locally available resources as part of resource- use efficient in agricultural production is essential for establishing the base of ISFM under given local conditions. Animal manures will continue to play part in sustaining the health of the soil. However, the combination of organic fertilizers and high quality inorganic fertilizers with primary, secondary and microelements is also important in enhancing crop production on degraded sandy textured soils

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Soil chemical properties as influenced by organic inputs and mineral fertilizer in Mbeere District, Kenya

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Abstract

Farmers in central highlands of Kenya experience declining agricultural productivity majorly due to soil desiccation and soil fertility depletion. In order to increase crop productivity, and reduce production risks, improved nutrient use efficiency is required. One way of reversing the trend of declining land productivity in smallholder farms in Kenya, is believed to be the combined application of organic and mineral sources of nutrients. In order to investigate this, field trials were established in a dry land environment in Central Kenya, at Machang'a. The objective of the research was to assess the effect of organic and inorganic inputs on soil nutrients in semi arid regions of the Central Highlands of Kenya. The study was carried out in Mbeere District, Kenya from 2004 to 2010 and the trial followed a randomised complete block design with three replications. The treatments consisted of four organic sources (Tithonia diversifolia, Lantana camara, Mucuna pruriens and goat manure) combined with mineral nitrogen fertilizer, sole fertilizer and a control. Goat manure was superior in terms of improving soil chemical properties such as soil pH, magnesium, potassium, calcium and nitrogen across the sites. Soil pH declined in most of the treatments, more so with the combinations of organics and mineral fertilizers compared to the sole application of organics such as Lantana camara, Mucuna pruriens and manure. Calcium in the soil increased significantly in sole Lantana camara, sole manure and Tithonia diversifolia + 30 kg N ha-1 treatments (t-test, $p = 0.029$, $p = 0.022$, and $p = 0.0264$, respectively). Soil potassium increased significantly in manure + 30 kg N ha-1 (t-test, $p = 0.017$). Soil organic carbon decreased in all the treatments except in the sole manure treatment and manure + 30 kg N ha-1. The decline in soil organic carbon was significant in sole Lantana camara, Lantana camara+ 30 kg N ha-1, sole Tithonia diversifolia, Tithonia diversifolia + 30 kg N ha-1, sole Mucuna pruriens, Mucuna pruriens+ 30 kg N ha-1, fertilizer (60 kg N ha-1) and control treatments (t-test, $p = 0.012$, $p = 0.033$, $p = 0.0224$, $p = 0.0166$, $p = 0.0349$, $p = 0.0129$, $p = 0.0004$ and $p = 0.0341$, respectively). Goat manure needs to be promoted among farmers in the drier areas because of its good performance in improving soil properties.

Key words: goat manure, soil organic carbon, Tithonia diversifolia.

Introduction

Declining soil fertility and soil desiccation are major impediments to the growth of agriculture and the reason for slow growth in food production in sub-Sahara Africa (Sanchez *et al*., 1995). The soil fertility depletion and soil desiccation have greatly affected crop productivity and have been recognized as root causes of low and declining per-capita food production in smallholder farms of Africa (Miguel *et al*., 1997). Soil desiccation is caused by low and unreliable rainfall, poor water harvesting techniques and unsustainable farming practices. Low and declining soil fertility arises from continuous cultivation where levels of soil replenishment, by whatever means, are too low to mitigate the process of soil mining, whereby the soil fertility is not replaced by new inputs (Shisanya *et al*., 2009). No matter how effectively other constraints are remedied, per-capita food production in Africa will continue to decrease unless soil fertility depletion is addressed (Sanchez and Jama, 2002).

Most African soils are inherently low in organic carbon (<20 to 30 mg kg-1) due to; low root growth of crops and natural vegetation, continuous cultivation of crops and rapid turnover rates of organic materials with high soil temperature and microfauna (Bationo *et al*., 1995; 2006). The loss of soil organic matter consequently results in soil acidity, nutrient imbalance and low crop yields (Ayoola *et al*., 2007). Furthermore, there are indications that up to 0.69 tons loss of carbon ha-1 year-1 in the soil surface layers are common in Africa even with high levels of organic inputs (Nandwa, 2003). For a long-term productivity of agro-ecosystems and protection of the environment, it is necessary to develop and implement management strategies that maintain the quality of soil, which includes conserving the inherent soil organic matter (SOM).

The soil fertility in the central highlands has declined over time, with an annual net nutrient depletion exceeding 30 kg N (Smaling, 1993; Kapkiyai *et al*., 1998), as a result of continuous cropping without adequate nutrient replenishment. In most smallholder farms, these deficiencies could be replenished by use of mineral fertilizers, organic manures and cattle manure. However, few farmers have the economic power to purchase mineral fertilizers and those who can afford it, mostly apply less than 10 kg N ha-1, where the recommended rate is 60 kg N ha-1 (Adiel, 2004). Use of manure is also limited by its variable and low quality and quantity (Ikombo, 1984), as well as its bulkiness which implies that extra incorporation labour is required. In low potential areas such as Mbeere district, the situation is further aggravated by the fact that immigrants move with technologies from high potential areas and grow crops, which they used to grow in the high potential areas resulting soil degradation and occasional crop failures.

Continued application of fertilizers for soil fertility replenishment has been shown to affect soil chemical properties in various ways. For instance, Kang (1993), Schroth *et al*. (1995), and Mugendi *et al*. (1999) reported a general reduction in pH, total N and total P over time, as a result of fertilizer input for continuous cropping. On the other hand, Gao and Chang (1996), Clark *et al*. (1998), and Eghball (2002) reported a general increase in organic carbon, exchangeable Ca, Mg and K, after application of manure, herbaceous legumes (Calliandra calothyrsus, Leucaena trichandra) and mineral fertilizer over time. Several authors (Qureshi, 1990; Riffaldi *et al*., 1994; Reganold and Palmer, 1995; Kapkiyai, 1996) have reported significant losses of organic carbon in cultivated soils upon continuous application of inorganic and organic external inputs.

Therefore, in order to increase crop productivity, and reduce production risks, better use of available rainfall and improved nutrient use efficiency is required. The objective of the study was to assess the effect of organic inputs on soil nutrients in semi arid regions of the Central Highlands of Kenya.

Materials and methods

The Study area

The study was conducted Machang'a (00º 47' 26.8" S; 37º 39' 45.3" E) in Mbeere districts in the central highlands of Kenya from October 2004 to February 2011. The soils are sandy-clay-loam, blackish grey or reddish brown, classified as the Nitro-rhodic Ferralsols, mainly low in fertility and must be intensively manured and fertilized season after season (Jaetzold *et al*., 2006). The soils are shallow (about 1 m deep) and lose their organic matter, including nutrient rich aggregates within 3-4 years of cultivation without adequate external organic material inputs and soil protection from water erosion (Warren, 1998; Micheni *et al*., 2004; Jaetzold *et al*., 2006). The soil characteristics are shown in Table 1.

Machang'a lies in the marginal cotton (lower midland 4 - LM 4) agro-ecological zone (Jaetzold *et al*., 2006). The rainfall pattern is bimodal, falling in two seasons, the long rains (LR) lasting from March to June and short rains (SR) from October to December. The total rainfall is however unreliable, with a mean annual rainfall of 800-900 mm (Jaetzold *et al*., 2006). Total rainfall per season during the study period ranged between 209-731 mm. Rainfall for the four seasons in which the experiment was conducted is presented in Figure 1.

Table 1 **: Soil characterization in Machang'a site, Mbeere district, Kenya**

Soil parameters	
pH in water	6.4
Total N (%)	0.09
Total soil organic carbon (%)	1.05
Exchangeable P (ppm)	12.9
Exchangeable K (cmol kg-1)	0.35
Exchangeable Ca (cmol kg-1)	1.0
Exchangeable Mg (cmol kg-1)	0.14
Clay (%)	22
Sand (%)	67
Silt (%)	11

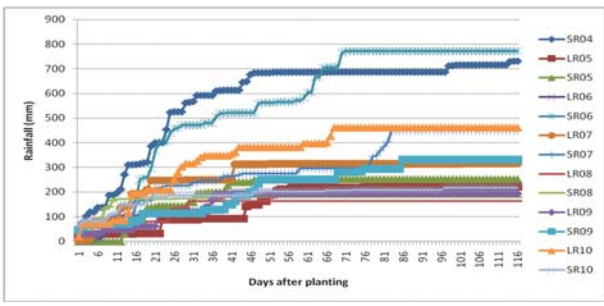

Figure 1 **: Rainfall distribution from 2004 to 2011 in Machang'a site, Mbeere district, Kenya**

The major cropping enterprises include maize (Zea mays L.) and beans (Phaseolus vulgaris L.). Other food crops include cowpea (Vigna unguiculata), millet (Eleusine coracana), sorghum (Sorghum bicolor L), green grams (Vigna radiata), and fruits {pawpaws, (Carica papaya L) and mangoes (Mangifera indica)}. Livestock (cows, goats, sheep, and poultry) production is a major enterprise and the farmers mainly keep the local breeds. Bee keeping is also a major enterprise in the area. Farmers plant food crops and keep livestock with a high staple and economic value as they do not grow any "cash crop" therefore the crops they grow double as food crops and cash crops. Mbeere District is sparsely populated with 81 persons per km-2, Machang'a is located in Mavuria location with a population density of 81 persons per km-2 (Jaetzold *et al.*, 2006). About 56% of the arable land is currently under cultivation and the remaining 44% is not enough for the necessary livestock and fallow period for replenishing soil fertility. The average farm size per family is less than 5 hectares (Jaetzold *et al.*, 2006).

Experimental layout and management

The experiments were laid out as a randomized complete block design replicated thrice with the plots measuring 6 x 4.5 m. The test crop (maize -Zea mays L, var. Katumani) was planted at a spacing of 0.9 and 0.6 m as inter- and intra-row, respectively. The Katumani variety was bred for the semi-arid and coastal areas of Kenya as it is early maturing and has low rainfall requirements. External nutrient replenishment inputs were applied to give an equivalent amount of 60 kg N ha-1 (Table 2). This is the recommended rate of N to meet maize nutrient requirement for an optimum crop production in the area (FURP, 1987) with the exception of the herbaceous legume treatment where, the amount of N was determined by the biomass harvested and incorporated in the respective treatments.

Table 2: Experimental treatments in Machang'a, Mbeere South District, Kenya

Sn	Treatment	N from biomass	N from inorganic fertilizer
1	Lantana camara	60 kg N ha-1	0
2	Lantana camara + 30 kg N ha-1	30 kg N ha-1	30 kg N ha-1
3	Mucuna pruriens	Dependent on biomass produced	0
4	Mucuna pruriens + 30 kg N ha-1	Dependent on biomass produced	30 kg N ha-1
5	Tithonia diversifolia	60 kg N ha-1	0
6	Tithonia diversifolia + 30 kg N ha-1	30 kg N ha-1	30 kg N ha-1
7	Goat manure	60 kg N ha-1	0
8	Goat manure + 30 kg N ha-1	30 kg N ha-1	30 kg N ha-1
9	Inorganic fertilizer (60 kg N ha-1)	0	60 kg N ha-1
10	Control	0	0

All organic inputs were harvested, weighed, chopped and incorporated into the soil to a depth of 15 cm during land preparation. Calcium ammonium nitrate (CAN) was the source of mineral N and was applied at the rate of ⅓ after four weeks of planting and ⅔ after six weeks of planting. Since organic inputs were being applied in this experiment and they (organic inputs) are often limited in their ability to increase P availability due to their low P content (Palm *et al*., 1997), P was applied in all plots at the recommended rate (60 kg P ha-1) in the form of triple super phosphate (TSP) to minimize the possibility of its confounding effects. Other agronomic procedures for maize production were appropriately followed after planting.

Soil analysis

At the beginning and end of the experiment, soil samples were collected with an alderman auger at 0-15 cm. Soil augering was done at six spots per plot and bulked to make a composite sample per plot. The soil samples were analysed for soil organic carbon, total nitrogen, available P (olsen), Ca, Mg and K, and pH using standard methods (Anderson and Ingram, 1993).

Statistical analysis

Data on soil chemical properties were subjected to analysis of variance using Genstat software version 10 (Genstat, 2002). The means were separated using Least Significant Differences (LSD) of means at $p < 0.05$. To determine the soil chemical changes during the thirteen years cropping period, t tests comparing means between the two sampling periods (October 2004 and February 2011) were carried out to determine whether the changes were significant at $p < 0.05$.

Results

Soil chemical properties

The soil pH, Ca, total N carbon were significantly different ($p < 0.008$, $p = 0.012$, $p = 0.0126$ and $p = 0.003$, respectively) across the different treatments in 2004, while on the other hand, pH, Ca, Mg, K, total N and organic carbon were significantly different ($p < 0.0001$, $p < 0.0001$, p = 0002, $p < 0.0001$, $p = 0.006$, and $p = 0.0014$, respectively) across the treatments in 2011 (Table 3). All the soil properties were significantly higher in the sole manure and manure +30 kg N ha-1 treatments in 2011.

There were no significant changes over the thirteen cropping seasons for soil pH and total nitrogen across all the treatments. Calcium in the soil increased significantly in sole Lantana camara, sole manure and Tithonia diversifolia + 30 kg N ha-1 treatments (t-test, $p = 0.029$, $p = 0.022$, and $p = 0.0264$, respectively). Magnesium also increased significantly in sole manure, manure+30 kg N ha-1, Lantana camara, Lantana camara+ 30 kg N ha-1, sole Tithonia diversifolia, Tithonia diversifolia + 30 kg N ha-1, fertilizer (60 kg N ha-1) and control treatments (t-test, $p = 0.0006$, $p = 0.0017$, $p = 0.0027$, $p = 0.038$, $p = 0.0015$, $p = 0.0161$, $p = 0.0231$ and $p = 0.0118$, respectively).

Soil potassium increased significantly in manure + 30 kg N ha-1 (t-test, p = 0.017). Soil organic carbon decreased in all the treatments except in the sole manure treatment and manure + 30 kg N ha-1. The decline in soil organic carbon was significant in sole Lantana camara, Lantana camara+ 30 kg N ha-1, sole Tithonia diversifolia, Tithonia diversifolia + 30 kg N ha-1, sole Mucuna pruriens, Mucuna pruriens+ 30 kg N ha-1, fertilizer (60 kg N ha-1) and control treatments (t-test, p = 0.012, p = 0.033, p = 0.0224, p = 0.0166, p = 0.0349, p = 0.0129, p = 0.0004 and p = 0.0341, respectively).

Table 3: Soil chemical properties at the beginning of the experiment in October 2004 and at the end of the experiment in March 2011 in Machang'a, Mbeere South District, Kenya

Treatment	pH		Ca		Mg		K		Total N		C		No. of parameters increased
	(H2O)		Exchangeable (C mol/kg)						%				
	2004	2011	2004	2011	2004	2011	2004	2011	2004	2011	2004	2011	
Lantana	6.7	7.1 (40)	1.3	5.4(410)	0.11	4.96(485)	0.49	1.53(104)	0.10	0.10(0)	1.14	0.49(-65)	4
Lantana + 30 kg N ha-1	6.4	6.6(20)	0.7	3.8(310)	0.11	2.95(284)	0.29	0.90(61)	0.08	0.08(0)	0.90	0.46(-44)	4
Manure	6.3	7.8(150)	1.0	8.0(700)	0.14	7.56(742)	0.33	2.00(167)	0.10	0.13(3)	1.04	0.87(-17)	5
Manure + 30 kg N ha-1	7.0	7.8(80)	1.7	8.5(680)	0.18	6.85(667)	0.49	2.18(169)	0.12	0.13(1)	1.23	0.87(-36)	5
Mucuna	6.4	6.3(-10)	1.0	3.1(210)	0.07	4.71(464)	0.37	0.56(19)	0.11	0.08(-3)	1.34	0.49(-85)	3
Mucuna + 30 kg N ha-1	6.2	5.8(-40)	0.8	2.5(170)	0.15	1.93(178)	0.30	0.44(14)	0.08	0.06(-2)	1.19	0.30(-89)	3
Tithonia	6.5	6.6(10)	1.3	5.4(410)	0.25	4.00(375)	0.42	1.49(107)	0.10	0.10(0)	1.18	0.53(-65)	4
Tithonia + 30 kg N ha-1	6.2	6.1(-10)	0.6	3.4(280)	0.13	2.32(219)	0.25	0.86(61)	0.07	0.07(0)	0.89	0.39(-50)	3
Fertilizer (60 kg N ha-1)	7.0	6.5(-50)	2.0	3.1(110)	0.11	3.57(346)	0.51	0.63(12)	0.12	0.07(-5)	1.15	0.44(-71)	3
Control	6.5	6.4(-10)	1.2	2.6(140)	0.14	2.72(258)	0.40	0.50(10)	0.11	0.05(-6)	1.18	0.26(-92)	3
SED	0.28	0.245	0.4	0.586	0.04	0.964	0.1	0.173	0.02	0.019	0.12	0.120	
P	0.008	<0.0001	0.012	<0.001	0.36	0.0002	0.074	<0.0001	0.026	0.006	0.003	0.0014	

Values in brackets are percentage increases or declines in different properties in 2004-2011.

Discussions

Bekunda *et al*. (1997) have summarized information from selected experiments in Africa and their review indicates that continuous application of mineral fertilizer without organic inputs eventually results in a decline in crop yields. They attributed such declining yields to soil acidification through continuous mineral fertilizer application and decline in soil organic matter. The soil organic matter in the Machang'a soils was very low as depicted by the carbon content (Table 6). According to Tekalign *et al*. (1991), the soil organic carbon rated low (0.5 – 1.5%) in all the treatments at the beginning of the experiment and it gradually reduced as cropping continued. This low soil organic carbon could have also reduced the response of mineral fertilizers, agreeing with Greenland (1994) who reported that at low levels of soil organic matter, crop response to inputs is relatively poor and it is difficult to maintain yields with mineral fertilizers alone. The nutrient limitation may also be directly or indirectly be related to the decline in SOM with the multiple loss of soil physical condition.

The changes in the soil properties after thirteen continuous cropping seasons was very variable agreeing with Drinkwater *et al*. (1995) and Werner (1997) who noted that changes in soil properties under organically and conventionally managed farming systems have been found to be more variable, perhaps due to differences in climate, crop rotation, soil type, or length of time a soil has been under a particular management.

There was no significant effect of treatments on soil pH. Increase in soil pH in Lantana camara, Lantana camara + 30 kg N ha-1, sole goat manure and manure + 30 kg N ha-1 might be due to the moderating effect of organic manures, as it decreases the activity of exchangeable Al3+ ions in soil solution due to chelation effect of organic molecules (Hue, 1992). Bhogala *et al*. (2011), Benito *et al*. (2003) and Subehia *et al*. (2013) reported no significant effect of organic and inorganic inputs on soil pH.

Soil carbon decreased in most of the treatments. The reduction in C levels could be attributed to rapid decomposition rates. Mtambanengwe and Mapfumo (2005) reported that maintaining sufficient SOM to sustain good crop productivity is a challenge in smallholder farming systems because of low quantities of organic manures and rapid turnover rates of green manures and tree legumes under conventional tillage systems. This corroborates findings of Ndungu *et al*. (2003) who reported a decrease in organic C levels attributed to rapid decomposition because of favourable conditions in western Kenya. These results agree with Qureshi (1990) who reported a decrease in organic carbon of 17% where the crop residue was removed and 4% where the crop residue was retained after 10 years of continuous cultivation with annual application of manure at 10 t ha-1 in Kabete, Kenya. Swift *et al*. (1994) reviewed the same trial and in treatments with no inputs, soil carbon declined from >2% to about 1.1%. Addition of 10 t ha-1 dry weight ha-1 year-1 manure, soil C decreased to about 1.8%. Results from long-term soil fertility trials indicate that losses of up to 0.69 t carbon ha-1 yr-1 in the soil surface layers is common in SSA even with high levels of organic inputs (Nandwa, 2001). Glaser *et al*. (2002) notes that the advantages of organic manure amendments are short-lived in a sandy soil because of the rapid decomposition of soil organic matter under high temperature and aeration.

The decline of soil organic carbon in all the treatments could be attributed to the low content of clay (22%) in these soils. The potential for building soil organic matter in sandy soils is therefore very limited as the capacity of soils to store organic matter is strongly related to their clay and silt contents (Giller *et al*., 1997). Clay is the most important soil component that stabilizes soil organic carbon (Kihanda *et al*., 2006). For instance, in West Africa, long term experiments show a range between over 5% loss of soil organic carbon per annum on sandy soils to around 2% on more clayer soils (Pieri, 1995). Kihanda *et al*. (2006) reported that a soil with clay content of 30.9% had a slow loss of soil organic carbon with a trend of 0.5% and 1.5% per year in 1993-1997 and 1997-2002, respectively. In contrast Jones and Wild (1975) concluded that more sandy west African soils lost C at 5-10% per year until reaching a soil organic carbon of 25-45% of the value under natural vegetation. Sanchez *et al*. (1997) reported that the proportion of nutrients lost is normally greater in sandy soils, than in clayer soils. This is largely because SOM particles are less protected from microbial decomposition in sandier soils than in loamy or clayey ones (Swift *et al*., 1994).

Sole organic and the combination of organic and mineral fertilizer treatments had a higher positive contribution to soil carbon in comparison to the control. This agrees with Eghball (2002), who observed an increase in soil organic carbon after four years of manure application where about 25% C was retained in the soil carbon pool, however, he observed no significant difference in soil carbon with the mineral fertilizer application. This was because, whereas the organic materials had a major impact on mineralization rates by increasing soil C directly, the effect of mineral fertilizer N was less pronounced since it increased C only indirectly by improving plant growth (Antil *et al*., 2001).

Manure had the lowest decline in soil organic matter. This could be as a result of the low quality of the manure. Low quality organic resources are good precursors to SOM build-up because of their low turnover rates (Palm *et al*., 1997). The decline of nitrogen could be associated with the significant decline of soil organic carbon. Because the C:N ratio is relatively constant in soils, the maintenance of organic nitrogen is influenced by the carbon or soil organic matter, therefore the amount of soil organic nitrogen that can be maintained in any soil is, largely dependent on the amount of soil organic carbon present (Brady, 1990). The higher concentration of total N found in the treatments with manure with respect to those amended with other organics (Mucuna pruriens, Tithonia diversifolia and Lantana camara), inspite of the lower N content of the manure could be attributed to the fact that in manure, humified forms of N predominate, which are less subject to hydrolysis and leaching (Saviozzi *et al*., 1999). The low values of total N in the soil could be as a result of crop uptake, immobilisation by microorganisms and nitrogen loss through volatilisation (Defoer *et al*., 2000).

Increase in available potassium in the manure treatment might be due to the reduction of potassium fixation and release of potassium due to interaction of organic matter with clay, besides the direct potassium addition to the soil pool (Urkurkar *et al*., 2010). Such increase in the content of available potassium with the use of manure together with chemical fertilizers has been reported by Edmeades (2003), Gupta *et al*. (2006) and Walia *et al*. (2010). Slattery *et al*. (2002) observed a significant increase in exchangeable K because of application of composted feedlot manure (109 t ha-1).

Manure treatment exemplified an increase in most of the soil nutrients. Similar results have been observed in a number of medium- to long-term experiments where farm manures have been applied (Schjonning *et al*., 1994, 2007; Haynes and Naidu, 1998; Bhogal *et al*., 2009; Edmeades, 2003).

The decline of the soil properties in the soil even with continuous application of organic and mineral fertilizer inputs could be associated with the season after season cropping. Many studies have shown that frequent conventional tillage can break down the structure of soil aggregates, reduce SOC and results in soil degradation (Six *et al*., 1998; Rhoton, 2000; Debaeke and Aboudrare, 2004; Chen *et al*., 2007). Ghosh *et al*. (2011) also noted that increased frequency of tillage operations can exacerbate SOM mineralization resulting in diminished rate of SOC accretion and this can be further accelerated in arid regions where environmental conditions are generally favourable to mineralization.

Conclusions and recommendations

Manure showed superiority in terms of increased yields and soil properties. This is a resource that is locally available to most farmers and they should therefore be trained on better management of manure and be encouraged to use it in their farms to enhance productivity.

The seasonal addition of organic and mineral fertilizers to the soil was not able to prevent the decline in soil fertility due to cultivation.

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Response of orange fleshed sweetpotato to Arbuscular Mycorrhizal fungi inoculation and fertilizer application in western Kenya

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Abstract

Arbuscular mycorrhizal fungi represent a functionally important component of soil microbial community, which is of particular significance for plant mineral nutrition in agro-ecosystems. A pot experiment was conducted under greenhouse conditions to evaluate the effects of different Glomale mycorrhizal fungal inoculants with varying chemical phosphate fertilizer rates on biomass production and root colonization of two orange fleshed sweetpotato (OFSP) varieties SPK004 and Kabode. The inocula were tested as separate single species of Glomus mosseae, G. etunicatum, G. intraradices and G. aggregatum or as mixtures in granular formulation containing spores, root fragments and other propagules. These were tested in combination of varying rates of phosphorus (P) fertilizers at 0 kg P/ha, 20 kg P/ha and 40 kg P/ha. Mixed species inoculation recorded the highest root colonization compared to the separate single species. Singly, G. intraradices out-performed the other single species in terms of root colonization while G. aggregatum recorded the lowest root colonization. Application of chemical fertilizer at 40kgP/ha increased sweetpotato biomass production but reduced root colonization by the fungi. It was concluded that there is a functional complementarity among species within the Arbuscular mycorrhizal fungi community and that varieties may respond differently to infection by them. Optimal condition for the Arbuscular mycorrhizal fungi functioning in western Kenya therefore needs to be established.

Key words: arbuscular mycorrhizal fungi, root colonization, orange fleshed sweetpotato.

Introduction

Soil microorganisms are important components of many agricultural ecosystems because of their role in nutrient cycling (Cakmakci *et al*., 2006). They are involved in sustaining soil productivity through organic matter decomposition, nutrient transformations and cycling; thus reducing the need for chemical fertilizers. They also regulate the nutrient flow in the soil by assimilating nutrients and producing biomass and converting organically bound forms of nutrients especially carbon, nitrogen and phosphorus to mineral forms (Wani and Lee, 1995). Because of the great importance of plant-microorganism interactions in the soil for ecosystem functioning and nutrient cycling, it is vital to identify the factors that influence these soil microbial communities.

Fertilizers are usually added to the soil primarily to increase nutrient availability and crop productivity. Inorganic fertilizers, especially phosphorus and nitrogen, when applied continuously can directly or indirectly affect soil biological properties which, in the long run, can affect the quality and productivity of such soils (Acton and Gregorich, 1995).

Arbuscular mycorrhizal fungi (AMF) belong to the phylum Glomeromycota (Schüβler *et al*., 2001) and have the ability to form symbiosis with about 250,000 species of plants worldwide (Smith and Read, 1997). They propagate in soil as spores, hyphae, or colonized root fragments. During the plant-AMF symbiosis, the fungus penetrates the root cortical cell walls and forms highly branched intracellular fungal structures termed arbuscules, which are specialized hyphae that form as intercalary structures between coil hyphae and are thought to be the main site of nutrient exchange between fungus and plant (Hodge, 2000). The

hyphae of AMF provide the host plant roots with an increased surface to explore a greater soil volume for nutrients and water. Arbuscular mycorrhizal fungi influence plant growth in several ways (Klironomos, 2003). The extra radical hyphae of AMF extend several centimetres into the soil and help the plants in uptake of mineral nutrients especially the immobile nutrients such as phosphorus, zinc and copper (Marschner and Dell, 1994). Arbuscular mycorrhizal fungi role in nitrogen uptake has also been demonstrated (Toussaint *et al*., 2004; Govindarajulu *et al*., 2005; Atul-Nayyar *et al*., 2009). The AMF hyphae also play an important role in the stabilization of soil aggregates (Wilson *et al*., 2009). The soil fungal mycelium entangles soil particles within the hyphae network and cements particles together through exudation of extracellular polysaccharide compounds such as glomalin (Rilling, 2004; Treseder and Turner, 2007). Glomalin stores carbon in both its protein and carbohydrate (glucose or sugar) subunits and it permeates organic matter thereby binding it to silt, sand, and clay particles which is described as a major factor in the formation of soil aggregates (Bossuyt *et al*., 2001; Miller and Jastrow, 2002). Studies have shown that AMF also enhance plant resistance to pathogens (Lingua *et al*., 2002) and tolerance to environmental stresses (Newsham *et al*., 1995).

Sweetpotato (Ipomoea batatas L. (Lam.) is an important secondary food crop for many Kenyans whose staple diet is based on cereals, particularly maize (Gakonyo, 1993). In Kenya, sweetpotato growing is mainly concentrated in the Western districts of Kakamega, Bungoma, Busia, Homa-Bay, Rachuonyo and Kisii districts and to a less extent at the Coast and Central provinces. In these areas; sweetpotato acreage has been steadily increasing, rising from about 55,000Ha in 1988 to about 77,821Ha in 2009 (FAOSTAT, 2009). It is an important food security crop especially when maize is in short supply or in years of drought (Mutuura *et al*., 1992). Its productivity is however hampered by among others poor soils. Orange fleshed sweetpotato varieties were recently introduced and have gained popularity in the Western Kenya region. They are rich in beta carotene, a precursor of vitamin A, and as such important in alleviating vitamin A deficiency nutritional disorders which are on the rise in Kenya (MoA and UNICEF, 1995).

Mycorrhizal infection has been shown to increase sweetpotato growth and yield in a number of studies. For instance Paterson *et al*. (1987), Kandasamy *et al*. (1988), Mulongoy *et al*. (1988), Khasa *et al*. (1992), Paula *et al*. (1992), Dowling *et al*. (1994) and Floyd *et al*. (1988) have reported that the extent of mycorrhizal infection is positively correlated with yield, and negatively correlated with the crop response to phosphorus fertilizer over a range of soils. In other studies however, the effect is greatest under low phosphorus fertility, while in others arbuscular mycorrhizal fungi (AMF) may have no benefit or even a negative effect on crops which are well supplied with phosphorus (Negeve and Roncadori, 1985). Demonstration that AMF are capable of increasing productivity in mycorrhizal plants compared to non-mycorrhizal plants has created much interest in AMF symbioses in agriculture, forestry and rehabilitation of environments where practices have altered the soils' native state (Friberg, 2001; Cuenca *et al*., 1998). Therefore, the objective of this study was to determine the response of the orange fleshed sweetpotato to arbuscular mycorrhizal fungi inoculation and fertilizer application in Western Kenya.

Materials and methods

Plant preparation: Clean orange fleshed sweetpotato cuttings of varieties Kabode and SPK004 were obtained from the Roots and Tubers program at the Kenya Agricultural Research Institute (KARI)-Kakamega and raised in the greenhouse for use. Single species of arbuscular mycorrhizal fungi (AMF) that is; Glomus mosseae, Glomus etunicatum and Glomus intraradices were sourced by the Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT) from Dudutech Naivasha. The other species Glomus aggregatum was sourced from the National Museums of Kenya Mycology laboratory. Chemical phosphorus fertilizer in the form of triple superphosphate (TSP) was bought from a localagrochemical shop.

Soil preparation and treatment: Soil for the study was collected from KARI-Kakamega. Samples of the soil were analysed for organic carbon, available phosphorus, pH, total nitrogen, exchangeable bases and texture following methods outlined in Okalebo *et al*. (2002). In preparation for planting, the soil was autoclaved at 700 C twice at an interval of 24 hours and allowed to cool. A factorial experiment with six treatment levels

of AMF, three triple super phosphate (TSP) fertilizer levels and two varieties of orange fleshed sweetpotato (OFSP) replicated five times was set up. The OFSP varieties were SPK004 and Kabode. Arbuscular mycorrhizal fungi (AMF) treatments were made up of: T1: Control (no AMF inoculation), T2: Glomus aggregatum, T3: Glomus mosseae, T4: Glomus etunicatum, T5: Glomus intraradices, T6: mixed inoculum (Glomus mosseae + Glomus etunicatum + Glomus intraradices). The fertilizer treatments were applied once at planting at three rates i.e., 0 kg P/ha, 20 kg P/ha and 40 kg P/ha. The treatments were placed in planting trays (Plate 1) measuring 27 cm by 47 cm. Each tray contained 66 cells, each with a capacity of 37.68cm3. These trays were used for mycorrhization of the OFSP cuttings.

The Arbuscular mycorrhizal fungi (AMF) inoculation was done at the rate of 66 kg/ha (0.059 gAMF/cell) wherebythe inoculum was mixed with the pasteurized soil and put into the respective cells. The inoculum-soil mixture was moistened with distilled water before planting a single mini OFSP cutting in each cell. The cuttings were allowed to grow in these trays for eight weeks. Thereafter, they were transplanted into bigger gauge 200 polythene bags (Plate 2) measuring 5 x 9 x 10 cm each containing two kilograms of soil.

The plants were watered daily to field capacity regularly misted using distilled water to maintain high humidity. Plants were maintained in these bags for another eight weeks in a greenhouse at a temperature range of 14.3-28.30C and mean relative humidity of 40.7-87.3%. At harvesting, about 120 days after planting, the plant tops were cut at the base and the roots carefully harvested from the pots. The roots were washed free of soil using tap water and weighed. The number of root branches was determined and roots scanned on an EPSON Perfection V700 photo scanner to estimate root length. The roots were then divided in two samples, one for staining to assess AMF root colonization, and the other portion oven dried at 70oC to a constant weight for determining dry weight. The plant tops were also weighed and then oven dried at 70oC to a constant weight and their dry weight taken. Fungal spores were extracted from 25 g soil samples from each treatment by the Ingleby and Mason (1973) wet sieving technique and enumerated by counting healthy spores under a dissecting Leica Zoom 2000 microscope. Different fungal morphotypes were recorded depending on colour, size, shape and presence or absence of hyphae attachments. Spores were recorded as representatives of arbuscular mycorrhizal fungal species present in the 25g soil sample. In order to describe and identify the arbuscular mycorrhizal fungi species, permanent slides of the extracted spores were prepared following the process developed by Ingleby and Mason (1973). Each of the slides was labelled appropriately, mounting date stated and examined under a Leica EC3 compound microscope, at x 400 magnification. Observations were specially made for wall layers, hyphal features, properties, ornamentation, development features-saccule/scar, germination shield and reaction with Melzer's reagent. Photographs of the spores were taken on a Leica Application Suite LAS EZ.

Root staining and colonization assessment: The roots for staining were cleared with 2.5% KOH (25 g KOH in 1000 ml water) by heating in an oven at 70^{o} C for one hour and then rinsed with tap water. To remove phenolic substances, alkaline hydrogen peroxide (60 ml of 28-30% NH4OH, 90 ml of 30% H2O2 and 840 ml distilled water) was added and roots left standing in a hood for twenty minutes. The roots were thereafter rinsed with tap water and acidified with 1% HCl and left for 30 minutes. The HCl was decanted and without rinsing the roots, a staining reagent 0.05% trypan blue in acid glycerol (500 ml glycerol, 450 ml water, 50 ml of 1% HCl and 0.5 g trypan blue) was added and roots placed in the oven for 1hour at 70^{o}C. The stain was decanted and a de-staining solution comprising of acid glycerol (500 ml glycerol, 45 0ml water, and 50 ml of 1% HCl) was added. Fine root segments were cut into approximately 1cm-long pieces and 30 pieces randomly picked, mounted on slides and observed under a compound microscope to assess the frequency and intensity of AMF colonization. The presence of arbuscules, vesicles, internal and external hyphae was examined. The frequency of arbuscular mycorrhizal fungi (AMF) was recorded as the number of root fragments infected with AMF while the intensity of their colonization was recorded as percentage cover of infective propagules in each 1cm root fragment.

Data analysis: Data were subjected to analysis of variance (ANOVA) to determine significance of treatment effects. Treatment means were compared using the least significant difference (LSD) test at a significant level of 0.05. The analyses were performed using GENSTAT software version 14 for windows.

Results

Soil analyses

Results of initial soil chemical and physical characteristics are presented in Table 1. The results indicated that the study soils were moderately acidic with a pH (water) of 5.49 with low exchangeable bases except for Na (2.61 g/kg) and Ca (1.64 g/kg) which were relatively high. The cation exchange capacity was very low at 1.4 mg/kg. The soil total nitrogen was low at 0.122% while organic carbon was moderate at 2.4 % C. Soil available phosphorus was moderately supplied at 8.64 mg/kg and the soil texture was described as sandy clay.

Table 1: **Chemical characteristics of the soil used for study of mycorrhizal inoculation of sweetpotato seedlings in a greenhouse at the World Agroforestry Centre in 2011**

pH (water)	5.50
Available P (mg/kg)	8.64
Soil organic matter (%)	2.40
Total N (%)	0.12
Exchangeable K (g/kg)	0.23
Exchangeable Ca (g/kg)	1.64
Exchangeable Mg (g/kg)	0.15
Exchangeable Na (g/kg)	2.61
Exchangeable acidity (mg/kg)	1.40
Texture	Sandy clay

Mycorrhizal inoculation

The two varieties responded differently to arbuscular mycorrhizal fungi (AMF) inoculation and chemical fertilizer application in terms of biomass production. In terms of vine yield, SPK004 had a faster growth and produced more biomass than Kabode. The highest vine yield of 18.02 t/ha was recorded from SPK004 that was inoculated with G. etunicatum and fertilized with TSP at the rate of 40 kgP/ha. The same AMF treatment recorded the least vine yield for SPK004 (6.19 t/ha) with no TSP application. For Kabode, on the other hand responded well on mixed inoculant and fertilizer at 40 kgP/ha giving a vine yield of 16.36 t/ha against 5.22 t/ha for plants that were inoculated with G. etunicatum with no chemical fertilizer applied (Figure 1).

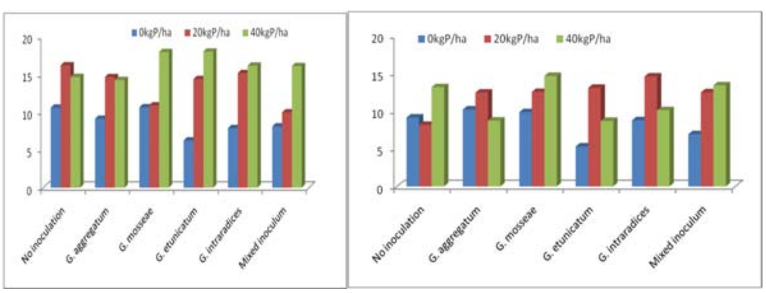

Figure 1: **Effect of arbuscular mycorrhizal fungi inoculation and fertilizer rate on vine yield production for the sweetpotato varieties SPK004 (left) and Kabode (right) at the World Agroforestry Centre during the 2011cropping season**

In terms of fresh root production, there were significant differences on the varieties response to AMF and fertilizer application. Overall, Kabode recorded the highest fresh root yield of 12.17 t/ha on plants inoculated with G. mosseae and fertilized at 40 kgP/ha. From the same variety, the least root yield (2.43 t/ha) was obtained from plants that were not treated with fertilizer but inoculated with G. etunicatum. For SPK004, the highest root yield of 11.42 t/ha was recorded from AMF un-inoculated plants that received TSP at 20 kgP/ha. The least root yield (3.33 t/ha) was in the G. etunicatum inoculated plants with no fertilizer application (Figure 2).

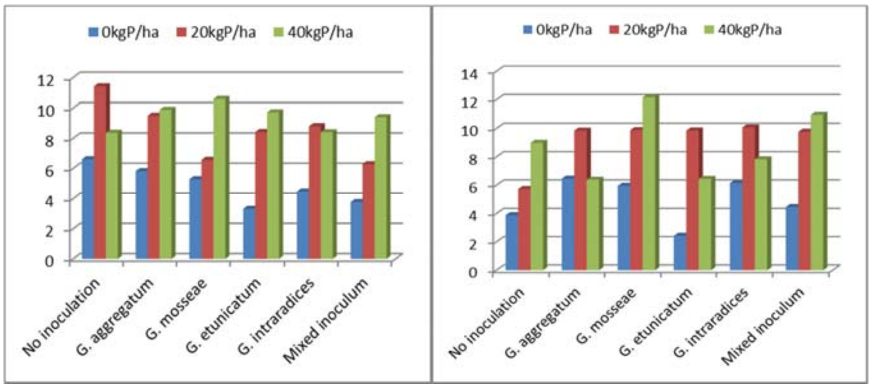

Figure 2: Effect of arbuscular mycorrhizal fungi inoculation and fertilizer rate on SPK004 (left) and Kabode (right) variety fresh root yield at the World Agroforestry Centre during the 2011cropping season

With regard to spore count, plants that were inoculated with a mixed species inoculum and fertilized at 20 kgP/ha recorded a higher number of spores (7.50 spores/g soil) from Kabode while SPK004 recorded a spore count of 6.00 spores/g soil from G. etunicatum and 20 kgP/ha treatment. The lowest counts were obtained from un-inoculated and unfertilized soils (Fig. 3).

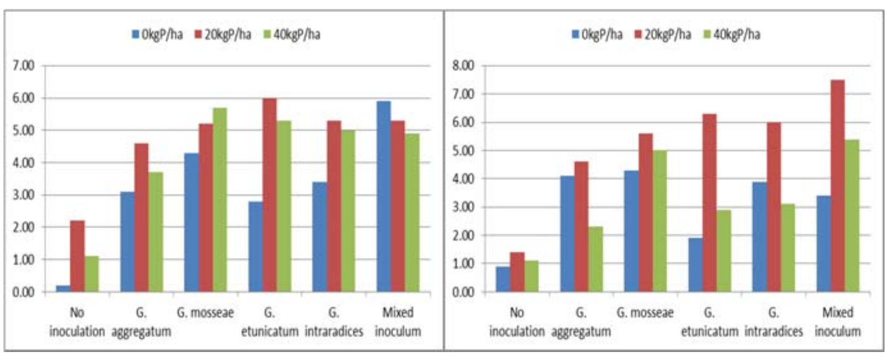

Figure 3: **Effect of arbuscular mycorrhizal fungi soil inoculation and chemical fertilizer rate on spore count at the World Agroforestry Centre during the 2011cropping season**

All the inoculation treatments formed mycorrhizal structures within the roots of the evaluated orange fleshed sweetpotato varieties. Root infection rates by the AMF inoculants varied widely in terms of

frequency and intensity. The mixed inoculant showed greater root infection rates than the single isolates. The highest root infection frequency (49.00%) was recorded in Kabode roots that received mixed inoculation and were fertilized with TSP at 20kgP/ha. The lowest root infection frequency (1.33%) for Kabode roots was in un-inoculated and both 0 kgP/ha and 40kgP/ha treated plants. Arbuscular mycorrhizal fungi root infection frequency of SPK004 roots was highest (35.33%) in mixed inoculum treated plants that did not receive any chemical fertilizer. The lowest root infection for SPK004 (0.33%) was recorded in un-inoculated and 0kgP/ha treated roots (Fig. 4).

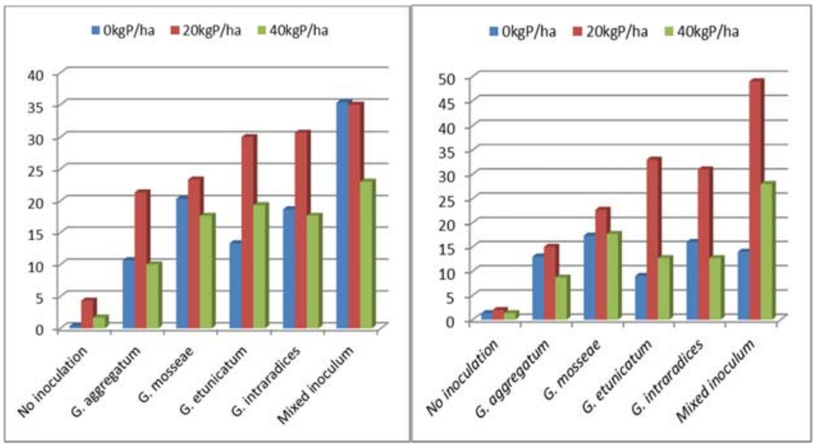

Figure 4: **Effect of arbuscular mycorrhizal fungi and fertilizer rate on SPK004 (left) and Kabode (right) root infection frequency at the World Agroforestry Centre during the 2011cropping season**

In terms of root colonization intensity the highest infections, Kabode (27.50 %) and SPK004 (17.70 %) were recorded from mixed inoculum and 20 kgP/ha fertilizer treated roots. The lowest infection intensities were in the un-inoculated and 0kgP/ha treated plants at 0.10 % for SPK004 and 0.40 % for Kabode at 40 kgP/ha (Figure 5).

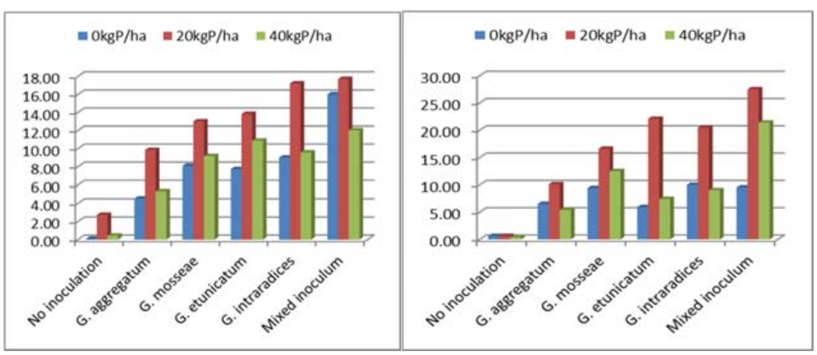

Figure 5: **Effect of arbuscular mycorrhizal fungi soil inoculation and fertilizer rate on root infection intensity for SPK004 (left) and Kabode (right) at the World Agroforestry Centre during the 2011-------cropping season.**

Discussion

The soils of the study site were low in plant nutrients such as N, P and basic cations, conditions that could be associated with continuous cropping coupled with non-application of fertilizer. The soils of the study site are low in plant nutrients such as N, P and basic cations and this could be associated with continuous cropping coupled with non-application of fertilizer. Another reason could be due to the previous crop grown and in this case, cassava which is a heavy feeder and derives most of its nutrients from the soil. Burning of crop residues or removal of the residues from the farm, which is also a common practice during land preparation reduces the organic resources that should otherwise be returned to the soil to improve on its resource base (Karanja *et al*., 2006; Achieng *et al*., 2010). The practice reduces the soil organic matter (SOM) thus affecting available soil nutrients such as N and P since SOM is important in storing and releasing nutrient stocks through mineralization hence offsetting nutrient deficiency in crops. This is likely to result also in a reduction of water and nutrient retention capacity which negatively impacts on fertilizer use efficiency and generally affects provision of ecosystem services (Bationo *et al*., 2006). This condition could be reversed by appropriate management of agricultural lands and efficient recycling of organic resources (Bationo and Buerkert, 2001).

Many tropical soils are fragile and have characteristics that constrain crop production. Such characteristics are low nutrient capital, low pH, high P fixation and loss of soil biodiversity (Sanchez *et al*., 2003). Studies by Jama *et al*., (2000), Okalebo *et al*., (2003 and 2007) and Achieng *et al*., (2010) have shown that phosphorus is one of the most limiting nutrients in western Kenya and its deficiency in soil is often accompanied by very low crop yields. In many acid soils, when phosphate fertilizers are incorporated in the soil, the major share of P is fixed thereby making it unavailable to plants (Janssen, 2006). In such cases, soil P can be replenished by addition of inorganic fertilizers or organic matter. However, application of chemical fertilizers alone in acid soils is uneconomical due to high costs and low use efficiencies due to high P fixation.

Tropical crops, such as cassava, sweetpotato and cowpea are often heavily colonized by arbuscular mycorrhizal fungi (AMF) under natural conditions. However, environmental conditions affect the formation of AMF and influence the extent of root colonization and hence its effectiveness. The results obtained from root colonization indicate that sweetpotatoes are mycorrhizal. O'Keefe and Sylvia, (1993) and Harikumar and Potty, (2007) reported mycorrhizal symbiosis in sweetpotato. Studies by Johnson *et al*., (1992, 1997) and Jansa *et al*., (2002) have shown that individual species of AMF and even fungal isolates in one species, differ in their ability to promote plant growth, and that promotion of plant growth depend on the particular matching of plant and fungal species. When tested on a single plant species, the fungal isolates can increase, decrease, or have little effect on plant growth and as such these inter- and intraspecific variations make it essential to screen for efficient AMF for particular host-plant species. There was wide variation in the degree of functional compatibility between sweetpotato and the arbuscular mycorrhizal fungal isolates tested. In terms of AMF root infection, the sweetpotato plants varied in their response to inoculation with different mycorrhizal fungi. The increase in root infection by the mixed inoculant confirms previous work done by Koide (2000) and Alkan *et al*., (2006) who observed that the greater the diversity of AMF in the soil, the more the benefits conferred to the host crop i.e. sweetpotato in this study. This is because the mycorrhizal communities tend to offer a broader range of functions, so that t if a plant is colonized by AMF species that are complementary in their functions, they may be more beneficial for the plant as a mixture than as individual species separately.

In this study, application of TSP fertilizer at varied rates had significant effect on AMF root infection rates that ranged from positive to negative. It was observed that lower concentration of P at 20 kgP/ha enhanced AMF root infection. Lower concentration of TSP at 20 kgP/ha showed higher mycorrhizal root colonization and spore number compared to high concentration of 40 kgP/ha. Similar observations were made by Kahiluoto *et al*., (2001), Harwani (2006) and Johansson *et al*., (2004) who found that increased chemical fertilizer application reduced AMF development. Azcon-Aguilar and Barea, (1996) in their study observed that the overall level of arbuscular mycorrhizal fungi colonization and spore number decreased with increasing availability of soluble P. The observations from this study indicated that application of P fertilizers influenced plant-AMF interactions concurring with studies by Covacevich *et al*., (2007), Liu *et al*.,

(2000); Bohrer *et al*. (2001), van der Heijden, (2010) and Treseder, (2004) that high P levels in soil negatively impacted on the abundance of AMF and benefits associated with them.

Conclusion and recommendation

In view of the importance of sweetpotato in western Kenya and in the light of the fact that the current soil fertility status cannot support optimum productivity, approaches that are affordable with minimum negative effects to the soil and the environment are necessary. This study on Arbuscular mycorrhizal fungi has shown that in some situations, they can have significant effect on sweetpotato yields. It is not clear, however, what these conditions are. For example, their effect was variety specific. Varietal characteristics that influence their performance need to be investigated. There was also interaction between arbuscular mycorrhizal fungi effectiveness with level of soil P, with high levels of this nutrient suppressing its effects. Therefore critical levels of soil P amount that interact with AMF to give a positive response may also need to be established. This however requires facilitation in microbiology laboratory facilities in sweetpotato growing regions for ease of research.

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Bacterial diversity in Lake Nakuru and their potential utilization in agriculture and environment management

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Abstract

Albeit their known importance in decomposition which is an important function in environmental health and soil's nutrient replenishment, bacteria have been largely omitted from ecosystem studies of saline lakes. An inventory was taken in Lake Nakuru to determine the biodiversity of bacteria of the alkaline waters and potential utilization of microorganism in agriculture and environment restoration through decomposition. Samples were collected in three different depths at five points of the lake selected based on their locations, proximity to fresh water inlets and depth of the lake. The samples were collected once a month for six months in the year 2011. Bacterial were cultured and pure cultures were isolated, identified and introduced to different pollutants and materials to elucidate their decomposition potential. Decomposition potentials of the isolated bacteria were observed for various materials including plastic cup and polythene papers. The experimental set up was put in a shaker set at seventy revolutions per minute and at room temperature for 90 days, after which the final weight was determined. Twenty one different types of bacteria were identified. Some bacteria were found to be effective in decomposition of materials and hence important in agriculture and environment waste handling. Some of the bacteria that were identified as having high potential in utilization in agriculture and environment management include Sphingomonas paucimobilis, Streptococcus pyogenes, Tatumela ptyseas, Bacillus anthracoides, Chryseobacterium indologenes, Chryseobacterium meningosepticum, Pseudomonas cepacia, proteus penneri, Morganella morganii, Moraxela sp., Alcaligene sp., Providencia stuarti, and Providencia rettgeri.

Introduction

Bacteria are one of the most abundant and species rich groups of organisms that mediate many critical ecosystem processes (Claire *et al*., 2003). Bacteria are economically important as they are used in industrial microbiology, as biological pest control, in vitamin synthesis and in remediation of the environment (Liese *et al*., 1999). It is important to understand patterns of bacterial biodiversity because they mediate many of the environmental processes that sustain life on the earth and their diversity is greatly applied in bioremediation and in search for novel bio-chemicals for use in medicine, agriculture and industry (Claire *et al*., 2003).

Saline lakes have significant economic, ecological, biodiversity and cultural value. They are an important source of minerals, water, fish, biochemical products and food stuffs or aquaculture. Many have a high aesthetic value and cultural significance (Hammer, 1986). Halophiles which are found in these halophilic lakes are used in bioremediation, biodegradation and in oil recovery (Dubey *et al*., 2003).

Bioremediation is any process that uses microorganisms, fungi, green plants or their enzymes to return the environment altered by contaminants to its original conditions (Shristi *et al*., 2006). It is a process caused by biological activity which leads to the change of the chemical structure of a material to naturally occurring metabolic products (Yutaka *et al*., 2009) Naturally-occurring bioremediation and phytoremediation technologies have been used in desalination of agricultural land by phytoextraction. Bioremediation technologies can be generally classified as in situ or ex situ. In situ bioremediation involves treating the contaminated material at the site while ex situ involves the removal of the contaminated material to be treated elsewhere. Some examples of bioremediation technologies are bioventing, landfarming, bioreactor, composting, bioaugmentation, rhizofiltration, and biostimulation (Mandri and Lin, 2007). Bioremediation

has a number of advantages such as broad applicability, low cost and low risk of exposure to hazardous chemicals during cleanup (Hoff, 1993).

The elimination of a wide range of pollutants and wastes from the environment is a requirement to promote a sustainable development of the society with low negative environmental impact. Biological processes play a major role in the removal of contaminants due to catabolic versatility of microorganisms to degrade or convert such compounds (Diaz, 2008). Plastics which are non-biodegradable waste have been widely used due to their light weight, inertness and low cost. Their disposal especially those used for packaging have become a major environmental concern due to poor waste management practices. Their accumulation especially in urban areas is a challenge worldwide. Some plastics collect water and become the breeding places of mosquitoes worsening the problem. In addition, they block drainage systems. Moreover, plastics have also been recently recognized as a major threat to marine life. They sometimes cause blockage in fish intestine, birds and marine mammals. There is considerable research interest in the microbial degradation of plastics waste material since microbes are able to degrade most organic and inorganic materials (Shristi *et al*., 2006). Plastics are high molecular weight polymers that are at some stage in their existence capable of flow but may also be brought into a non-fluid form in which they have sufficient toughness and strength to be useful in self supporting applications (Brysdon, 2010).

A plastic is a broad name given to different polymers with high molecular weight which can be degraded by various processes (Iwata *et al*., 1998). Polymers are a broad class of material which are made of repeating units of smaller molecules called monomers. A plastic material is called biodegradable if all its organic compounds undergo a complete biodegradation process (Iwata *et al*., 1998). It is also said to be biodegradable if the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae and ultimately the material is converted to water, carbon dioxide and/or methane and a new cell biomass (Suyama *et al*., 1998). Environmental factors have a crucial influence on the polymer to be degraded, on the microbial population and on the activity of the different microorganisms themselves (Gu *et al*., 2000). Parameters such as humidity, temperature, pH, salinity, presence or absence of oxygen and the supply of different nutrients have an important effect on the microbial degradation of the polymers. Presence of molecular oxygen is a prerequisite for the degradation of polymers (Doi, 1990). Biodegradation of plastics is a heterogeneous process which involves biotic and abiotic processes (Tokiwa, 1994). The major mechanisms involved in the biotic degradation of plastic are; the adherence of the microorganism on the surface of the plastic followed by colonization of the exposed surface. Due to properties and the size of the polymer molecules, microbes are unable to transport the polymeric material directly into the cells where most biochemical processes take place. They first excrete extracellular enzymes which depolymerize the polymers outside the cells. This yields smaller molecules of short chains, for example oligomers, dimers, and monomers that are able to pass semi-permeable outer bacterial membrane and be utilised as carbon and energy sources (Frazer, 1994). Consequently if the molar mass of the polymers can be sufficiently reduced to generate water soluble intermediates, these are transported into the microorganism and fed into the appropriate metabolic pathways. As a result the end products of these metabolic processes include water, carbon dioxide and methane in case of anaerobic degradation. This degradation process is called mineralization (Barzal *et al*., 1989).

Biodiversity and occurrence of plastic degrading microbes vary depending on the environment such as soil, sea, compost and activated sludge (Yutaka *et al*., 2009). A number of aerobic and anaerobic microorganisms that degrade plastics particularly fungi and bacteria have been isolated from various environments (Lee, 1996).

Materials and methods

Study area

The study site was Lake Nakuru, located in the Rift Valley Province, Nakuru County, Kenya, at an altitude of 1,759 m. It consists of a shallow pan of water lying on salt impregnated clay which retains coarser polar sediments. Its surface area is 40-60 km2 but is subject to marked fluctuations because lake level is constantly

rising and falling. The average depth is 1 m (Kairu, 1991). The length of shoreline is 27 km. The water level is unregulated. It has a catchments area of 1,800 km2 (Vareshi, 1982).

Sampling locations

Five sites were selected and geo-referenced using Geographical Positioning System (GPS): Middle lake or Jetty mid (latitude -0.354781, longitude 36.093118) hippo point (latitude -0.319546, longitude 36.), Nderit (latitude -0.386313, longitude 36.110497) Makalia (latitude -0.391499, longitude 36.083254l) and Njoro ((latitude -0.331833, longitude 36.092667). These sampling points reflected different catchments areas.

Serial dilution was carried out by using a sterile pipette and transferring 1ml of the sample water to 9ml of sterile water to make a dilution of up to 106. 1ml of the diluted sample water was inoculated on sterile Nutrient agar media using spread plate method. The media was sterilized by autoclaving at 121^{o}C for 15 minutes. The inoculated plates were incubated upside down at 35□C for 24 hours. This was done to prevent condensation droplets from falling onto the surface of the agar. The petri dishes were sealed using adhesive tape to prevent contamination. Sub-culturing was done by streaking method.

Single colonies were picked using a sterile wire loop and streaked on sterile media to obtain pure cultures.

The bacteria isolated were identified based on physical characterization and biochemical tests as outlined in Bergey's manual of determinative bacteriology (Holt, 1994). Morphological characteristics such as shape and size were observed under light microscope. Gram stain was conducted. In this procedure, a thin film of each isolate was smeared on the surface of the slide and heated gently over fire to fix it. The smear was first stained with crystal violet, left to stand for a few seconds and then rinsed with a stream of water. It was then treated with a mordant (iodine). The slide smear was then washed with a decolorizing agent (acetone) and counterstained with safrinin. The smear slide was then observed under oil immersion using a light microscope.

Motility test was determined by microscopically observing the bacteria in a wet mount. An inoculum from a freshly prepared culture was used to prepare the wet mount. The inoculum was transferred to a drop of water on a microscope slide, mixed and covered using a cover slip. The slide was observed under light microscope. The bacteria that were observed to swim randomly against the current of water streaming across the slide surface were positive for this test.

Lactose test was conducted in order to determine whether the bacteria fermented this carbohydrate as a carbon source. An inoculum from a pure culture was transferred aseptically to a sterile tube of phenol red lactose broth. The inoculated tube was incubated at 35□ C for 24 hours. A positive test indicated colour change from red to yellow.

Hydrogen sulfide gas production test was carried out to determine whether the bacteria were able to reduce sulfur containing compounds to sulfides during metabolism process. An inoculum from a pure culture was transferred aseptically to a sterile triple sugar ion agar slant. The inoculated tube was incubated at 35□ C for 24 hours. A black colour in the agar slant media indicated a positive test.

Citrate test was carried out to determine the ability of the bacteria to utilize sodium citrate as the only source of carbon. A sterile wire loop was used to inoculate 3ml of sterile Koser citrate medium with a broth culture of bacteria. The inoculated broth was incubated at 35□ C for three days. A change of colour from green to blue indicated a positive result.

Serotyping using Analytical Profile Index (API) kits was carried out. API kits used were enteric (API 20E) non-enteric (API 20NE) and streptococcus kits (API 20strep.) manufactured by Biomerieux Inc. USA.

Degradation of plastics disks

Degradation of plastic disks was determined by percentage weight loss of the materials, as described by Kathiresan, (2003). The experiment was set up in four replicates and carried out for a period of 90 days. Disks of 0.6 cm diameter were prepared from clear polythene bags and white disposable plastic cups. Ten mg of each type of disk was put in a conical flask, 150 ml of distilled water and inorganic nutrients composed of 0.01M ammonium phosphate, 0.002M magnesium sulfate, 0.012M potassium phosphate and

0.144 M non-iodinated sodium chloride were added to the conical flasks, sealed using alluminium foil and sterilized by autoclaving at 121 C for 20 minutes. The contents in the conical flasks were inoculated with different bacterial species separately after cooling to 25 C. The conical flasks were covered with parafilm to provide aeration, avoid contamination and evaporation.

The negative control contained ten mg of sterile disks measuring 0.6 cm in diameter, 150 ml of distilled water, and the inorganic nutrients as stated above. A positive control contained 150 ml of distilled water, 5 g of soil from mangrove forest collected at Mtwapa, Kenya, and the inorganic nutrients. This soil was collected at a depth of 5 cm, placed in sterile polythene bags and taken to the laboratory for the purpose of the culturing, isolation and identification of the bacteria present. The soil was autoclaved after bacteria isolation and later inoculated with these bacteria. These were put in conical flasks which were covered using parafilm.

The experimental set up was put in a shaker set at seventy revolutions per minute and at room temperature for 90 days. After 90 days of shaking, the plastic and polythene disks were washed thoroughly using distilled water, shade dried and then weighed for the final weight. From the data collected, the average weight loss caused by each bacterium was computed for both plastic and polythene bags. The degradation was then determined as percentage weight loss and calculated as

Degradation = Initial weight - Final weight ×100

Initial weight

Results

The waters of Lake Nakuru were found to have diverse bacteria. Various types of bacteria grew on nutrient agar forming colonies of different sizes and colours. Twenty one species were isolated and identified from the waters of Lake Nakuru (Table 1). The bacteria were classified according to their different morphological characteristics. There were seventeen bacilli, one coccus, one coccobacillus, one vibrio and one filamentous. There were nineteen Gram negative and two Gram positive bacteria. They were further identified using other biochemical tests and API kits. There were twelve enteric and nine non enteric bacteria. Fifteen bacteria were motile while six were non motile. The bacteria isolated and identified from mangrove soil were Bacillus sp., Micrococcus sp., Staphylococcus sp., and Streptococcus sp.

Table 1. Bacteria species isolated from Lake Nakuru, classified according to shape, gram staining and biochemical tests

Bacteria species	Gram stain	Citrate test	H2S production	fermentation	Motility test	Enteric/non enteric	Shape
Bacillus anthracoides	+	-	-	+	+	Non enteric	Rods
Streptococcus pyogenes	+	-	-	-	-	Non enteric	spherical
Erwinia mallotivora	-	-	-	-	+	Enteric	Rods
Erwinia amylovora	-	-	+	+	+	Enteric	Rods
Sphingomonas paucimobilis	-	-	-	-	+	Non enteric	Rods
Morganella morganii	-	-	+	+	_	Enteric	Rods
Enterobacter or Pantonea agglomerans	-	-	-	+	_	Enteric	Rods
Yersinia pseudotuberculosis	-	-	-	+	_	Enteric	Rods
Chryseobacterium meningosepticum	-	-	-	-	_	Non enteric	Rods
Providencia stuarti	-	+	-	-	+	Enteric	Rods
Vibrio vulnificus	-	-	-	+	+	Non enteric	Comma
Pseudomonas cepacia	-	-	-	-	+	Enteric	Rods
Proteus penneri	-	-	-	-	+	Enteric	Rods
Erwinia nigrifluence	-	-	-	+	_	Enteric	Rods
Agrobacterium radiobacter	-	-	-	+	+	Non enteric	Rods
Providencia rettgeri	-	+	-	+	+	Non enteric	Rods
Alcaligen sp.	-	-	-	+	+	Enteric	Rods
Tatumella ptyseas	-	-	-	+	+	Enteric	Rods
Moraxella sp.	-	-	-	+	+	Non enteric	Spherical and rods
Chryseobacterium indologenes	-	-	-	-	_	Non enteric	Filamentous
Acinetobacter sp.	-	-	-	-	_	Enteric	Rods

Biodegradation of plastics cups by selected bacteria isolates from Lake Nakuru

The percentage weight loss of white disposable plastic cups that was caused by the bacteria was calculated as the percentage weight loss that was obtained after subtracting the amount of weight lost by the plastic in the negative control. Table 2 shows the percentage degradation of plastics that had taken place after ninety days of degradation. The initial weight of plastic that was put in each experimental set up was 10 mg. The bacteria from mangrove soil had the highest percentage of plastic degradation with the plastic discs loosing 27.5% of the original weight (Table 2).

These bacteria which were isolated from the mangrove soil included Bacillus sp., Micrococcus sp., Staphylococcus sp., and Streptococcus sp. The microorganism that caused the highest percentage of plastic degradation from Lake Nakuru was Sphingomonas paucimobilis with a percentage of (17.5%). Erwinia nigrifluence was also effective in degradation of plastic with weight loss of 12.5% of the original weight of plastics. Other bacteria that were observed to degrade plastic were Streptococcus pyogenes (11.5%) Tatumella ptyseas (11%) Pseudomonas cepacia, (9.5), Chryseobacterium meningosepticum (8%), Erwinia Amylovora (7%) Moraxella sp., (6.5%) Bacillus anthracoides (6%), Providencia rettgeri (5.0%) Proteus penneri (4.50%), Chryseobacterium indologenes (3%), Morganella morganii (2%) Providencia stuarti (1.5%) and Alcaligen sp. (0.5%). Providencia stuarti and Alcaligen sp. were slow degraders. Yersinia pseudotuberculosis and Acinetobacter species were unable to degrade plastics.

Biodegradation of polythene bags

The results in Table 3 show that the bacteria from the mangrove soil presented the highest percentage (50.5%) of degradation of polythene. These bacteria were Bacillus sp., Micrococcus sp., Staphylococcus sp. and Streptococcus sp. Among the bacteria isolated from Lake Nakuru, Sphingomonas paucimobilis presented the highest percentage of polythene degradation (37.5%). Pseudomonas cepacia caused 35.5% polythene degradation. Streptococcus pyogenes and Alcaligen sp. had the same percentage of degradation (27.0%). Tatumella ptyseas degraded polythene by 21.5%. Chryseobacterium meningosepticum reduced the polythene weight by 19.5 % while Proteus penneri reduced the weight of polythene by 18%. Other bacteria from Lake Nakuru that were able to degrade polythene were Providencia rettgeri (13.5%), Erwinia nigrifluence (11.5%), Providencia stuarti (5.50) and Chryseobacterium indologenes (7.5%). Erwinia amylovora and Acinetobacter sp. were slow degraders as they had only degraded (1%) of plastics in 90 days. Yersinia pseudotuberculosis and Morganella morganii were unable to degrade polythene (0%).

Most bacteria were able to degrade polythene at a higher percentage than plastics (Fig. 1). Morganella morganii degraded plastics though to a smaller degree but was unable to degrade polythene. Yersinia pseudotuberculosis was unable to degrade both plastics and polythene. Sphingomonas paucimobilis, Erwinia nigrifluence, Tatumella ptyseas and Streptococcus pyogenes showed high rates of degradation of both plastics and polythene. Acinetobacter sp. was able to degrade polythene but unable to degrade plastics. Alcaligen sp. indicated a high percentage of degradation of polythene but low percentage of degradation of plastics.

Table 1 : **Mean weight (mg) and percentage weight loss of plastics after treatment with different species of bacteria isolated from lake Nakuru. Initial weight of plastic put in each experimental set up was 10 mg**

Name of bacteria species	Mean wt (mg)±SE after 90 days of degradation	Wt loss (mg) after 90 days	Wt loss (%)	Wt loss due to bacteria (%)
Bacillus anthracoides	5.750 ± 0.0005	4.25	42.5	6.00
Yersinia pseudotuberculosis	6.350 ± 0.0005	3.65	36.5	0.00
Providencia rettgeri	5.850 ± 0.0005	4.15	41.5	5.00
Positive control	3.600 ± 0.0090	6.40	64.0	27.5
Providencia stuarti	6.200 ± 0.0040	3.80	38.0	1.50
Morganella morganii	6.150 ± 0.0015	3.85	38.5	2.00
Sphingomonas paucimobilis	4.600 ± 0.0060	5.40	54.0	17.5
Acinetobacter sp.	6.350 ± 0.0015	3.65	36.5	0.00
Moraxella sp.	5.700 ± 0.0030	4.30	43.0	6.50
Erwinia amylovora	5.650 ± 0.0025	4.35	43.5	7.00
Negative control	6.350 ± 0.0005	3.65	36.5	0.00
Alcaligen spp.	6.300 ± 0.0100	3.70	37.0	0.50
Proteus penneri	5.900 ± 0.0090	4.10	41.0	4.50
Chryseobacterium meningosepticum	5.550 ± 0.0005	4.45	44.5	8.00
Pseudomonas cepacia	5.400 ± 0.0020	4.60	46.0	9.50
Erwinia nigrifluens	5.100 ± 0.0000	4.90	49.0	12.5
Tatumella ptyseas	5.250 ± 0.0015	4.75	47.5	11.0
Chryseobacterium indologenes	6.050 ± 0.0035	3.95	39.5	3.00
Streptococcus pyogenes	5.200 ± 0.0010	4.80	48.0	11.5

Weight loss was calculated by subtracting the mean weight from the original weight (10mg) put in the set up. Weight loss attributed to bacteria was calculated by subtracting the weight lost by the negative control from the weight lost in each bacterium set up

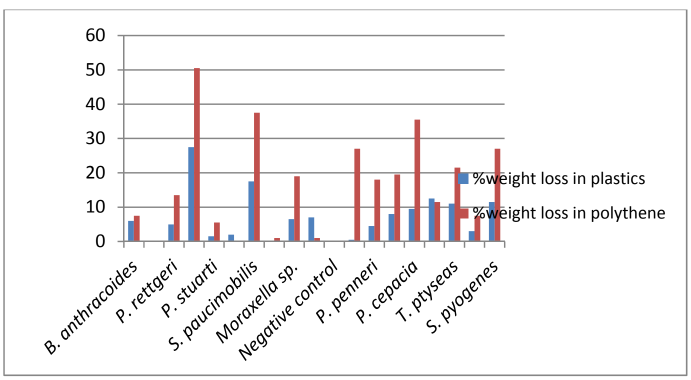

Figure 1: **Comparison of the percentage weight loss in plastic cups and polythene bags by each bacterium species isolated from lake Nakuru**

Table 2**: Mean weight (mg) and percentage weight loss of polythene after 90 days of treatment with different species of bacteria isolated from lake Nakuru. Initial weight of polythene put in each experimental set up was 10 mg**

Name of bacteria species	Mean wt (mg)±SE of degradation	Wt loss (mg)	Weight loss (%)	Wt loss due to bacteria (%)
Baccilus anthracoides	8.40 ± 0.0010	1.60	16.0	7.50
Yersinia pseudotuberculosis	9.15 ± 0.0005	0.85	8.50	0.00
Providencia rettgeri	7.80 ± 0.0110	2.20	22.0	13.50
Positive control	4.10 ± 0.0030	5.90	59.0	50.50
Providencia stuarti	8.60 ± 0.0050	1.40	14.0	5.50
Morganella morganii	9.15 ± 0.0005	0.85	8.50	0.00
Sphingomanas paucimobilis	5.40 ± 0.0020	4.60	46.0	37.50
Acinetobacter sp.	9.05 ± 0.0005	0.95	9.50	1.00
Moraxella sp.	7.25 ± 0.0105	2.75	27.5	19.00
Erwinia amylovora	9.05 ± 0.0005	0.95	9.50	1.00
Negative control	9.15 ± 0.0005	0.85	8.50	0.00
Alcaligen spp.	6.45 ± 0.0045	3.55	35.5	27.00
Proteus penneri	7.35 ± 0.0005	2.65	26.5	18.00
Chryseobacterium meningosepticum	7.20 ± 0.0010	2.80	28.0	19.50
Pseudomonas cepacia	5.60 ± 0.0010	4.40	44.0	35.50
Erwinia nigrifluens	8.00 ± 0.0040	2.00	20.0	11.50
Tatumella ptyseas	7.00 ± 0.0150	3.00	30.0	21.50
Chryseobacterium indologenes	8.40 ± 0.0100	1.60	16.0	7.50
Streptococcus pyogenes	6.45 ± 0.0045	3.55	35.5	27.00

Weight loss was calculated by subtracting the mean weight from the original weight (10mg) put in the set up. Weight loss attributed to bacteria was calculated by subtracting the weight lost by the negative control from the weight lost in each bacterium set up

Discussion

Diversity of Bacteria in Lake Nakuru

The results from this study show that lake Nakuru has a rich diversity of bacteria. This may be due to diverse ecological niche of the lake. Twenty one species of bacteria were identified. They had different morphological and biochemical characteristics. There were bacillus, coccus, coccobacillus, vibrio and filamentous bacteria. Some of the bacteria were inhabitants of the Lake as they are known to be found in various habitats including salty waters for example Vibrio vulnicus. Other bacteria were likely to be in the Lake as a result of pollution for example Streptococcus pyogenes. Vareshi, (1982) had reported that the ecosystem in the lake may have changed due to pollution.

Degradation of Plastics and Polythene

The study revealed that the waters of lake Nakuru are a good source of bacteria capable of degrading plastics and polythene. There were visible changes in the plastic and polythene materials such as rough surface and dull colour. In the control, there was no observable change. Ikada, (1999) reported that parameters of visual changes can be used as a first indication of any microbial attack. According to katheserian, (2003) Streptococcus sp, Pseudomonas sp, and Moraxella sp. were able to degrade polythene and plastics. Bacillus sp was able to degrade polythene but unable to degrade plastics. In this study these bacteria, including Bacillus sp. were able to degrade both plastic and polythene.

Sphingomonas paucimobilis caused the highest percentage weight loss which is attributed to degradation for both plastics (17.5%) and polythene (37.5%). This bacterium can be used in bioremediation and biodegradation. S. paucimobilis occurs in various enviroments hence easy to isolate and culture for remediation purpose. S. paucimobilis is metabolically versatile, which means it can utilize a wide range of naturally occurring compounds as well as some types of environmental contaminants. Burd, discovered that Sphingomonas can degrade over 40% of the weight of polythene in less than three months (http://www.mnn.com/green-tech/research-innovations). Studies have been held to further explore its metabolic mechanisms for application in biotechnology, in addition to its current utilization in bioremediation and in the food technology. Sphingomonas paucimobilis is able to degrade lignin-related biphenyl chemical compounds (Nilgiriwala, 2008). According to Ni'matuzahroh *et al*. (1999) Sphingomonads have been utilised for a wide range of biotechnological applications, from bioremediation of environmental contaminants to production of extracellular polymers such as sphingans e.g. gellan, wellan, and rhamsan which are used extensively in the food and other industries due to their biodegradative and biosynthetic capabilities. One strain, Sphingomonas sp. 2MPII, can degrade 2-methylphenanthrene.

Streptococcus pyogenes was able to degrade both plastics (11.5%) and polythene (27.0%). According to Kathiresan, (2003) Streptococcus sp. was able to degrade polythene at 2.19% and 1.07% of plastics per month. It can be used for the elimination of these two pollutants. It is also applied in biotechnology whereby many of its proteins are known to have unique properties, which have been harnessed to produce a highly specific "superglue" (Zakeri, 2012) and a route to enhance the effectiveness of antibody therapy (Baruah, 2012).

Alcaligen sp. was able to degrade polythene at a high percentage (27%) and plastics at low percentage (0.5%). This may be due to the molecular weight of plastic which is higher than that of the polythene. This bacterium was able to degrade polythene at a higher percentage which could be attributed to its low molecular weight. The surface area of the plastic exposed to this bacterium was smaller compared to the surface area of polythene that was exposed to it. The surface area of the material being degraded that is exposed to the bacteria affects the percentage of degradation. The more the surface area exposed to the bacteria, the higher the rate of degradation (Goldberg, 1995). Alcaligen sp. is known to be used in remediation of environmental pollutants. According to Anderson, (2003) A. faecalis converts the most toxic form of arsenic, arsenite ($AsO2-$) to its less dangerous form, arsenate ($AsO4-$). Alcaligenes has been used for the industrial production of non standard amino acids. Alcaligen eutrophus also produces the biopolymer polyhydroxybutyrate (PHB). Species of Alcaligenes generate energy in a number of ways, including arsenite oxidation. This species can be used to clean up environments contaminated with polythene.

Acinetobater sp. was able to degrade polythene (1%) but unable to degrade plastics. This may be attributed to the thickness of plastics that was higher than that of the polythene and also to the surface area of polythene exposed to the bacteria compared to the plastics. This species is metabolically versatile and hence can be exploited in various biotechnological applications including biodegradation and bioremediation (Gutnik, 2008). Gerischer (2008) reported that many of the characteristics of Acinetobacter ecology, taxonomy, physiology, and genetics point to the possibility of exploiting its unique features for future applications. Acinetobacter strains are often ubiquitous and robust (Gutnik, 2008). Some provide convenient systems for modern molecular genetic manipulation and subsequent product engineering. These characteristics are being exploited in various biotechnological applications including novel lipid and peptide production, enzyme engineering, biosurfacant and biopolymer production and engineering of novel derivatives of these products. It is anticipated that progress in these fields will broaden the range of applications of Acinetobacter for modern biotechnology (Gutnik, 2008).

Burkhoderia cepacia was able to degrade plastics (9.5%) and polythene (35.5%). This bacterium can be used in the remediation of environment polluted by these wastes. This bacterium is found in water and

soil and can survive for prolonged periods in moist enviroments hence easy to isolate and culture for remediation purpose. This bacterium is also clinically important as it is a human pathogen which most often causes pneumonia in immunocompromised individuals (Mahenthiralingam, 2005).

Erwinia nigrifluens and Tatumella ptyseas were able to degrade plastics and polythene (12.5%, 11%) and (11.5%, 21.5%) respectively. These bacteria can be used for remediation of plastic and polythene polluted environments. Apart from being important in biodegradation they are also clinically important. Erwinia nigrifluens is the causative agent of shallow bark canker of walnut (Wilson *et al*., 1957) while Tatumella ptyseas is a human pathogen.(Berka,2001).

Moraxella sp. was able to degrade plastics (6.50%) and polythene (19.0%). Kathiresan, (2003) reported that Moraxella sp. was able to degrade 7.75% of polythene and 8.16% of plastic per month. This bacterium can be utilized in bioremediation of the environment from these pollutants. Proteus penneri, Chryseobacterium meningosepticum and pseudomonas cepacia were also good in degradation of both plastic and polythene. Apart from being important in biodegradation, Chrysebacterium meningosepticum is also clinically important as it causes opportunistic infections in immunocompromised patients (Murrey *et al*., 2007). Pseudomonas cepacia degraded plastic (9.50%) and polythene (35.50%). Kathiresan, (2003) reported that pseudomonas sp. degraded polythene at 20.54% and plastics at 8.16% per month. It is typically found in water and soil hence easy to isolate and culture for remediation purposes. Yersinia pseudotuberculosis was unable to degrade both plastics and polythene whereas Morganella morganii was unable to degrade polythene.

The type of microorganism affects the rate of degradation of polymer (Artham and Doble, 2008). Hence there were different rates of degradation of both plastics and polythene depending on the species of the bacteria present. Different bacteria species were able to degrade plastic and polythene at different rates although they had received the same amount and type of nutrients. Sphingomonas paucimobilis had the highest percentage of degradation compared to the rest of the bacteria species. This bacterium is known to be metabolically versatile since it can utilize a wide range of compounds as well as pollutants. It was able to metabolise the plastics and polythene at a higher percentage than the rest of the bacteria. Other microorganisms that were good in degradation of both plastic and polythene were Streptococcus pyogenes, Tatumella ptyseas, Pseudomonas cepacia, Erwinia nigrifluence, Chryseobacterium meningosepticum and Moraxella sp

The surface area of the plastic and polythene exposed to microorganism affects the rate of degradation. The more the surface area exposed, the higher the rate of degradation (Goldberg, 1995). The higher rate of degradation by bacteria on the polythene bags may be attributed to the surface area exposed to the bacteria. More polythene discs were put in the experiment set up than the number of plastic discs to achieve the same mass. Hence more surface area of polythene was exposed to the bacteria than that of plastics leading to a higher percentage of degradation of polythene than that of plastics.

Generally, increase in molecular weight of the polymer decreases its degradability by microorganisms. High molecular weight results in a decrease in solubility making them unfavourable for microbial attack. This is because bacteria require the substrate to be assimilated through the cellular membrane and then be further degraded by cellular enzymes (Gu *et al*., 2000). Plastics have a higher molecular weight and are thicker than polythene. In this research, this might have contributed to the higher weight loss of the polythene than that of plastic for each bacteria species. The weight loss of polythene was higher than that of plastics for each bacteria species except for Erwinia spp. and Morganella morganii. Erwinia spp. had a higher weight loss of plastics than polythene while Morganella morganii was unable to degrade polythene. These bacteria could be having enzymes that are more specific to the degradation of the compounds found in the plastic cups or in the polythene bags.

Polymer degradation is a change in the polymer properties such as tensile strength, colour, shape or molecular weight under the influence of one or more environment factors such as light, chemicals, and

in some cases by galvanic action (Faudree, 1991). Degradation is due to the scission of polymer chain via hydrolysis leading to a decrease in the molecular mass of the polymer. The initial breakdown of a polymer can result from a variety of physical, chemical and biological forces with chemical hydrolysis being the most important. Embrittlement which is one of the physical forces initiating degradation of polymers is activated primarily by sunlight or heat (Goldberg, 1995). These leads to reduction of molecular weight of the polymer and hence increase in the microbial accessibility (Ghazali, 2004).

In this study, initial reduction of molecular weight is attributed to the physical and chemical forces which were activated by heat generated during shaking (Doi, 1990). The moleculer weight reduction may have been as a result of carboxyl group oxidation. Oxidation starts at tertiary carbon atoms because the free radicals formed are more stable and long lasting making them more susceptible to attack by oxygen (Faudree, 1991). Discolouration on the surface may have been as a result of the deposition of carbonates from the salts added. Lapishin *et al*., (2010) reported that salts cause the discolouration effect on plastic during the process of degradation. Chlorine gas also has an oxidizing effect on polymer. This gas attacks sensitive parts of the chain molecules, oxidizing the chain cleavage. Cracks can be formed by Ozone.

In the plastic experiment 36.5% weight reductions occurred in the negative control. This may be attributed to physical and chemical forces (Faudree, 1991). In the polythene experiment, 8.5% weight reduction occurred in the negative control. This is attributed to the physical and chemical forces of degradation (Goldberg, 1995).

Conclusion

In conclusion, the bacteria from Lake Nakuru can be used to eliminate pollutants through biodegradation and hence leading to soil's nutrient replenishment. The processing of waste degradation using living organisms is environmentally friendly, relatively simple, and cost effective.

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Response of rice to different levels and sources of nitrogen in a sandy clay loam soil in Morogoro, Tanzania

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Abstract

Inadequate supply of Nitrogen by tropical soils is an important constraint to productivity of lowland rice. Limited information is available on the use of green manure especially lablab on increasing nitrogen in rice fields. A study was conducted to investigate the response of rice to different levels and sources of nitrogen from urea and lablab in a sandy clay loam soil in Morogoro. Field experiment was conducted. Treatments evaluated were absolute control, three levels of Nitrogen from urea or lablab and the same levels of Nitrogen from combination of lablab and urea at equal levels of Nitrogen plus a treatment supplying Nitrogen from lablab roots arranged in a randomized complete block design and replicated three times. Phosphorus (30 kg/ha) was applied. The results showed that treatments with 120 kg N/ha led to highest crop performance and rice yield than the control. Highest rice yield (4.1 t/ha) was obtained at 120 kg nitrogen pre hectare (ha) from urea followed by a combination of lablab (60 kg N/ha) and urea (60 kg N/ha) which gave 3.7 t /ha. Incorporation of lablab resulted in a rapid build-up in total Nitrogen suggesting an improvement in soil nitrogen status. It is concluded that, urea at the rate of 120 kg N/ha produced the highest rice grain followed with a combination of 60 kg N/ha from urea and 60 kg N/ha from lablab. It is recommended to use 120 kg N/ha from urea or a combination of 60 kg N/ha from urea and 60 kg N/ha from lablab.

Key words: rice grain yield, green manure, lablab, soil and plant nutrients

Introduction

Rice [Oryza sativa (L.)] is the most important food crop of the developing world. In Tanzania, rice ranks second in production coming after maize and sorghum (Ministry of Agriculture and Cooperatives, 1998). The average yield is estimated at 1.5- 2.1 tons/ha but yields as high as 6 tons/ha have been obtained in irrigated rice projects (FAO, 2007). Low soil fertility is one of the greatest biophysical constraints to rice production (Ley *et al*. 2005). In Tanzania, continuous cropping without adequate fertilization has led to low soil fertility and subsequent low crop yields (Ikerra *et al*. 2006). In Morogoro, the major soil fertility constraint in paddy rice is Nitrogen deficiency followed by Phosphorus and Zinc deficiency (Semoka *et al*. 1995).

Use of leguminous plants in crop rotations, improved fallows, intercropping, cover crops, and green manures is among the possible strategies to alleviate the trend of declining soil fertility (Ikerra *et al*. 2006). Crop rotation of rice with lablab resulted in significant increase in soil N, P and K and consequently increases in rice yields in Mombo and Kwemazandu irrigation schemes in Tanga region (Ikerra and Kalumuna, 2009).

Use of Lablab purpures L. as green manure in lowland rice improve soil fertility because lablab is incorporated at 10 weeks after planting when nutrient accumulation is at maximum stage as compared to lablab that is incorporated at harvesting stage.

The overall objective of this study was to determine the efficacy of Lablab with or without inorganic N in improving the productivity of lowland rice in a mother- baby trial at Kiroka Irrigation Scheme in Morogoro region of Tanzania. The specific objectives were

To assess the effect of levels and sources of N from lablab and urea on increasing N in rice farms;

To assess the effect of levels and sources of N from lablab and urea application on increasing the yield of rice and

To assess the response of rice yield components on levels and sources of N application from lablab and urea

Material and methods

Location

The field study was conducted at Kiroka village in Morogoro rural district about 24 km south-east of Morogoro Municipality. The site is situated at 37o82' E / 6o84'S at an altitude of 200 m. The rainfall amount in the area ranges from 900 mm to 1700 mm per year. The annual temperature ranges from 21.3oC to 25.9oC.

Soil sampling and analysis

Composite soil samples were collected at the site from 0-20 cm to determine soil mineral N before incorporation of lablab into the soil. The composite soil sample was analysed for texture, pH, CEC, Total Nitrogen, available Phosphorus, Organic carbon, Sodium, Potassium, Calcium, Magnesium, Copper, Zinc, Manganese and Iron.

Lablab plant sampling, analysis and planting

Lablab plant samples were sampled for the determination of N for both biomass and roots. Lablab beans were sown and then their leafy materials harvested and incorporated in the soil in the field and in pots after ten weeks. Lablab biomass was chopped into small pieces before being incorporated into the soil which was planted two weeks thereafter. The amount of lablab incorporated in the soil depended on the amount of N in the lablab which was 3.21% in biomass and 3.0% in roots.

Layout and treatments

The experiment had twelve treatments replicated three times in a Randomized Completely Block Design (RCBD).

Land preparation, lablab planting and incorporation

Site clearing was done manually in a field. Plot size was 6.4 m x 2.8 m and each plot was closed by small ridges to prevent surface movement of water from one plot to another. Lablab seeds were sown and biomass was incorporated into the soil after being chopped into small pieces 72 day after planting before flowering. The amount of lablab incorporated in the soil depended on the amount of N in the lablab which was 3.2% in lablab biomass and 3.0% in lablab roots.

Raising seedlings in the nursery

The seed beds were prepared 30 days before transplanting. Seeds were soaked in water for 24 hours before they were sown onto the seedbed.

Soil sampling

Soil sampling was done two weeks after incorporation of lablab into the soil at the depth of 0-20 cm to monitor mineral-N released through lablab decomposition.

Fertilization, transplanting of rice and water application

Lablab green manure was incorporated into the soil ten weeks after planting following and two rice seedlings were transplanted two weeks later into the same plots where lablab green manure had been incorporated. Both rain water and irrigation were applied. Flooding was done by irrigation soon after applying the first dose of N.

Data collection

Plant height, number of tillers, Grain yields and straw weight in each experimental unit were determined and recorded.

Harvesting

At maturity an area of 10 m2 in each plot was harvested by cutting the shoots at 1 cm above the soil surface and paddy threshed manually, winnowed and weighed.

Data analysis

Data for grain yield, plant height, dry matter yield, number of panicles and number of tillers per plant were subjected to analysis of variance. Means were separated by using Duncan's Multiple Range Test. The statistical significance was evaluated at $P<0.05$. The MSTAT-C computer package was used for statistical data analyses.

Results and discussion

Soil fertility status of the experimental site

Some of the physical- chemical properties of the soil used in the study are presented in Table 1 bellow.

Table 1**: Some of the physical – chemical properties of the experimental site**

Parameter	Magnitude	Rating
pH (H2O)	7.0	Neutral
Organic C (%)	1.7	Low
Total N (%)	0.1	Low
Available P (mg/kg)	17.0	High
Na (meq/100g)	0.7	Medium
K (meq/100g)	0.7	High
Ca (meq/100g)	8.9	Medium
Mg (meq/100g)	0.7	Medium
CEC (Cmol (+)/kg	24.5	Medium
Cu (mg/kg)	2.7	High
Zn (mg/kg)	2.4	High
Mn (mg/kg)	74.8	High
Fe (mg/kg)	55.1	High
Sandy (%)	66.0	
Silt (%)	7.0	
Clay (%)	27.0	
Textural Class	Sandy Clay Loam	

The pH of the soil was 7.0 which was categorized as medium/high (Landon, 1991). The pH was conducive for rice production as recommended by Landon (1991). Organic carbon of the soil was 1.66 % which is categorized as low (Landon, 1991) and total soil N value was 0.06 % which is again categorized as very low (Landon, 1991). Available soil P in the study area was 17.0 mg/kg which rates as high (Landon, 1991). However for optimum rice production and soil fertility maintenance there is a need to fertilize these soils with P. The cation exchange capacity of the soil was 24.5 (Cmol (+)/kg) which is rated as medium and hence capable of supporting the growth of rice (Landon, 1991; EUROCONSULT 1989. The texture of the soil was sandy clay loam. According to Landon (1991) and De Datta (1981), medium to heavy textured soils are appropriate for rice production due to their good water holding capacity and nutrient supply. Generally the fertility status of the site is rated as medium to high except for N and OC.

Lablab characteristics incorporated into the soil

The dry matter content of lablab incorporated into soil was 22.5 % for shoots and 31.0 % for roots. Total N was 3.21 % in the shoots and 3.0 % in the roots. The total P was 0.142 % in the shoots and 0.12 % in the roots. Potassium was 1.81 % in the shoots and 1.21 % in the root.According to Palm *et al*., 2002, organic materials with N content > 2.5% are classified as high quality organic materials as far as N is concerned

Effect of Nitrogen rates and sources on grain yield, dry matter yield, and yield characters

Application of 120 kg N/ha significantly (P< 0.05) increased rice grain yield (Table 2). The highest grain yield (4.1 t/ha) was recorded at 120 kg N/ha from urea alone followed by treatments with 80 kg N/ha from urea, a combination of 60 kg N/ha from urea and 60 kg N/ha from lablab and combination of 40 kg N/ha from urea and 40 kg N/ha from lablab (3.7 t/ha). The lowest grain yield of 2.0 and 2.2 t/ha were recorded in the absolute control and in the treatment with nitrogen from roots (12 kg N/ha), respectively. Nitrogen application increased dry matter yield significantly (P< 0.05).The highest shoot dry matter (6.2 t/ ha) was recorded in treatment with 120 kg N/ha from urea. The lowest shoot dry matter (3.5 and 3.7 t/ha) were recorded in the treatment without N application which were N from roots and absolute control respectively.

Table 2: **Effects of nitrogen rates and sources on grain yield and shoot dry matter**

Treatment	(t/ha)	
	Grain yield	Shoot dry matter
Absolute control	2.0 d	3.7 ef
N80 (Lablab) + P0	2.4 bc	4.1ef
N40 (Urea) + P30	2.8 c	3.9 ef
N40 (Lablab) + P30	2.3 cd	4.4 def
N40 (20 from urea + 20 from lablab) + P30	2.9 bc	4.6 cde
N80 (Urea) + P30	3.7 ab	5.5 abc
N80 (Lablab) + P30	2.5 cd	4.2 def
N80 (40 from urea + 40 from lablab) + P30	3.7 ab	5.1 bcd
N120 (Urea) + P30	4.1 a	6.2 a
N120 (Lablab) + P30	2.8 cd	4.4 def
N120 (60 from urea + 60 from lablab) + P30	3.7 ab	6.0 ab
N12 (roots) + P30	2.2 cd	3.5 f
Mean	2.92	4.63
CV (%)	14.25	11.80
SE	2.24	0.315

Means within a column followed by the same letter (s) are not significantly different (P< 0.05) according to DNMRT.

Effect of Nitrogen rates and sources from urea and lablab on plant components

High N application significantly ($p < 0.05$) increased the number of tillers per plant (Table 3). Plants with N from urea had relatively higher number of tillers per plant than plants with lablab-N. The highest (13) number of tillers per plant was recorded with 80 kg N/ha from urea alone. The lowest (8 and 9) number of tillers per plant were recorded with low N application (40 kg N/ha) from lablab alone and those without N.

Table 3: **Effect of Nitrogen rates and sources on number and height of tillers**

Fertilizer rate	No. of tillers/plant	Height of tillers (cm)
Absolute control	8.7 cd	60.2 bcde
N80 (Lablab) + P0	8.7 cd	50.9 e
N40 (Urea) + P30	10.7 abcd	62.7 abcd
N40 (Lablab) + P30	7.7 d	63.5 abcd
N40 20 from Urea + 20 from Lablab + P30	9.7 bcd	69.1 ab
N80 (Urea) + P30	13.0 a	67.1 abc
N80 (Lablab) + P30	8.7 cd	53.7 de
N80 40 from Urea) + 40 from Lablab + P30	11.3 abc	69.6 ab
N120 (Urea) + P30	12.3 ab	71.1 a
N120 (Lablab) + P30	9.7 bcd	56.3 de
N120 60 from Urea + 60 from Lablab + P30	12.3 ab	63.6 abcd
N12 (roots) + P30	9.0 cd	57.1 cde
Mean	10.1	62.1
CV %	17.1	8.87
SE	0.99	3.18

Means in the same column followed by the same letter are not significantly different ($P<0.05$) using Duncans Multiple Range Test

High N application significantly ($p < 0.05$) increased plant height (Table 3). Plants in treatment with N from urea were taller than plants in treatment with N from lablab. The tallest (71.1 cm) were recorded in treatment with 120 kg N/ha from urea alone. The shortest (50.9 and 53.7 cm) were recorded in treatments with lablab alone without P and treatment with roots.

Effect of Nitrogen rates and sources on nitrogen, phosphorus and potassium

Incorporation of lablab in the soil significantly ($p < 0.05$) increased Total N and available P in the study area (Table 4). But incorporation of lablab had no significant influence on K.

Initial total N concentration in the soil was 0.06% (Table 1). However incorporation of lablab in the soil significantly ($p < 0.05$) increased N concentration up to 0.37% .The highest increase of N was in plots where lablab was incorporated at the rate of 120, 80 and 60 kg N/ha where the increase was 522.2%, 344.4% and 250.0% respectively.

Initial available P in the soil was 17.0 mg/kg of soil. However incorporation of lablab in the soil significantly ($p < 0.05$) increased available P up to 28.3 mg/kg of soil .The highest increase of P was in plots where lablab was incorporated at the rate of 120, 80 and 60 kg N/ha where the increase was 66.4%, 43.0% and 38.8% respectively.

Initial K in the soil was 0.67 me/100 g of soil. However incorporation of lablab in the soil had no significantly increased ($p < 0.05$) of K in the soil but the increases were up to 1.0 me/100g of soil.

Table 4: **Effect of Nitrogen from Urea and Lablab on nitrogen, phosphorus and potassium**			
Fertilizer rate	Nitrogen (%)	Phosphorus (mg/kg)	Potassium (Me/100g)
Absolute control	0.07c	17.60de	0.74a
N80 (Lablab) + P0	0.27ab	24.31b	0.91a
N40 (Urea) + P30	0.06c	18.35de	0.75a
N40 (Lablab) + P30	0.15bc	23.20bc	0.85a
N40 20 from urea + 20 from lablab + P30	0.11bc	20.69bcd	0.82a
N80 (Urea) + P30	0.07c	16.35e	0.78a
N80 (Lablab) + P30	0.27ab	24.48b	0.96a
N80 40 from urea + 40 from lablab + P30	0.12bc	24.17b	0.86a
N120 (Urea) + P30	0.07c	19.12de	0.75a
N120 (Lablab) + P30	0.37a	28.29a	1.00a
N120 60 from urea + 60 from lablab + P30	0.21abc	23.59bc	0.87a
N12 (roots) + P30	0.07c	19.84cde	0.80a
Mean	0.154	21.67	0.84
CV %	66.54	9.91	18.31
SE	0.06	1.24	0.09

Means within column (s) followed by the same letter (s) are not significant different (P< 0.05 according to DNMRT

Conclusion

The use of lablab as a green manure in lowland rice is a practice that is potentially useful for nutrient management and improve plant characteristics and grain yield. Based on the findings of this study, the following conclusions can be made:-

The highest rice grain yield (4.1 t/ha) was obtained at 120 kg N/ha from urea followed with 3.7 t/ha from a combination of 60 kg N/ha from urea and 60 kg N/ha from lablab. Lablab alone at the same rate gave a yield of 2.8 t/ha which was significantly lower than that of 120 kg N from urea and a combination of 60 kg N/ha from urea and 60 kg N/ha from lablab

The best N source for rice grain yield was 120 kg N/ha from urea followed with a combination of 60 kg N/ha from urea and 60 kg N/ha from lablab

The best N source for N build up in soil was 120 kg N/ha from lablab followed with 80 kg N/ha from lablab

Integrated soil fertility management with the application of lablab and urea in rice fields increased crop yield and minimize costs to the farmers

Recommendations

Since lablab increased N in the soil, the following are recommended:

It is recommended to use urea alone at 120 kg N/ha or combination of urea and lablab at the total rate of 120 kg N/ha because they gave comparable yield

Integrated soil fertility management with the application of lablab and urea is recommended in rice farms because application of lablab to this soil resulted in improvement in soil chemical properties related to P and N availability

Lablab is the good source of N in rice farms because after incorporated into the soil and left for two weeks, released N which used by rice

In addition, further trials should be carried out to establish optimum levels or rates of lablab for both field and pot experiments because large amount of lablab biomass can be produced in the field

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Soil properties and yam performance as influenced by poultry manure and tillage on an Alfisol in southwestern Nigeria

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Abstract

Field experiments were conducted to investigate the effect of soil tillage techniques and poultry manure application on the soil properties and yam (Dioscorea rotundata) performance in Ondo, southwestern Nigeria for two farming seasons. Five soil tillage techniques, namely ploughing (P), ploughing plus harrowing (PH), manual ridging (MR), manual heaping (MH) and zero-tillage (ZT) each combined with and without poultry manure at the rate of 10tha-1 were investigated. Data were obtained on soil properties, nutrient uptake, growth and yield of yam. Soil moisture content, bulk density, total porosity and post harvest soil chemical characteristics were significantly ($p>0.05$) influenced by soil tillage-manure treatments. Addition of poultry manure to the tillage techniques in the study increased soil total porosity, soil moisture content and reduced soil bulk density. Poultry manure improved soil organic matter, total nitrogen, available phosphorous, exchangeable Ca, K, leaf nutrients content of yam, yam growth and tuber yield relative to tillage techniques plots without poultry manure application. It is concluded that the possible deleterious effect of tillage on soil properties, growth and yield of yam on an alfisol in southwestern Nigeria can be reduced by combining tillage with poultry manure.

Introduction

Loosening the soil constitute an integral part of the soil management in yam production. Loosening of soil during land preparation will generally improve drainage, soil aeration, reduce root rot and increase yield of yam. It will also facilitate the harvest and reduce tuber damage during harvest. In tropical traditional farming, tuber crops are grown in raised beds particularly mounds. Farmers make mounds or ridges with manually operated tools or with equipment drawn by draught animals. However, manual soil preparation limits the hectarage under cultivation (Ezumah, 1986). Farmers in southwestern Nigeria rarely use mechanized land preparation techniques such as ploughing, harrowing and ridging due to the limited cropping particularly at subsistence level, high cost of acquisition and high cost of hiring machines for land preparation.

Few studies on response of yam to soil tillage were conducted mainly on comparison of ridging and flat planting (Opara-Nadi and Lal, 1987). Agbede and Ojeniyi (2003) investigated manual tillage and zero-tillage on alfisol of southwestern Nigeria and reported that manual tillage produced better soil physical properties, leaf nutrients and tuber yield than zero-tillage while zero-tillage produced better soil nutrients status than manual tillage. There is need to improve research information base on response of yam to zero tillage and mechanized tillage methods compared to traditional mounding and ridging methods. Mechanized tillage is expected to provide a finer tilth which may enhance performance of yam and nutrient uptake while zero-tillage is expected to reduce labour input in soil preparation and conserve soil productivity.

Land improvement techniques used for yam production in southwestern Nigeria include mulching, bush fallow and crop rotation. However, population pressures have enforced the shortening of the fallow period and field rotation cycle resulting in the loss of soil productivity with consequent reduction in yam yield. Application of inorganic fertilizers constitutes a practice by farmers in an attempt to correct the deficiencies of nutrient elements and increase crop yield. In southwestern Nigeria, the use of inorganic

fertilizers in yam production is on limited scale because of the perception and belief of the farmers that inorganic fertilizers affect the taste of "pounded yam" a highly preferred food of the people in southwestern Nigeria, promote weeds, vegetative growth rather than tuber formation and yield of poor qualities in terms of taste and storage life (Daramola, 1989; Bamire and Amujoyegbe, 2005). The use of organic manure is considered less likely to have detrimental effects on soil properties and crop quality compared with inorganic fertilizers. The use of poultry manure in yam production is expected to have positive effects on soil physical properties, improves soil organic matter, increase soil nutrients content, improve biotic life in the soil and increase yield of yam. Therefore, combining poultry manure with tillage is expected to ameliorate deleterious effects of tillage on soil properties and enhance yam tuber yield. Hence, this study was designed to investigate effects of tillage-poultry manure treatments on soil properties and performance of yam on alfisol in southwestern Nigeria.

Materials and methods

Field experiments and experimental design

Five soil tillage techniques, namely ploughing (P), ploughing plus harrowing (PH), manual ridging (MR), manual heaping (MH) and zero-tillage (ZT) each combined with and without poultry manure at the rate of 10tha-1 were investigated in a factorial experiment arranged in split-plot design at Ondo

(070 05'N, 040 55'E) in the rain forest zone of southwestern Nigeria for two farming seasons (2007 and 2008). A total land area of 110m x 50m was used for the experiment. The land area was divided into three (3) blocks, adjacent blocks were demarcated by 5-metre alley ways. Each block was further divided into five (5) main plots of 15mx15m on the basis of soil tillage techniques which were similarly demarcated by 5- metre alley ways. Each main plot was further divided into two subplots of 5mx15m on the basis of poultry manure rates which were also demarcated by 5m alley ways. The treatments were assigned to the plots and each replicated three times. The same treated plots were maintained for the two cropping seasons. Yam sets having average weight of 300g were planted. Other cultural practices were adequately carried out.

Determination of soil physical properties

Soil bulk density was determined from oven-dried undisturbed core samples collected to the depth of 10cm by core method (Stolte *et al*, 1992). Total porosity (Ps) was calculated from bulk density (Db), assuming a particle density (DP) of 2.65g cm-3, using the relationship between particle density (Dp) and bulk density (Db) i.e Ps = 100 (l-Db /DP). Soil moisture content was measured with TDR-100 moisture meter. These soil physical properties were measured a month after the treatments were applied and at a 4 – weekly intervals and for 20 weeks of the field experimentation.

Growth and yield data

Ten yam stands were selected per replicate (plot) for the measurement of growth and yield parameter at harvest. Vine girth was measured at 15cm above heap level using a pair of vernier calipers. The vine length was measured with a measuring tape. The number of branches from the main vine per plant was recorded. Tuber weight was determined using a weighing balance and tuber length with a measuring tape. Leaf area was determined graphically.

Leaf nutrient contents analysis

At five months after planting, mature leaves were collected from the 10 tagged yam stands per plot. The leaf samples were oven dried at 650C for 48 hours and ground for routine chemical analysis. Leaf N was determined using the micro-kjeldahl digestion method. P was determined colorimetrically by vanadomolybdate method, K by flame photometer and Ca, Mg by the atomic absorption spectrophotometer.

Soil chemical analysis

The post harvest soil samples were collected, air-dried, sieved to pass through a 2-mm mesh and chemically analyzed. The soil pH was determined using glass electrode pH meter in a 1:2 soil-water ratio. Organic carbon content was determined by Walkley-Black dichromate oxidation method. Total-N was determined by the micro-kjeldahl method. Available P was extracted by the Bray-1 method and determined colorimetrically, exchangeable Ca, K, Mg, and Na were extracted with1.0N NH40Ac using a soil: solution volume ratio of 1:10. The K and Na in the extract were read using a flame photometer; while Ca and Mg were determined by Atomic Absorption Spectrophotometer (AAS). Exchange acidity was determined from 1.0N KCl extract and titrated with 1.0N HCl.Cation exchange capacity was determined by the summation of NH4oAc – extractable cations and KCl –exchange acidity. The micro-nutrients (Fe, Cu, Zn, Mn) were extracted with 1.0N HCl and determined on Perkin Elmer 20 AAS

Data analysis

Data on soil properties, leaf nutrient contents and yam tuber yield were subjected to analysis of variance using Statistical Analysis System Institute Package (SAS) and the mean values were compared using Duncan's Multiple Range Test at 0.05% level of significance.

Results

The soil moisture content of plots under various tillage techniques improved significantly with the application of poultry manure (Table 1). Highest soil moisture content was obtained in zero-tillage plot amended with poultry manure (98.67gkg-1). The improvement in soil moisture content of plots amended with poultry manure under the various tillage techniques were 15.8%, 17.4%, 21.8%, 19.4% and 16.7% for zero-tillage (ZT), ploughing (P), ploughing plus harrowing (PH), manual heaping (MH) and manual ridging (MR) respectively. Manually ridged plots had the least moisture content at both cropping season.

Table 1. **Effect of tillage and poultry manure on soil physical properties**

Treatment	Moisture Content g kg-1		Temperature 0c		Bulk Density g cm-3		Porosity %	
	2007	2008	2007	2008	2007	2008	2007	2008
ZT - M	90.61b	78.49c	30.55c	30.49d	1.50a	1.66a	43.24d	37.07e
ZT + M	106.83a	94.06a	29.60d	30.03d	1.44b	1.60a	44.57c	39.40d
P – M	69.86c	68.06d	31.73b	32.12b	1.42b	1.55b	46.58b	41.44c
P + M	83.86b	80.83b	30.33c	31.53c	1.36c	1.51bc	48.51a	42.86b
PH – M	85.06b	75.85c	31.13b	31.51c	1.48a	1.67a	44.30c	38.11e
PH + M	101.83a	88.18a	30.41c	31.13c	1.43b	1.58b	46.92b	41.28c
MR – M	61.50d	55.88e	32.13a	32.88b	1.39c	1.55b	47.39a	41.66c
MR + M	72.67c	84.54b	31.40b	32.13b	1.36c	1.50c	48.76a	43.32b
MH – M	67.49c	57.81e	32.33a	33.04a	1.41c	1.53c	46.42b	43.17b
MH + M	65.00cd	67.42d	31.53b	30.80cd	1.36c	1.48d	48.68a	44.38a

Means with the same letter in the same column are not significantly different at 5% level using DMRT:

ZT-M = zero tillage no manure; ZT + M = zero tillage plus manure; P –M = ploughing no manure; P + M =ploughing + manure; PH-M =ploughing plus harrowing no manure; PH + M= ploughing plus harrowing + manure; MR-M= manual ridging no manure; MR+M = manual ridging + manure; MH-M = manual heaping no manure; MH +M= manual heaping + manure

The soil bulk densities of plots under the various tillage techniques at second cropping (2008) were relatively higher than the values obtained at the first cropping (2007).Bulk density increased by 11.56%, 13.24%, 15.19%, 8.85% and 7.56% over the first cropping (2007) for ZT, P, PH, MH and MR plots respectively. Zero-tillage plots had the highest mean value of soil bulk density (1.57gcm-3) and the least mean value of soil bulk density (1.43gcm-3) was obtained in manually heaped plots amended with poultry manure. Application of poultry manure to the soil tillage techniques in the study reduced soil bulk densities of the corresponding tillage technique plots without poultry manure application. The reduction in soil bulk density of the various tillage techniques plots amended with poultry manure was more in the second cropping (2008) than the first cropping (2007).

At both cropping seasons, zero-tillage plots had the least soil total porosity while the highest soil total porosity was obtained in manually ridged plots amended with poultry manure. Higher soil total porosity was obtained at the first cropping (2007) compared to the second cropping (2008). Plots amended with poultry manure had relatively higher soil total porosity than plots without poultry manure application. Manually ridged and heaped plots amended with poultry manure consistently had higher soil total porosity than other tillage techniques in the study.

Tables 2 and 3 show the effect of tillage and poultry manure on soil chemical characteristics for 2007 and 2008 cropping respectively. At both cropping, the effect of tillage and poultry manure on soil chemical characteristics were significant (P.0.05). At the end of the first cropping (Table 2), zero-tillage plots amended with poultry manure had the highest organic matter and soil pH. Manually ridged plots without poultry manure application had the least soil pH, soil organic matter, total-N and available P. Ploughed plots amended with poultry manure had the highest total-N, exchangeable Ca, Mg, K and CFC, Exchangeable cations (Ca, Mg, Na and K) were better enhanced in tillage techniques plots amended with poultry manure application. Tilled plots (i.e ploughed, ploughed plus harrowed, manually ridged and manually heaped) amended with poultry had higher concentration of exchangeable cations (Ca, MG, Na and K0 than zero-tillage plots. At the end of the second cropping (Table 3), zero-tillage plots amended with poultry manure had the highest soil organic matter, total-N and percent base saturation and the lowest exchange acidity. Manually ridged plots without poultry manure application had the lowest soil organic matter content, total-N and available P. Soil pH, organic matter, total-N, available P reduced at the end of the second cropping in all the tillage-poultry manure treatment combinations. However, the rate of the decline was more pronounced in tillage techniques plots without poultry manure application.

Effects of tillage and poultry manure on leaf nutrients concentration are presented in Table 4. Data in the table showed significant ($P>0.05$) effects of tillage and poultry manure on the leaf nutrients concentration at both cropping seasons. Yam grown under different tillage techniques amended with poultry manure contained higher concentration of leaf nutrients than their corresponding tillage techniques without poultry manure application. Yam leaf nutrients concentration under various tillage techniques amended with poultry manure in the second cropping (2008) were higher than those of the first cropping (2007). However, the yam leaf nutrients concentration under various tillage techniques without poultry manure reduced in the second cropping (2008) when compared with the first cropping (2007). Yam grown on manually heaped plots amended with poultry manure had the highest leaf N, P, K and Mg. The ploughed plots amended with poultry manure had the highest leaf Ca while yam grown on zero-tillage plots had the least leaf nutrients concentration.

Table 5 present data on effect of tillage and poultry manure on vegetative growth parameters of yam. Vegetative growth parameters of yam in the study were significantly ($P>0.05$) influenced by tillage – poultry manure treatments. Tillage techniques plots amended with poultry manure had better growth parameters than their corresponding tillage techniques without poultry manure at both cropping seasons. Zero tillage plots with and without poultry manure application produced the poorest vegetative growth parameters among the tillage techniques in the study. Vegetative growth parameters were better

enhanced in manually tilled (MH and MR) plots amended with poultry manure than other tillage-poultry manure combinations in the study.

Table 2: **Effect of Tillage and Poultry Manure on Some Soil Chemical Properties (2007)**

Treatment	pH	Org.M	TOT.N	AV.P	Ca	Mg	Na	K	Ex.Ac	CEC	Base sat.	Mn	Fe	Cu	Zn
	H2O	%	%	mg kg-1	c mol kg-1						%	mg kg-1			
ZT - M	6.30a	3.21b	0.44b	20.73f	0.76d	1.05bc	0.44c	0.16c	0.40a	2.81c	85.77c	0.05b	6.95ab	2.55d	10.20a
ZT + M	6.55a	3.80a	0.48a	36.89d	0.92c	1.51a	0.55b	0.20b	0.40a	3.58b	88.83b	0.04b	6.45b	2.10e	6.80c
P – M	6.16b	3.13b	0.48a	27.39e	1.08b	1.39b	0.53b	0.18b	0.40a	3.58b	88.83b	0.06a	6.60b	4.78a	9.45ab
P + M	6.64a	3.22b	0.51a	53.19c	1.10a	1.57a	0.56b	0.33a	0.30a	3.86a	982.22a	0.04b	6.60b	3.15b	9.25b
PH – M	6.26ab	2.98c	0.40c	61.11b	0.72d	0.84d	0.58b	0.15c	0.36a	2.62c	86.26c	0.06a	7.15a	3.50b	11.30a
PH + M	6.43a	3.37b	0.48a	77.79a	0.89c	1.56a	0.60a	0.18b	0.33a	3.56b	90.73a	0.04b	5.65c	2.80c	8.90c
MR – M	5.89c	2.91c	0.43b	11.45g	0.75d	0.97c	0.45c	0.16c	0.40a	2.33d	85.84c	0.05b	7.25a	3.05b	8.75c
MR + M	6.26ab	3.05bc	0.42bc	21.70f	1.03b	1.58a	0.69a	0.18b	0.37a	3.85a	90.40a	0.04b	6.54b	2.95bc	7.20d
MH – M	6.07b	2.97c	0.44b	11.45g	0.77d	0.93c	0.55b	0.14c	0.40a	2.97c	85.66c	0.07a	7.75a	3.30b	8.75bc
MH + M	6.46a	3.05c	0.49a	43.75d	0.85c	1.29b	0.60a	0.20b	0.30a	3.24b	89.51b	0.05b	7.15a	3.00b	7.23d

Means with the same letter in the same column are not significantly different at 5% level using DMRT

Table 3: **Effect of Tillage and Poultry Manure on Some Soil Chemical Properties (2008)**

Treatment	PH	Org.M	TOT.N	AV.P	Ca	Mg	Na	K	Ex.Ac	CEC	Base sat.	Mn	Fe	Cu	Zn
	H2O	%	%	mg kg-1	c mol kg-1						%	mg kg-1			
ZT - M	5.56d	3.03b	0.42b	33.33b	0.62c	1.73b	0.66b	0.16c	0.40e	3.57c	88.80a	5.15b	5.67c	4.20a	9.87a
ZT + M	6.08b	3.76a	0.50a	34.35b	0.89b	1.81a	0.70a	0.17bc	0.30f	3.70b	91.89a	4.20c	5.40c	3.20b	9.10b
P - M	6.14a	2.68c	0.38bc	24.86c	0.87b	1.22e	0.58c	0.11c	0.80b	3.58c	77.65b	5.35b	6.10b	3.37b	7.77c
P + M	6.15a	2.90b	0.40b	49.87a	0.98b	1.89a	0.64c	0.17bc	0.50d	3.83b	80.95b	4.18c	5.50c	2.50c	8.66c
PH - M	5.70c	2.67c	0.37c	11.52e	0.80b	1.17e	0.66b	0.13c	1.30a	4.23a	68.46c	4.70c	7.80a	3.60b	9.57a
PH + M	5.92c	2.85b	0.41b	12.18e	1.16a	1.32d	0.70a	0.43a	0.80b	4.09a	80.44b	3.35d	5.80c	2.79c	9.10b
MR - M	5.83c	1.64d	0.37c	8.74f	0.82b	1.74b	0.57c	0.12c	0.70b	3.41c	79.47b	5.80a	7.40a	2.97c	8.07c
MR + M	6.10a	2.76c	0.50a	21.00c	0.84b	1.89a	0.60b	0.24b	0.50d	4.07b	87.71a	3.10d	7.37a	2.57c	9.17b
MH - M	5.76c	2.90b	0.42b	9.80f	0.93b	1.50c	0.59bc	0.12c	0.60c	3.74b	83.96b	4.50c	6.37b	3.23b	8.00c
MH + M	5.82c	3.00b	0.42b	19.32d	1.05a	1.91a	0.68ab	0.16c	0.43e	4.23a	89.83a	5.00b	5.63c	2.20d	7.35d

Means with the same letter in the same column are not significantly different at 5% level using DMRT

Table 4: **Effect of Tillage and Poultry Manure on Leaf Nutrients Concentration of Yam (Dioscorea rotundata)**

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		Na (%)	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
ZT - M	3.63c	3.20c	0.23b	0.20c	0.45c	0.37d	0.12b	0.09d	0.17a	0.16c	0.11a	0.10b
ZT + M	4.85b	5.10a	0.23b	0.25b	0.55b	0.56b	0.11b	0.13b	0.16b	0.19b	0.13a	0.12b
P – M	4.91b	3.60b	0.22b	0.22c	0.43c	0.40d	0.13d	0.12c	0.15b	0.17c	0.10a	1.10b
P + M	5.20a	5.40a	0.24b	0.26b	0.55a	0.61a	0.17a	0.20a	0.16ab	0.18b	0.12a	0.12b
PH – M	3.73c	3.40b	0.22b	0.18c	0.47b	0.46c	0.14b	0.13b	0.12c	0.15c	0.10a	0.10b
PH + M	5.53a	5.56a	0.23b	0.25b	0.49b	0.51b	0.14b	0.15b	0.15b	0.21a	0.12a	0.13a
MR – M	3.90c	3.53b	0.23b	0.21c	0.49b	0.43d	0.12b	0.11c	0.14b	0.14c	0.11a	0.08b
MR + M	5.17a	5.37a	0.23b	0.25b	0.56a	0.62a	0.12b	0.14b	0.18a	0.19b	0.12a	0.13a
MH – M	3.20d	3.13c	0.24b	0.19c	0.50ab	0.43b	0.12b	0.12c	0.15b	0.12d	0.12a	0.10b
MH + M	5.67a	5.87a	0.27a	0.30a	0.52ab	0.64a	0.16a	0.17a	0.17a	0.21a	0.13a	0.13a

Means with the same letter in the same column are not significantly different at 5% level using DMRT

Tables 5**: Effect of Tillage and Poultry Manure on Vegetative Growth Parameters of Yam (Dioscorea rotundata)**

Treatments	Vine Length (cm)		Vine Girth (cm)		Leaves/Plant		Branches/Plant		Leaf Area	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
ZT - M	190.78e	188.67d	1.37c	1.38b	195.11f	193.24f	23.11e	22.97e	33.78b	28.92d
ZT + M	203.44e	208.78c	1.40c	1.42b	236.55e	269.44e	27.89d	24.00d	31.30c	33.00c
P – M	232.00c	220.89b	1.45c	1.42b	406.45c	360.22d	34.11b	32.68b	32.71c	33.00c
P + M	234.22c	251.11a	1.50b	1.43b	408.56c	411.24c	36.02a	38.67a	34.14b	33.97c
PH – M	217.45d	202.11c	1.46c	1.44b	338.00e	280.33e	28.40cd	28.67d	31.33c	30.03d
PH + M	219.11d	218.22b	1.50b	1.44b	384.44d	403.56c	31.23c	30.02c	31.97c	29.91d
MR – M	235.78c	217.62b	1.52b	1.48b	469.11b	430.45bc	34.43b	31.68bc	38.74a	37.30b
MR + M	255.89b	232.56a	1.5b	1.56a	487.44b	455.78b	36.67a	36.01a	41.44a	37.95b
MH – M	234.71c	215.11b	1.63a	1.52a	526.67a	521.22a	34.89b	34.00b	38.67a	35.01c
MH + M	278.44a	230.78a	1.54b	1.58a	536.10a	539.11a	36.04a	35.61a	42.04a	41.10a

Means with the same letter in the same column are not significantly different at 5% level using DMRT

Data in Table 6 shows effect of tillage-poultry manure combination on yam yield components at both cropping seasons. Tillage techniques plots amended with poultry manure produced better yam yield parameters than their corresponding tillage techniques without poultry manure application at both cropping seasons. Zero-tillage plots either with or without poultry manure application produced the least yam tuber yield when compared with other tillage-poultry manure combinations in the study. Also, manually heaped plots amended with poultry manure produced the highest tuber yield and this was closely followed by manually ridged plots amended with poultry manure.

Table 6: Effect of Tillage and Poultry Manure on Yield Parameters of Yam (Dioscorea rotundata)

Treatments	Tuber Length (cm)		Tuber Girth (cm)		Tuber Weight (kg/stand)		Tuber Yield (t ha-1)	
	2007	2008	2007	2008	2007	2008	2007	2008
ZT – M	16.33e	13.66f	32.67a	28.27b	1.69f	1.48f	16.91f	14.82f
ZT + M	18.67d	16.50e	30.33b	29.93a	1.92e	1.82e	19.24e	18.24e
P – M	21.10c	20.83c	26.01c	24.80c	2.33c	2.19c	23.31c	21.92c
P + M	23.37b	22.12b	29.33b	28.82b	2.31c	2.21c	23.10c	22.12c
PH – M	19.00d	17.18b	26.67c	28.63b	2.10d	1.83e	21.04d	18.34e
PH + M	20.67c	19.83c	29.33b	28.82b	2.33c	1.99d	23.31c	19.93d
MR – M	23.67b	18.76cd	30.67b	30.17a	2.49b	2.29c	24.93b	22.91c
MR + M	26.67a	23.56b	33.00a	31.45a	3.17a	2.98a	31.72a	29.84a
MH – M	23.53b	22.14b	28.67c	30.40a	2.81b	2.61b	28.14b	26.14b
MH + M	25.00a	26.50a	34.72a	30.80a	3.08a	3.10a	30.82a	31.11a

Means with the same letter in the same column are not significantly different at 5% level using DMRT

Discussion

At both cropping, zero-tillage plots consistently had the highest soil moisture content, while the least soil moisture content was obtained in manually heaped and ridged plots. The higher values of moisture content obtained in zero-tillage plots compared to other tillage techniques in the study could be attributed to the fact that crop residues left on the soil provided a mulching effect which enhanced moisture conservation. Also, it might partly be due to the increase in soil organic matter content of the zero-tillage plots. The lower soil moisture content of manually heaped and ridged soils could be attributed to the greater evaporating surface and increased movement of atmospheric air produced by heaped and ridged soils. Ridging and heaping exposed soil to drying. The Lower soil moisture of manually tilled plots could also be due to reduction in soil aggregate size and increase in pore size of the tilled plots, this is in accordance with the views of Ohiri and Ezumah (1990). A decrease in soil moisture content of the various tillage systems during the second cropping might partly be due to the decrease in soil organic matter contents of the soils under the various tillage methods in the study. Addition of poultry manure improved the soil moisture content in all the tillage techniques plots, this improvement in soil moisture content might be due to the colloidal and hydrophobic nature of the poultry manure, this view is in accordance with the finding of Mbah and Mbagwu (2006). Similarly, enhancement of soil water retention capacity due to animal manure, according to Khaleel *et al* (1981)could probably be due to structural improvement i.e increase in total porosity and the fraction of porosity involved in soil water storage.

At both cropping, soil bulk density was found to be highest in zero-tillage plots and lowest in manually heaped plots. This finding is in agreement with the findings of Osunbitan *et al* (2005), Ojeniyi *et al* (2006); Aluko and Lasisi (2009). The high bulk density of zero-tillage plots has implications for root growth and yam tuber induction. High soil density could cause mechanical impedance to root and tuber growth and this would adversely affect nutrient and water uptake. Addition of poultry manure to the tillage techniques reduced the soil bulk density, this reduction in soil bulk density could make appreciable difference in the

root growth and proliferation of yam. Soil total porosity was relatively higher in tilled plots (MH, MR, P and PH) compared to untilled plots (ZT), this is a consequence of soil loosening and the associated formation of additional macrospores. Improved soil total porosity of the tilled plots has implication for root growth, proliferation, water infiltration, aeration and nutrient uptake which could reflect in the performance of crops. Macropores play a major role in water movement and also serve as channels for root growth and solute movement (Ankenny *et al* 1990). Improvement in soil total porosity due to poultry manure might be as a result of the improved soil particle aggregation brought about by the improved soil organic matter content of the manured plots. Addition of poultry manure to the soil tillage techniques in the study reduced the soil bulk density and also increased soil total porosity and water holding capacity of the soils. These findings confirmed the earlier reports of Lombin (1991), Mbah *et al* (2004) that application of organic manures improve and ameliorate several soil physical properties such as bulk density, total porosity, penetration resistance and cohesion force.

Zero-tillage plots had the highest soil organic matter content, available P, exchangeable Ca and soil pH and therefore could be said to be the most fertile soil but this failed to translate to yield probably because of the poor soil physical conditions which might have hindered root growth and nutrient uptake especially nitrogen and phosphorus that are essential for high crop yield. The high soil N, P and Ca status of zero tillage plots can be related to the presence of high organic matter of zero-tillage plots. The relatively high concentration of nutrients in manually heaped and ridged plots might be due to the fact that heaps and ridges are built by concentrating nutrient rich surface soil. In support of this, Salako (2008) reported that soil chemical properties were generally significantly higher on the manually tilled plots than mechanically tilled plots except for cations which were generally similar between the two treatments. Additions of poultry manure to the soil tillage techniques in the study brought about improvement in most of the soil chemical properties. Soil pH, organic matter, total nitrogen, available phosphorous, exchangeable cations and percent base saturation were improved. Improvement in nutrients status of plots under the various soil preparation techniques in combination with poultry manure in the study implies that poultry manure could be used for soil fertility management for sustainable production of yam. In support of this, Ano and Agwu (2006) had found that animal manure increased soil pH and macronutrients of soil in southern Nigeria. The reduction in exchange acidity in plots amended with poultry manure suggests the ability of poultry manure in lowering soil Al3+ and Fe2+ concentration in the soil. The higher pH of plots amended with poultry manure when compared with plots without poultry manure application might partially be due to the calcium supplied to the soil by poultry manure. Recent studies had shown that poultry manure increased soil organic matter, nitrogen, pH, phosphorus, CEC (Adeniyan and Ojeniyi, 2003. Ayeni *et al*, 2008). Nutrients concentration in yam leaf tissue were better enhanced in tilled plots than untilled plots (ZT). The high soil density of zero-tillage plots might have caused mechanical impedance to root growth and this would have adversely affected nutrients uptake, hence yam grown on zero-tillage plots had relatively lower leaf nutrients concentration. Higher concentration of nutrients in yam leaf tissue of the tilled (MH, MR, P, pH) plots might be due to the improved microporosity and aeration due to tillage which might have enhanced better root growth and uptake of nutrients. In support of this, Oyeniyi *et al* (2009) attributed lower nutrient content and performance of yam on untilled soil to high bulk density which adversely affected tuber growth and nutrient uptake. Addition of poultry manure to the soil tillage techniques plots improved leaf nutrient concentration significantly, cumulative effect of poultry manure was observed in the leaf nutrients concentration during the second cropping of the plots, this is in agreement with Adenawoola and Adejoro (2005) observation that cumulative agronomic values of some organic manure could be more than five times greater in the post application period than the value realized during the year of application.

Growth parameters were better enhanced in manually tilled plots than zero-tillage and ploughed plus harrowed plots probably because of the reduction in soil compaction in manually tilled plots which might have allowed root penetration and improvement of the rhizosphere. It could also be attributed to the higher total porosity, lower bulk density and moisture content of the manually tilled plots while poor growth of yam in zero tillage plots could be attributed to the relatively high bulk density of the zero-tillage plots. The high bulk density of the zero-tillage plots is expected to reduce root growth resulting in reduced

nutrient uptake. Better growth performance of yam on tillage techniques plots amended with poultry manure when compared with corresponding tillage techniques plot without poultry manure application could be attributed to the ability of poultry manure in supplying nutrients and organic matter to the soil and in improving the soil physical conditions.

Yam tuber yield obtained from manually heaped and ridged plots were better than the yield obtained from zero-tillage and ploughed plus harrowed plots, this might be due to the fact that manually tilled plots had lower bulk density and higher total porosity which might have improved root penetration and tuber induction in the soil. Higher bulk density of zero-tillage and ploughed plus harrowed plots might have adversely affected tuber initiation and tuber growth. Varsal *et al* (1998) indicated that tillage reduced bulk density by loosening the soil particles thus increasing root penetration and yield of crop, hence, plots with lower soil bulk density had the highest tuber yield in this study. Better yam tuber yield obtained in poultry manure amended plots when compared with tillage techniques plots without poultry manure application might be due to the improved soil physical properties and soil nutrients status, however, yam tuber yield in the study could not entirely be related to differences in soil chemical properties, most of the chemical properties did not show consistency in distribution among the tillage techniques in the study. For instance, zero-tillage plots gave higher soil organic matter, nitrogen, available phosphorous status and with lower yam tuber yield when compared with manually tilled plots with lower nutrients status and higher yam tuber yield.

Conclusion

Soil physical and post harvest soil chemical properties, yam nutrients uptake, vegetative growth and tuber yield were influenced by tillage poultry manure treatments. Addition of poultry manure to the tillage techniques plots improved soil physical properties and soil nutrients status, hence, the use of poultry manure in combination with tillage would slow down the rate of degradation in soil quality due to tillage treatments.

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Ameliorating Aluminium toxicity in soybean production with combinations of fertilizer materials on an alfisol in southwestern Nigeria

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Abstract

Aluminium (AI) toxicity is a major limitation to leguminous crop production in acidic soils and fertilizer treatment could ameliorate the condition. In this investigation, direct and residual effects of different fertilizer materials on the growth and yield of soybean grown with or without Al treatment were evaluated on an Alfisol. The investigation involved a greenhouse (5 kg soil/pot) experiment conducted at the Agronomy Department, University of Ibadan, Nigeria, with two factors: fertilizer types - control, organic fertilizer (OF), inorganic fertilizer (IF) and OF + IF mixture at ratio 1:1 and Al treatment (0, 50, 100 and 150µM AlCl3). Sunshine organic fertilizer and single superphosphate (SSP) were used as OF and IF respectively. Treatment combinations were replicated three times in a completely randomized design, giving a total of 48 experimental units. Data on growth parameters (plant height, number of leaves and stem girth) as well as yield parameters (biomass and pod weights) were analysed using ANOVA (p=0.05) while treatment means were separated by Duncan's Multiple Range Test. High Al rate (150µM) reduced the growth and yield of soybean while moderate Al application rates (50 and 100µM) enhanced the performance of crop. Combination of OF +IF enhanced crop growth and yield even when 100µM Al was applied. However, it was only sole application of organic fertilizer that promoted crop performance at 150µM Al concentration. Organic fertilizer had the highest residual effects among the treatments confirming that organic based fertilizers could be used to minimize the deleterious influence of aluminium toxicity on the production of soybean in acid soils.

Keywords: soybean, fertilizer treatments, aluminium treatments, alfisols.

Introduction

Aluminium (Al) is the most abundant metal in the earth's crust and occurs in a number of different forms in the soil. Its toxicity is a primary factor limiting plant growth on acid soils (Kochian, 1995). Toxic effects of the element on plant growth have been attributed to several physiological pathways, but the precise mechanism has not yet been understood. Proposed mechanisms include Al interactions with the root cell wall, aluminum disruption of plasma membrane and membrane transport processes, and AI inhibition of mineral uptake and metabolism, especially that of Ca and P (Rout *et al*., 2001; Akinrinde, 2006). Besides salinity, Al toxicity is among the widespread problems of ion toxicity stress in plants. Deficiency of P, Ca and Ma coupled with presence of phytoxicity substances (soluble Al and Mn) are responsible for the fertility limitation of acid soils as aggravated by industrial pollution and nitrification. Poor growth in acid soils could be related directly to Al saturation (Akinrinde *et al*., 2004). In acid soils, Al toxicity limits plants' growth due to series of chemical factors interactions including toxicities of H, Al and Mn. Estimates of soil limitation to plant growth in developing countries show that an average of 23% of the soil used is constrained to Al toxicity (Oluwatoyinbo *et al*., 2005). The restriction of plant growth by excess soluble Al in acid soils may arise from either the direct inhibition of nutrient uptake or disturbance of root cell functions (Kochian, 1995). Aluminium exists in soils in many mineral forms, including hydrous oxide, aluminium silicates, sulphates and phosphates although accumulation and distribution of many mineral elements are often strongly affected by aluminium. A common symptom of aluminium toxicity is P deficiency symptom (Haynes, 1984; Huang *et al*., 1992). Acid soils result from leaching of basic cations (in areas of high rainfall), having behind the more resistant Al3+ which predominates. Inadequate farming practice as further acidified agricultural soils in developing countries. Continuous use of ammonia fertilizer under intensive agriculture further acidifies the soil (Hoekenge *et al*., 2003),. Soil acidity is normally

corrected by calcitic and dolomitic lime. Liming has a beneficial effect on plant growth under Al stress and alleviating Al toxicity of plants (Bessho and Bell, 1992). However, in many developing countries where subsistence agriculture prevails, the lack or high cost of lime effectively prevents its use. Liming may also have some negative effects on plant growth and soil properties (Ahmad and Tan, 1986). Deficiencies, for example, of some nutrients such as P, Sn, B, and Mn can be induced by liming. Data obtained from liming experiment in cool humid Zaire (Rutunga and Neel, 1980) in Africa (Wey *et al*., 1987) and in the world (Adams, 1984; IBSRAM, 1989) showed that addition of lime alone is insufficient to rehabilitate poor or depleted soils.However, a number of workers have shown that the addition of green manures and animal wastes to acid soils can reduce aluminium toxicity and increase crop yields (Berek*et al*., 1995., Hue, 1992). Additions of organic residues increase nutrient uptake and crop growth on P deficient soils (Hue, 1990; Hue *et al*., 1994).

The application of organic residue to acid soils to minimize the need for lime and fertilizer P would be beneficial to resource poor semi-subsistence farmers (Hayness and Mokolobate, 2001). The most important legume grown all over the world is soybean (Glycine max), a member of the family Fabacea, subfamily Papilonidae (Kochobor, 1986). It has high protein and oil content both of which are adapted to the nourishment of man and livestock. Thus, world production of the crop has been stimulated by a strong demand for edible oils and protein feed supplement. It is also a source of vitamin B. Leguminous crops have soil enriching ability as they fix atmospheric nitrogen (N), serving as mulching materials thus protecting soil against direct impact of rain, conserving soil moisture and reducing soil temperature. Poor growth of soybean in acid soils has been attributed to various factors including low pH, low levels of Ca, Mg, P, K, micronutrients like B, Zn (Fageria, 1994), low population of beneficial micro-organisms like rhizobia, vesicular arbuscular (VAM) fungi and inhibition of root growth.

This study investigated the short- and long-term (residual) effects of organic, inorganic and mixture of organic and inorganic fertilizers at ratio 1:1) on the growth, yield of soybean (with or without Al toxicity inducement) on an Alfisol.

Materials and methods

An experiment was carried out in the green house at the Department of Agronomy, University of Ibadan (7o 24′ N, 3o 54′E at 234 m), Nigeria from February to June, 2012. The experimental soil was an Alfisol. A sample of the soil was taken to the laboratory for pre-cropping physicochemical properties. The soybean variety used was the early maturing type TGX 1987- 62F and the treatments were: Sunshine organic fertilizer, Single super phosphate; Mixture of sunshine organic fertilizer and single super phosphate at ratio (1:1). The experimental treatment also involved the application of four level of Al (0, 50, 100 and 150µM) using AlCl3.6H20. Sixteen treatments combination were arranged in a Completely Randomized Design (CRD) with three replicates. It was a factorial experimental with two factors; Aluminium at four level, (0, 50, 100, and 150µM) and four fertilizer treatments (control, organic, inorganic and mixture of organic and inorganic at ratio 1:1). The total treatment combinations were 16 as given above: Control; Al0 and OF; Al0 and IF; Al0 and OF+IF; Al50; Al50 and OF; Al50and IF; Al50 and OF +IF; Al100; Al100and OF; Al100and IF; Al100 and OF+IF; Al150; Al150 and OF; Al150 and IF; Al150 and OF +IF. The fertilizer were applied at the rate of 100 kg P2O5 ha before planting while Aluminium was done along with irrigation. Soybean variety TGX 1987- 62, obtained from International Institute of Tropical Agriculture, Ibadan (IITA) was used as test crop. There were 16 experimental pots (polybags) per replicate, giving a total of 48 polythene bags. The soils were air dried, sieved with 2-mm sieve and filled into 5 kg polythene bags. The polythene bags were labelled according to their respective treatment combinations. They were randomly arranged on metal table within the green house complex and they were watered to 60% field capacity.The seeds were pre-germinated for three days in moistened filter papers placed in germination boxes in the laboratory to enhance uniform germination. About 95% of seeds germinated. Three pre-germinated seeds were later transplanted into each polythene bag in the green house. Thinning was carried out after 9 days of transplanting, thus making if two vigorous seedling per bag. The first hand weeding operation was carried out at four weeks after transplanting and other subsequent operations done as necessitated by weed

occurrence. Cypermethrin was applied fortnightly at the rate of 2 ml per litre of water to control insect pest attack from two weeks after transplanting and continued until podding. The experiment was carried out twice. Aluminium and fertilizer treatments were used only in the first experiment. The second experiment was used to evaluate the residual effects of the treatments on soybean. Both experiments were terminated after eight weeks. The parameter measured during morphological growth includes plant height, number of leaves, stem girth, leave area and number of branches per plant. At final harvest, the soils were moistened for easy removal of roots and the plants were partitioned into shoots and roots. All the pods and their grains produced per pot were counted and weighed to obtain the respective yields per treatment pot.The plant parts were dried in a forced air tight oven at 650C until constant weight was obtained. They were weighed on an electric top loading balance and their respective weights recorded.

Data were subjected to analysis of variance (ANOVA) using statistical analytical system with significant means separated using Duncan multiple range tests (DMRT) at 5% probability level.

Results and discussion

Pre-cropping soil fertility status

The physical and chemical properties of the soil used are given in Table 1. The particle size distribution of the soil indicated that the slightly acidic (pH 6.0) and the organic matter content (17.21 g kg-1) was below the critical level of 26 g kg-1 (Adeoye and Agboola, 1985). Exchangeable Ca (2.21cmol kg-1) was below the critical level proposed by Agboola and Corey (1973) while Mg (1.37 cmol kg-1) was high compared with 0.26 cmol kg-1 proposed as critical value. The Aluminium content of the soil was 0.003 mg kg-1, while total N (0.73g kg-1) content and Available P (8 mg kg-1) were marginal in the soil.

Physical and chemical properties of soil used for the experiment

Parameters	Values
pH (H2O)	6.0
Org C (g/kg)	9.98
Org. M (g/kg)	17.21
Total N (g/kg)	0.73
Available P (mg/kg)	8.0
Exchangeable base (c molkg-1)	
K	0.4
Ca	2.21
Mg	1.37
Na	1.51
Exchangeable acidity	0.2
Extractable micronutrients (mgkg-1)	
Mn	134
Fe	76.4
Zn	2.24
Cu	1.8
Al	0.003
Particle size distribution (g/kg)	
Sand	789
Silt	91
Clay	120

Textural class	Sandy loam

First cropping

The immediate or short term effects of fertilizer application (Fig. 1) revealed that soybean performed better under inorganic fertilizer application on height of soybean. There was a general increase from 4 to 7 weeks after planting with the highest height obtained from plant treated with inorganic fertilizer and this could be adduced to the fast release of nutrients, by inorganic fertilizer. This is in consonance with the study of Mokuwunye and Vlek (1986) which revealed that the judicious use of N and P fertilizer can bring out substantial yield increase in West Africa.

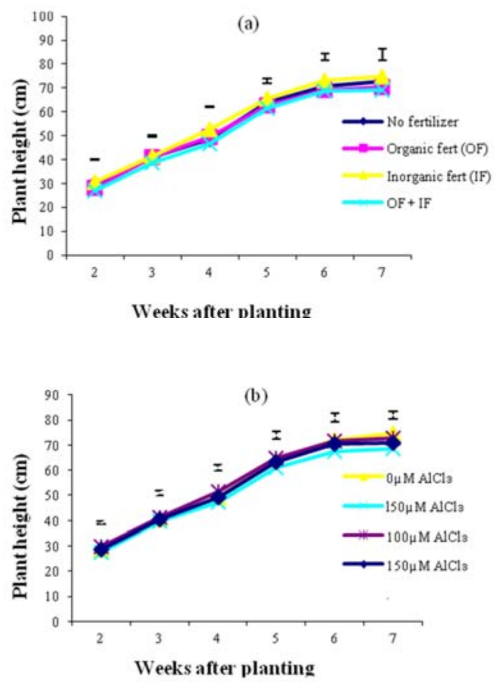


Figure 1: **Effect of (a) fertilizer and (b) aluminum on height (cm) of soybean at sucessive weeks after planting (error bars on graph represent standard error)**

Alumininium did not have (Fig. 1) significant difference among the various treatments when compared with treated and untreated plants on soybean height. However, the highest height was obtained from control. This suggests that Al had no significant effects on height of soybean.

The result (Fig. 2) of the effect of fertilizer applications on number of leaves of soybean shows that there was no significant difference in term of number of leaves for soybean irrespective of fertilizer treatments except at 7WAP. However, the results showed that soybean performed better with application of organic fertilizer at 6 and 7 WAP when compared with other fertilizer types and control.

The effects of Al treatments on number of leaves of soybean (Fig. 2) show that there was no significant difference among the various treatments when comparing treated and untreated plant except at 6 and 7 WAP. The highest number of leaves obtained when Al was applied at 50µM.

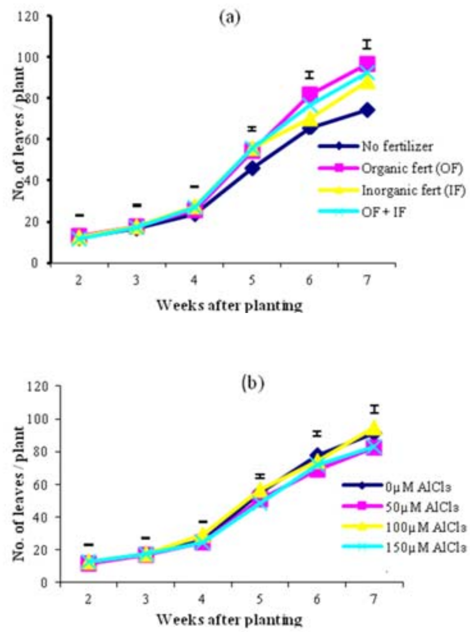


Figure 2 : **Effects of (a) fertilizer and (b) aluminium treatments on number of leaves/plant of soybean at successive weeks after planting (error bars on graph represent standard error)**

Data summarizing the effects of interaction between fertilizer and Al application on soybean number of leaves (Table 3). During the first cropping indicates there were significant differences at 4 to 6 WAP among treatment means of soybean. At 4WAP, the highest number of leaves (33) was obtained when 100µM AlCl3 was applied with inorganic fertilizer. However, this trend was maintained throughout the duration of the experiments. The result could be attributed to fast release of nutrients by inorganic fertilizer coupled with the growth enhancement ability of Al at low concentration .In addition, it was observed that Al application reduced the performance of crop when applied at the highest rate (150µM) with the highest number of leaves (79) obtained from organic fertilizer. This confirms that Al limits plant growth at high concentration Kochain (1995). This observation shows that organic fertilizer application had a beneficial effect on Al detoxification as it had been established by many researchers (Ahmad and Tan, 1986; Hue and Amien, 1989).

The influence of fertilizer treatments (Fig. 3) on shoot dry weight of soybean indicate that inorganic fertilizer had the greatest dry matter yield when compared with organic and OF + IF. However, inorganic fertilizer proved to be most effective fertilizer type for soybean production.

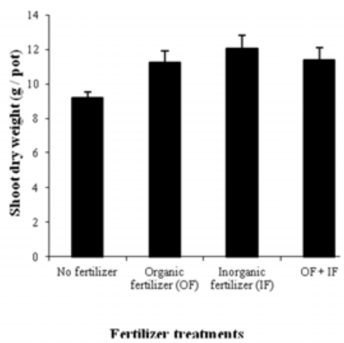
Table 3. **Effects of each fertiliser types (at different levels of aluminium application) on number of leaves/plant of soybean**

Treatment combination		No of leaves/plant at successive weeks after planting			
AlCl3 Application (μM) levels	Fertilizer types	3	4	5	6
0	Control	17	24ab	47bcd	69abc
	Organic (OF)	18	26ab	59abc	83a
	Inorganic (IF)	18	27ab	58abc	80ab
	OF+IF	16	27ab	57abcd	79ab
50	Control	16	24ab	47bcd	63abc
	Organic (OF)	17	21b	52bcd	82a
	Inorganic (IF)	16	21b	45cd	56c
	OF+IF	19	31ab	60ab	75abc
100	Control	17	25ab	43d	60bc
	Organic (OF)	17	30ab	56abcd	82a
	Inorganic (IF)	18	33a	70a	79ab
	OF+IF	17	28ab	59abc	78ab
150	Control	17	22b	47bcd	70abc
	Organic (OF)	18	26ab	50bcd	79ab
	Inorganic (IF)	18	28ab	49bcd	66abc
		16	22b	47bcd	73abc
		ns			

OF+
IF

Means with the same letters in the same column are not significantly different from each other, p=0.05 (DMRT)

The results of the sole application (Fig 3) on soybean indicate that application of Al at 100µM AlCl3 enhances the shoot yield when compared with control, 50 and 150µM AlCl3, though there were no significant difference between control, 50 and 150µM AlCl3. This confirms that Al limits plant growth at high concentration, it is also in line with the submission of Kochain (1995) which reported that Al toxicity is a primary factor limiting plant growth on acid soil.



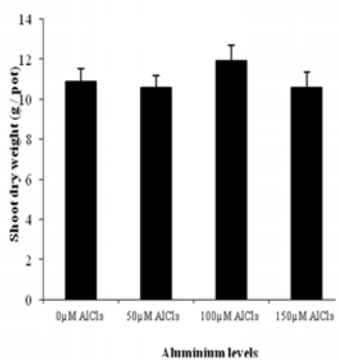
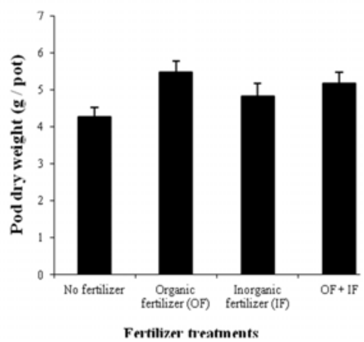


Figure 3**: Effects of (a) fertilizer and (b) aluminium treatments on soybean shoot dry weight (bars on chart represents standard error)**

Application of fertilizer significantly affected the soybean pod dry weight (Fig. 4).The control plants had the least pod dry wield (4.2 g pot-1) while organic fertilizer 5.5 (g pot-1) proved to be most effective followed by OF + IF (5.0 g pot-1). This could be adduced to the fact that organic fertilizer improves moisture availability and nutrient supply.

Sole application of Al on soybean at (Fig. 4) different rates in different from each other. Plant treated with 100µM AlCl3 gave the highest value. The least pod yield was obtained from plants treated with 150µM

AlCl3. The confirms that Al limits plant growth of high concentration, it is also in line with the Kochian (1995) who reported that Al toxicity is a primary factor limiting plant growth on acid soils.



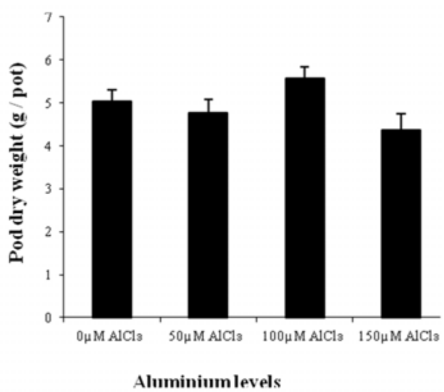


Figure 4**: Effects of (a) fertilizer and (b) aluminium treatments on pod dry weight (bars on chart represents standard error)**

The effects of interaction between fertilizer and Al treatments on soybean (Table 4.5) were not significant. Application of 100μM Al along with OF + IF gave the highest shoot production (13.53g /pot). Also, application of 50μM and 100μM AlCl3 enhanced the performance of crop, while high aluminium concentration reduced the crop performance which organic fertilizer sustained shoot yield. This is in support of the submission of some researchers which states that the addition of green manures and animal wastes to acid soils can reduce aluminium toxicity and increase crop yield (Berek et.al; Hue, 1992, Hue, 1990, and (Hue et. al, 1991).

There was significant interaction between AI and fertilizer treatments (Table 5) on soybean pod dry yield. The highest soybean pod dry yield (6.08 g pot-1) was obtained with 100μM Al with OF + IF which could be adduced to the fact that combined benefits of organic manure such as nutrients supply, soil structure improvement and inorganic fertilizer (high and fast nutrient release) that enhanced yield production. Also, at high Al concentration, there was reduction in the performance of soybean and organic fertilizer proved to be most effective, which could be adduced to the fact that organic addition also supply N to the legume

crops which could be limiting factor for the grain legumes if biological activity is low. Carsky (2003) observed that organic additions substantially increased soybean pod yield.

Table 4. **Effects of fertilizer type (at different levels of aluminium application) on soybean dry shoot weight**

Treatments combination		
AlCl3 Application (μM) level	Fertilizer type	Soybean dry shoot
		(g pot-1)
0	Control	10.20ab
	Organic (OF)	10.58ab
	Inorganic (IF)	12.09ab
	OF+IF	10.57ab
50	Control	8.50ab
	Organic (OF)	9.72ab
	Inorganic (IF)	12.12ab
	OF+IF	11.79ab
100	Control	8.86b
	Organic (OF)	12.27ab
	Inorganic (IF)	13.00ab
	OF+IF	13.53a
150	Control	9.20ab
	Organic (OF)	12.34ab
	Inorganic (IF)	10.00ab
	OF+IF	9.69ab

Means with the same letters in the same column are not significantly different from each other, p=0.05 (DMRT)

Table 5. **Effects of each fertilizer type (at different levels of aluminium application) on soybean dry pod weight**

Treatment combinations		Dry pod weight
AlCl3 application µM level	Fertilizer type	
		(g pot-1)
0	Control	3.86bc
	Organic (OF)	5.67ab
	Inorganic (IF)	4.92abc
	OF+IF	5.67ab
50	Control	3.46c
	Organic (OF)	5.57ab
	Inorganic (IF)	5.00abc
	OF+IF	5.00abc
100	Control	5.00abc
	Organic (OF)	5.67ab
	Inorganic (IF)	5.49ab
	OF+IF	6.08a
150	Control	3.83bc
	Organic (OF)	5.00abc
	Inorganic (IF)	4.69abc
	OF+IF	3.91bc

Means with the same letters in the same column are not significantly different from each other, p=0.05 (DMRT)

Second cropping

The residual effect of the interaction between fertilizer and Al treatments on number of leaves (Table 6) indicate there was a general increase from 3 to 6 WAP with the highest number of leaves of soybean (40.7) obtained from treated with organic fertilizer at high Aluminium concentration and this could be adduced from the benefits of organic manure such as nutrient supply and soil structure improvement that enhanced vegetable production (Olaniyan et.al, 2006)

Table 6. **Residual effects of each fertilizer type (at different levels of aluminium application) on number of leaves/plant of soybean**

Treatment combination		weeks after plating			
AlCl3 Application (μM) level	Fertilizer type	3	4	5	6
0	Control	21.00ab	26.00	28.00ab	32.67
	Organic	22.33a	26.33	31.33a	38.33
	Inorganic	23.00a	25.00	26.67ab	32.67
	0F + IF	23.00a	25.33	30.00ab	34.00
50	Control	21.00ab	25.67	26.67ab	29.67
	Organic	22.00ab	27.00	28.33ab	32.00
	Inorganic	23.00a	25.67	27.67ab	36.33
	0F + IF	23.00a	25.33	29.67ab	38.67
100	Control	20.00b	23.67	26.00b	33.00
	Organic	22.00ab	24.33	27.67ab	30.67
	Inorganic	21.00ab	26.33	30.00ab	42.67
	0F + IF	23.00a	27.00	28.67ab	34.00
150	Control	20.00b	25.33	29.67ab	32.33
	Organic	20.00b	26.00	26.67ab	40.67
	Inorganic	22.33a	24.33	26.67ab	29.67
	OF + IF	22.33a	27.00	28.33ab	37.33

Means with the same letter(s) in the same columns are not significantly different from each other, p = 0.05 (DMRT)

Table 7**. Residual effects of each fertilizer type (at different levels of aluminium application) on soybean shoot dry weight**

Treatment combination		Soybean dry shoot weight
AlCl3 application (μM) level	Fertilizer types	
0	Control	(g pot-1)
	Organic	7.74b
	Inorganic	8.05ab
	OF + IF	5.72b
		7.08b
50	Control	5.00b
	Organic	7.19b
	Inorganic	7.03b
	OF + IF	7.40b
100	Control	5.88b
	Organic	6.92b

	Inorganic	6.09b
	OF + IF	7.43b
150	Control	5.25b
	Organic	10.62a
	Inorganic	6.92b
	OF + IF	7.62b

Means with the same letter(s) in the same columns are not significantly different from each other p = 0.05 (DMRT)

There was significant interaction between Al and fertilizer treatment on soybean (Table7) dry shoot weight. The highest soybean weight (10.62 g pot-1) was obtained with the high Al application 150µM along with organic fertilizer while the least shoot dry weight (5.00 g pot-1) was obtained with 50µMAl without fertilizer. These results show that organic fertilizer enhanced the yield of soybean in soil with high Al concentration beyond 100µM.

Conclusions

It is evident from this work that Al toxicity (induced with 150µM) reduced the growth and yield of soybean while low and moderate Al application rates (50 and 100µM) enhanced the performance of crop. Combination of OF + IF enhanced crop growth and yield even when 100µM Al was applied. However, it was only the sole application of organic fertilizer that was able to increase the growth and yield parameters of soybean at 150µM Al concentration. Also, organic fertilizer proved to have the highest residual effects among the various fertilizer treatments confirming that organic based fertilizers could be used to minimize the deleterious influence of Al toxicity on the production of soybean in acid soils.

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Maize growth response and phosphorus availability following Busumbu phosphate rock application in a Desmodium-maize rotation system

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Abstract

It has been demonstrated that in soils deficient in plant available phosphorus (P), legumes supplied with phosphate rocks (PR), increase P availability and uptake by the succeeding crop. The aim of this study was therefore to assess the extent to which Desmodium spp fertilized with Busumbu phosphate rock (BPR) can increase soil available P, nutrient uptake and biomass yield of maize (Zea Mays) planted after Desmodium spp in a greenhouse experiment conducted in two phases. In the same pots, sole maize and two Desmodium spp: (D. intortum-(Mill.) Urb. cv Greenleaf and D. uncinatum-(Jacq). DC., cv Silverleaf) with and without BPR were grown separately in the first phase of the experiment followed by sole maize with no P application in the second phase of the experiment. Pots were arranged in a completely randomized design replicated four times. Reference treatments with soluble P (KH2PO4) were included. In the first phase of the experiment, application of BPR to D. uncinatum significantly (p=0.05) increased dry matter yield (DMY) by 1.55 g container-1 above DMY of D. uncinatum with no P application. The DMY of D. intortum with or without BPR application were similar. In the second phase of the experiment, the average maize DMY following Desmodium (3.71 g container-1) was more than twice as large compared to maize following a first maize crop (1.12 g container-1). Desmodium intortum previously fertilized with BPR gave the highest and significant (p<0.05) above ground maize DMY (6.05 g container-1) and P concentration (16.15 mg P kg-1). Application of BPR did not increase soil available P in both sole maize and Desmodium systems during the first and the second phase. This study demonstrated that Desmodium spp receiving BPR enhances yield of the following maize crop compared to sole maize system.

Key words: Desmodium, phosphorus, dry matter yield, Busumbu phosphate rock.

Introduction

Although phosphorus (P) deficiency is widespread in east Africa, it is most severe in the intensively cultivated highlands of western Kenya (Jama and van Straaten, 2006). Inorganic P fertilizers are often not within economic reach of smallholder farmers, and therefore, alternative strategies are needed to improve P nutrition of crops (Pypers *et al*., 2007). Use of rock phosphate as a source of P fertilizer is worthwhile in tropical acidic soils because many rock phosphate deposits exist in the region with conducive environmental conditions that favor their use (Abd-Elmonem and Amberger, 2000). However, due to their low solubility and slow P release, they are rarely used as a direct P input (Pypers *et al*., 2007; Stamford *et al*., 2005). Use of BPR from eastern Uganda, particularly in western Kenya is limited and alternatively Minjingu phosphate rock (MPR) has vastly been promoted in this region (Kifuko *et al*., 2007; Ndungu et.al., 2006). Although BPR neutral ammonium solubility (NAS) of 2.3% is of lesser reactivity than MPR, its close proximity to western Kenya (< than 20 km away) compared with MPR (>820 km away) makes it attractive in this region (van Straaten, 2002) and. there is need to exploit ways that can enhance its solubility.

It has been reported that microbial acidification of phosphate rocks, in leguminous cropping systems could be used to enhance P solubility from PRs (Ndung'u-Magiroi *et al*., 2011; Salimpour *et al*., 2010). The main mechanisms resulting in enhanced PR utilization are acidification of the rhizosphere through exudation of organic acids (Pypers *et al*., 2007; Vanlauwe *et al*., 2000). It is speculated that in this way, legumes are able to convert PR into a more available P source without altering soil pH to levels that may negatively affect plant growth (Pypers *et al*., 2007). A cereal crop following the legume can then benefit directly from the enhanced P availability in the soil and acquire P released from the decomposing legume residues (Pypers *et al*., 2007; Horst *et al*., 2001).

Desmodium spp have become increasingly popular in western Kenya mainly due to its Striga and stemborer suppressing capacity, in the context of the "push- pull" system (Kifuko- Koech *et al*., 2012, Khan *et al*., 2008). Despite the widely reported role of Desmodium in this region, , it remains unclear to what extent a Desmodium crop supplied with PR would directly improve P availability and plant growth when grown in rotation with maize. The need to understand this concern prompted the research presented in this paper. The objective of this study was therefore to assess maize growth response and phosphorus availability following Busumbu phosphate rock application in a Desmodium- Maize Rotation System.

Materials and methods

Soil collection and characterization

Greenhouse experiments were conducted in Soil Science Department of University of Eldoret, Eldoret, Kenya. Bulk soil was obtained from a site in Matayos, Busia County (0° 26.1' N, 34° 52.2' E, 1182 m above sea level) at a plough depth of 0-20 cm. A soil sample was taken from the bulk soil for the initial soil characterization analysis according to procedures outlined by Okalebo *et al*., (2002). The remaining bulk soil was air dried and passed through a 5 mm sieve to remove clods and debris. The sieved soil was weighed (4.5 kg) into each pot. To eliminate deficiency of other macro and micronutrients, all pots received a blanket application of nutrients in solution containing CaCl2.2H2O, MgCl2.6H2O, MgSO4.7H2O, ZnSO4.7H2O, CuSO4.5H20, MnSO4.4H2O and H3BO3 salts. The optimal nutrients doses were calculated based on an average of maximum and minimum tissue concentration of the respective nutrients in maize crop and biomass production of 30 g in 4.5kg soil-1.

Experimental design

The experiment was conducted in two phases. In the first phase, the experimental treatments were fifteen in total (Table 1). The first six treatments (T1-T6) included; first crop (sole maize, D. uncinatum, D. intortum) and BPR application (with and without). This was followed by sole maize with no P applied in the second phase of the experiment. The remaining nine treatments (T7-T15) in the first phase were reference Desmodium-maize systems with two factors: first crop (sole maize, D uncinatum, D. intortum) and P application (without P, with BPR and SP) followed by SP applied as KH2PO4 to sole maize in the second phase of the experiment.

Basal P application was based on the optimal P obtained in the P response experiment which was observed to be 120 mg P kg-1 soil applied as KH2PO4. In the first six treatments (T1-T6) additional P was applied as BPR (500 mg P kg-1 soil) while in the reference treatments with soluble P, additional P was applied at 250 mg P kg-1 as KH2PO4 during the first phase of the experiment. In the second phase of the experiment, soluble P was applied to reference treatments only at a rate of 250 mgP kg-1 soil as KH2PO4. The pots of the various treatments and their four replication were arranged in a completely randomized design with daily rotations to reduce local bench effects. After germination Desmodium and maize (H513) seedlings were thinned to 12 and 1 maize seedling per pot. Before and immediately after germination, pots were watered at 70% water holding capacity followed by 80% and finally 90% at maturity using N free water. The pots were manually maintained weed free and pest free by application of appropriate insecticides.

Table 1: Treatment structure for comparing a Desmodium-maize rotation system and a sole maize cropping system as affected by BPR application

		crop 1	Supplied with	crop 2	Supplied with
T1	Maize(0P)/maize(0P)	maize	-	maize	-
T2	Maize (BPR)/maize (0P)	maize	BPR	maize	-
T3	D. uncinatum (0P)/maize (0P)	D. uncinatum	-	maize	-
T4	D. uncinatum (BPR)/maize (0P)	D. uncinatum	BPR	maize	-
T5	D. intortum (0P)/maize (0P)	D. intortum	-	maize	-
T6	D. intortum (BPR)/maize (0P)	D. intortum	BPR	maize	-
T7	Maize(0P)/maize(SP)	maize	-	maize	SP
T8	Maize (BPR)/maize (SP)	maize	BPR	maize	SP
T9	Maize (SP)/maize (SP)	maize	SP	maize	SP
T10	D. uncinatum (0P)/maize (SP)	D. uncinatum	-	maize	SP
T11	D. uncinatum (BPR)/maize (SP)	D. uncinatum	BPR	maize	SP
T12	D. uncinatum (SP)/maize (SP)	D. uncinatum	SP	maize	SP
T13	D. intortum (0P)/maize (SP)	D. intortum	-	maize	SP
T14	D. intortum (BPR)/maize (SP)	D. intortum	BPR	maize	SP
T15	D. intortum (SP)/maize (SP)	D. intortum	SP	maize	SP

SP- Soluble Phosphorus, BPR- Busumbu phosphate rock

Soil and plant tissue sampling and laboratory analysis

Desmodium biomass and maize shoots were harvested at 10 and 7 WAP and soil sampled for analysis of the soil available P (Olsen method). Biomass was put in labeled paper bag and fresh weight recorded. The samples were oven at 65 oC and ground for analysis of total P (Okalebo *et al*., 2002). At the end of the second experiment, maize plants were harvested at 7 WAP and soil and plant tissue taken.

Statistical analysis

A one-way analysis of variance (ANOVA) was conducted to evaluate differences between all the treatments and a two-way ANOVA for interactions between Desmodium spp and BPR rates using mixed procedure (SAS Institute Inc., 2003). Treatment differences were evaluated by computing least square means and the standard errors of difference (SED), referred to as SED1 and SED2 for the one-way and two-way ANOVA, respectively.

Results

Site characterization

The initial characterization of the study site showed that the soil in Busia was slightly acidic (pH 5.0) had low available Olsen P (1.94 mg P kg-1), organic carbon (1.44%) and total nitrogen (0.16%). The textural class was sandy clay loam and was classified as Orthic Ferralsol (WRB, 2006).

Above ground maize DMY and P concentration in maize and Desmodium as affected by BPR in Desmodium-maize rotation experiment (First phase)

The DMY and P concentration of maize and Desmodium BPR in the first phase of the experiment are shown in Fig 1. Application of BPR to D. uncinatum significantly (p=0.05) increased DMY by 1.55 g container-1 above DMY of D. uncinatum with no P. The DMY of D. intortum with or without BPR were similar. The DMY of D. intortum was significantly higher than D. uncinatum with or without BPR. Application of BPR to D. intortum and D. uncinatum achieved 59 and 38% respectively of the maximum yield observed when

the two Desmodium spp were fertilized with soluble P. Application of BPR to sole maize significantly (p=0.04) increased maize DMY by 2.5 g above DMY of sole maize with no P.

Phosphorus concentration in D. intortum was significantly (p<0.05) higher by 3.46 g P container-1 than in D. uncinatum with or without BPR. There was significant interaction (p<0.05) effect between Desmodium spp and BPR on P concentration but only D. uncinatum grown with BPR significantly (p<0.05) increased P concentration above D. uncinatum with no P in the first phase of the experiment.

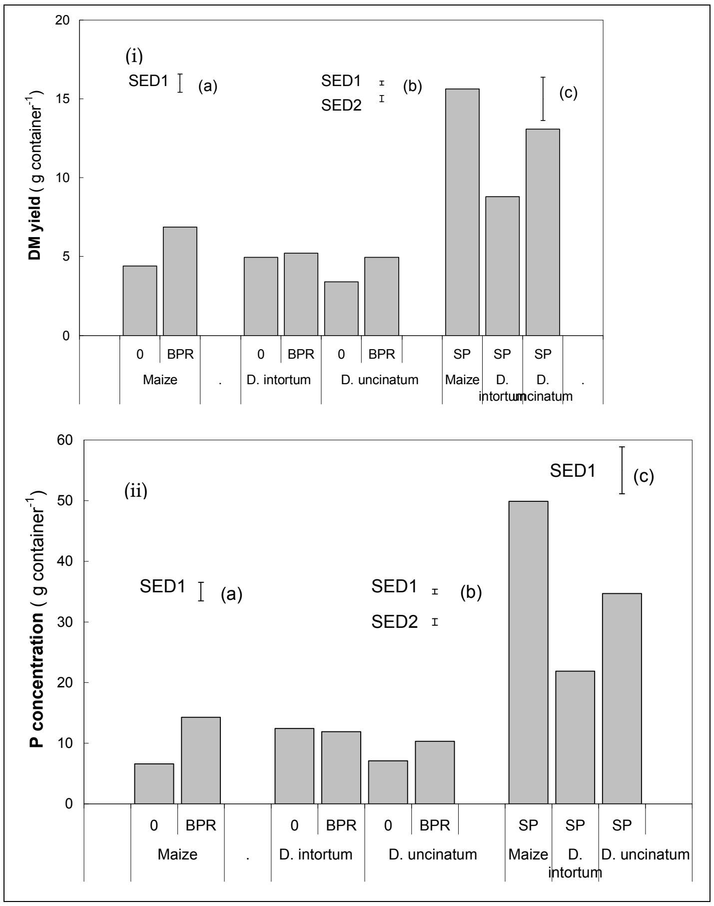

Figure 1: **Biomass yields (i) and P concentration (ii) of maize and two Desmodium spp as affected by BPR applications in the first phase of the experiment. 2**

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2 SED1 and SED2 -standard errors of difference for comparison of treatments (one-way ANOVA) and for the interaction effect between Desmodium species and BPR (two-way ANOVA), respectively (a) represent SED for comparisons of sole maize system (b) represent SED for comparisons of Desmodium system (c) represent SED for comparisons of all the 9 treatments

Soil available P following application of BPR to maize and Desmodium in Desmodium maize rotation experiment (first phase)

During the first phase of the experiment, application of BPR had no significant effect on soil available P in sole maize system (Table 2). Significantly ($p<0.05$) higher amount of available P was obtained when the two Desmodium spp did not receive BPR compared to when BPR was added. D. intortum with no BPR applied significantly increased available P by 26.59 mg P container-1 above D. intortum with BPR applied. Increase in available P in the soil did not result to corresponding increase in plant P concentration.

Table 2. Available P (mgP kg-1 soil) from maize and two Desmodium spp as affected by BPR applications (first phase)

Crop	P source	Available P (mgP kg-1)
Maize	control (no BPR)	20.30
	BPR	20.61
Mean		20.45
SED1 (a)		1.386
D. intortum	control (no BPR)	45.20
	BPR	18.62
D. uncinatum	control (no BPR)	38.98
	BPR	30.46
Mean		33.32
SED1 (b)		6.716
SED 2 (b)		6.716
Maize	SP	65.74
D. intortum	SP	75.38
D. uncinatum	SP	70.98
Mean		70.7
SED1 (c)		5.982

Note: SED1 and SED2 -standard errors of difference for comparison of treatments (one-way ANOVA) and for the interaction effect between Desmodium species and BPR (two-way ANOVA), respectively (a) represent SED for comparisons of sole maize system (b) represent SED for comparisons of Desmodium system (c) represent SED for comparisons of all the 9 treatments

Maize DMY as affected by previous cropping system (maize or Desmodium) and BPR application in Desmodium-maize rotation experiment (second phase).

Figure 2 shows maize dry matter yield as affected by previous cropping system and BPR application. The average maize DMY following Desmodium (3.71 g container-1) was more than twice as large compared to maize following a first maize crop (1.12 g container-1). This significant positive effect of previous Desmodium growth on the second phase maize DMY occurred with or without BPR application. Significant ($p<0.05$) interaction effect was observed but only D. intortum previously fertilized with BPR improved maize vigor and significantly ($p<0.05$) increased maize DMY in the second phase of the experiment by 3.12 g pot -1 above D. intortum previously not receiving BPR. D. intortum previously with BPR achieved 49 and 46% of the maximum yield observed in the reference treatment previously without and with BPR additions but followed by application of soluble P in the second phase of the experiment respectively. In the second phase of the experiment however, maize DMY from D. uncinatum previously with or without BPR addition and followed by no P application were similar.

Phosphorus concentration in maize following Desmodium was more than three times as large compared to maize following first maize with or without BPR application (Fig 2). The previous cropping system and BPR application in isolation had no significant effect on P concentration but a significant increase in P concentration occurred in the combined treatment. Desmodium intortum previously fertilized with BPR and followed by no P application significantly increased maize P concentration in the second phase of the experiment (i) unfertilized D. intortum.

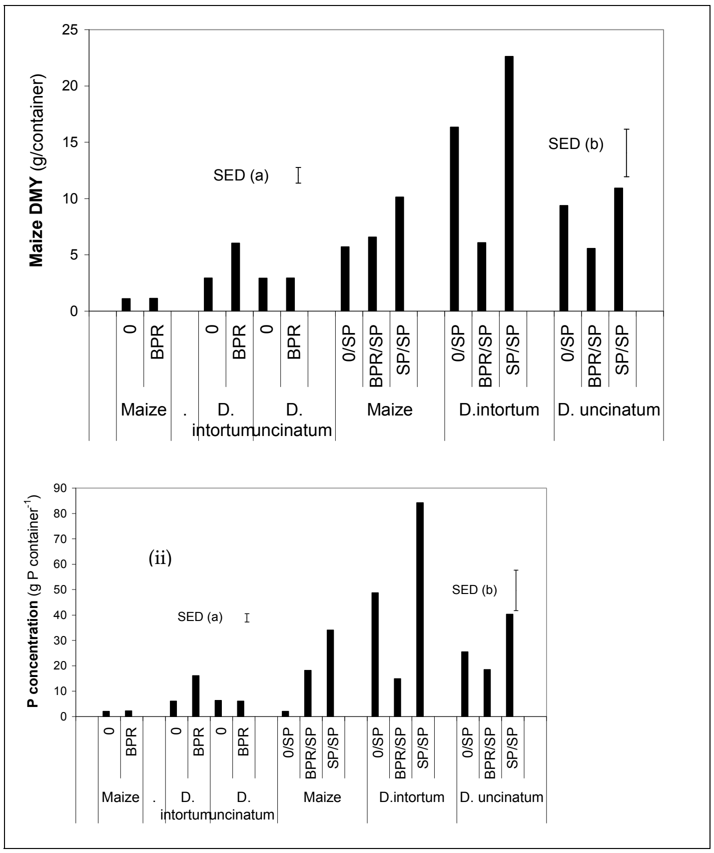

Figure 2: **Maize DMY (i) and maize P concentration (ii) as affected by the previous cropping system (maize, D. intortum and D. uncinatum) and BPR application. [3]**

Soil available P as affected by previous cropping system (Desmodium or maize) and BPR application (Second phase)

3 Additional treatments (see Table 1) include reference treatments with previous crop (maize, D. intortum and D. uncinatum) with no P, BPR, or soluble P applied followed by second crop (maize) with soluble P applied. (a) represent SED for comparisons of the first six treatments while (b) represent SED for comparisons of all the 15 treatments.

The effect of previous cropping system and BPR application on soil available P is shown in Table 3. Generally, after the harvest of the second crop, the soil available P was lower compared to the harvest of the first crop irrespective of the previous Desmodium spp and BPR application. Available P in soils with maize following Desmodium system and sole maize following sole maize system were similar. This contradicted the larger dry matter yield and P concentration in maize following Desmodium crop and therefore this increase was not explained by soil available P. In fact negative correlation coefficient between available P and P concentration (r= -0.55), available P and yield (r= -0.57) were observed in the second phase of the experiment in maize following Desmodium with or without BPR application.

Table 3: **Available P as affected by the previous cropping system (maize, D. intortum and D. uncinatum) and BPR application**

Crop	P source 1st crop	P source 2nd crop	Available P (mgP kg-1)
Maize	control (no BPR)	no P	16.21
	BPR	no P	18.84
D. intortum	control (no BPR)	no P	22.32
	BPR	no P	19.20
D. uncinatum	control (no BPR)	no P	27.03
	BPR	no P	20.15
Mean			20.62
SED1 (a)			5.373
Maize	control (no BPR)	Soluble P	52.90
	BPR	Soluble P	58.16
	Soluble P	Soluble P	87.06
D.intortum	control (no BPR)	Soluble P	39.15
	BPR	Soluble P	41.86
	Soluble P	Soluble P	72.57
D. uncinatum	control (no BPR)	Soluble P	45.39
	BPR	Soluble P	43.07
	Soluble P	Soluble P	74.87
Mean			53.56
SED1(b)			8.78

Note: SED1- Standard error of difference for comparison of treatments (one way ANOVA) .(a) represent SED for comparisons of the first six treatments while (b) represent SED for comparison of all the 15 treatments. Additional treatments (see Table 6.1) include reference treatments with previous crop (maize, D. intortum and D. uncinatum) with no P, BPR, or soluble P applied followed by second crop (maize) with soluble P applied

Discussion

During the first phase, application of BPR did not increase available P in both sole maize and Desmodium cropping systems. However, higher amount of available P was obtained when the two Desmodium spp did not receive BPR compared to when BPR was added and this was more pronounced in soils where D. intortum had earlier been grown. This was possibly an indication that although the two species were able to access sparingly soluble soil P sources, D. intortum was more efficient. This observation could be attributed to differences in morphological characteristics of the two Desmodium spp, whereby D. intortum has an extensive and deep rooting system compared to D. uncinatum (Imrie *et al*., 1983). Legume crops with extensive deep rooting system increase phosphorus (P) pools in the cropping system because of their ability to access sparingly soluble P sources (Hinsinger, 2001).

In the second phase of Desmodium-maize rotation experiment, improved maize vigor maize yield and P concentration in treatments where previously Desmodium had been grown irrespective of BPR application compared to sole maize demonstrates that growing legume in a rotation enhances the growth and plant P uptake in the subsequent crop. The increase in maize DMY was however not explained by increase in soil available P and indeed there was a negative and significant correlation coefficient between maize DMY with available P in soils with maize following Desmodium crop. It is possible that most of the P that was made available was used by the growing maize crop which resulted to reduced levels of soil available P. Pypers *et al*., (2007) reported similar results while working with velvet bean, and concluded that, in addition to P there was possibly another limiting factor which was offset by the growth of legume.

Comparisons of the two Desmodium spp showed that in pots where previously D. intortum had received BPR, yield and P concentration were superior compared to pots where previously BPR had been added to D. uncinatum, suggesting that D. intortum was a more potent solubilizer of BPR. D. intortum is a higher yielder and has higher biological nitrogen fixing potential compared to D. uncinatum. Kifuko- Koech *et al*., (2013) demonstrated enhanced N mineralization in maize intercropping system with D. intortum compared to D. uncinatum with high amounts of $NH4^{+}$ in the former in western Kenya. $NH4^{+}$ ions are associated with increased P availability within the rhizosphere as they tend to lower the rhizosphere pH of the roots; hence P is brought to solution (Abd-Alla, 1994). Abd-Alla (1994) assessed the ability of Rhizobium and Bradyrhizobium strains to solubilize phosphate from hydroxyapatite in a medium containing NH4Cl or KNO3 and concluded that the presence of NH4 + in the medium resulted in higher solubilization of phosphate compared to the presence of NO3-. Several authors have however shown that legumes are able to increase the dissolution and utilization of PR P and reduce P sorption because of their acidifying effect on the rhizosphere (Pypers *et al*., 2007, Melenaghen *et al*., 2004; Horst *et al*., 2001; Vanlauwe *et al*., 2000).

Conclusion

In the second phase of the Desmodium-maize rotation experiment, improved maize yield and maize P concentration in soils where Desmodium had previously been grown relative to continuous maize cropping demonstrates that growing Desmodium in a rotation enhances the growth and plant P uptake in the subsequent crop. The increase in maize DMY was however not explained by increase in soil available P an indication that there was another factor that also contributed to this increase. Comparison of the two Desmodium spp showed that D. intortum was efficient in accessing sparingly soluble P in the soil and is a more potent solubilizer of BPR compared to D. uncinatum.

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Comparative effects of organic and inorganic phosphorus sources on maize yields at two acidic sites in western Kenya

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Abstract

The objective of this work was to evaluate the effects of FYM and tithonia, when applied alone or in combination with Minjingu phosphate rock (MPR), Busumbu phosphate rock (BPR) or triple superphosphate (TSP), on maize yields and financial benefits in acid soils at Bukura and Kakamega in western Kenya. The response of maize to the nutrient inputs was site specific. At Bukura maize did not respond to inorganic P sources applied in combination urea but responded when the inorganic P sources were applied in combination with FYM or tithonia while at Kakamega maize responded to TSP but not MPR or BPR when applied with urea. Tithonia combined with TSP gave the highest yields and net financial benefits at both sites but this did not translate to economic attractiveness since the benefit cost ratio was lower than 2, which is considered the threshold below which farmers will not adopt a technology. Only FYM when applied alone seemed to meet this criterion at Bukura and therefore the most likely of the tested practices to be adopted at this site while at Kakamega none of the tested technologies was economically attractive.

Key words: farmyard manure, Tithonia, phosphate rocks.

Introduction

Western Kenya is dominated by Ferralsols, Acrisols and Nitisols whose agricultural productivity is commonly limited by low availability of phosphorus with 80% of the soils across farms in this region being severely P-deficient (Jama *et al*., 1998). The situation is exacerbated by the high acidity of these soils with possibility of aluminum phytotoxicity (Jama and van Straaten, 2006). Although these soils can be managed by use of P fertilizers and lime, this has not been widely adopted by the smallholder farmers due to their high costs. Thus, there is growing interest in finding alternative affordable and sustainable technologies to replenish soil fertility with focus shifting to solutions that utilize local resources such as organic materials (OMs) and phosphate rocks (PR). In western Kenya, the most widely used OM is farmyard manure (FYM) whose use is however often constraint by its poor quality and inadequate quantity (Okalebo *et al*., 2006). Other alternative non-traditional sources of nutrients, such as Tithonia diversifolia (tithonia) are therefore being explored. The sole use of OMs source of P is, however, likely to be constrained their low P content and they may need, therefore, to be combined with inorganic P sources in order to meet the crop demand for P. The use of PR as P source has been recognized for a long but early studies with PRs produced results that have been reported as erratic and sometimes conflicting, leading to confusion and disagreement on their utilization of PRs (Khasawneh and Doll, 1978). There has, however, been renewed interest in the use of PRs, especially when combined with OMs as low cost alternatives to conventional inorganic P fertilizers and lime in developing countries. The objective of this study was therefore to determine the effect of FYM and tithonia, when applied alone or in combination with Minjingu phosphate rock (MPR), Busumbu phosphate rock (BPR) or triple superphosphate (TSP), on maize yields and financial benefits in acid soils of western Kenya.

Materials and methods

The study was conducted in April to July 2007 at Bukura and Kakamega, in western Kenya, chosen on the basis of contrasting soil characteristics. The soil at Bukura is a Ferralsol with the following characteristics; pH = 4.8; exchangeable acidity = 0.89 cmol kg−1; organic C = 20.9 g kg−1; cation exchange capacity (CEC) = 3.89 cmol kg−1; Al saturation = 23%; Olsen extractable P = 5.6 mg kg−1. The soil at Kakamega is Cambisol with the following characteristics; pH = 5.1; exchangeable acidity = 0.35 cmol kg−1; total organic C = 27.9 g kg−1; CEC = 4.85 cmol kg−1; Al saturation = 7.2%; Olsen extractable P = 2.5 mg kg−1. A randomized complete block design with three replications was used. The treatments consisted of three inorganic P sources; TSP, MPR and BPR each applied in combination with FYM, tithonia or urea. Other treatments included a control with no P input, and FYM and tithonia, each applied alone. FYM and tithonia were applied to supply 20 kg P ha−1 in treatments where they were used either alone or in combination with the inorganic P sources. The inorganic P sources were applied to provide 40 kg P ha−1 in the OM/inorganic P source combinations, but when they were used in combination with urea, they were applied at 60 kg P ha−1. Tithonia had 3.0% N, 0.3% P and 3.8% K, and FYM had 1.8% N, 0.4% P and 1.2% K. Urea was applied at 100 kg N ha−1 where it was used. Maize was grown using the recommended agronomic practices and harvested at maturity.

Table 1**: Values used for cost benefit analysis (USD)**

Parameter	Value	
Price of TSP kg-1	0.54	0.62
Price of MPR kg-1	0.27	0.35
Price of BPR kg-1	0.23	0.31
Price of urea kg-1	0.46	0.54
Transport of fertilizers to the farm 100 kg-1	1.75	1.75
Labour for applying fertilizer per hectare	1.67	1.67
Price of FYM‡ 100 kg-1	0.80	0.80
Cost of application of FYM ha-1‡	26	26
Cost of cutting and application of 6.7 t ha-1 of tithonia‡	605	605
Price of maize kg-1	0.32	0.32
Price of maize stover 100 kg-1	15	12

‡Values of FYM (farmyard manure) and tithonia are expressed on dry matter basis.

The net financial benefits were computed using partial budgeting. The costs of maize, and nutrient inputs were determined through a market survey of the area (Table 1). Grain yield data were subjected to analysis of variance using the Genstat statistical package and treatments means compared using the standard error of difference between means at $p < 0.05$.

Results

Maize grain yields

The grain yield data are presented in Table 2. There was no significant response by maize to application of the inorganic P sources when applied in combination with urea at Bukura. At Kakamega, maize responded to application of TSP but not MPR or BPR when applied in combination with urea. All the treatments with tithonia applied alone or in combination with PRs or TSP increased yields above the control at both sites.

Table 2 : **Effect of phosphorus sources on maize grain yield at Bukura and Kakamega**

Treatment	Total P (kg-1)	Kakamega	Bukura
		Grain yield t ha-1	
1. Control (no P input addition)	0	2.6	1.9
2. Tithonia (20 kg P ha-1)	20	4.2	4.3
3. FYM (20 kg P ha-1)	20	3.5	3.2
4. MPR (60 kg P ha-1) + urea	60	3.4	2.6
5. BPR (60 kg P ha-1) + urea	60	2.4	2.0
6. TSP (60 kg P ha-1) + urea	60	3.9	2.2
7. Tithonia (20 kg P ha-1) + MPR (40 kg P ha-1)	60	4.7	4.9
8. Tithonia (20 kg P ha-1) + BPR (40 kg P ha-1)	60	4.1	4.4
9. Tithonia (20 kg P ha-1) + TSP (40 kg P ha-1)	60	5.4	5.1
10. FYM (20 kg P ha-1) + MPR (40 kg P ha-1)	60	3.7	3.2
11. FYM (20 kg P ha-1) + BPR (40 kg P ha-1)	60	2.7	2.7
12. FYM (20 kg P ha-1) + TSP (40 kg P ha-1)	60	3.8	2.9
SED		0.50	0.49

FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock; SED = standard error of difference between means

FYM significantly increased grain yields above the control when combined with TSP or MPR but not when combined with BPR at both sites. Maize yields with application of tithonia applied alone or in combination with inorganic P sources, were on average higher at Bukura than Kakamega while yields with inorganic P sources applied with urea or FYM were higher at Kakamega than Bukura. Among the OM/inorganic P source combinations, only tithonia when combined with TSP increased yields significantly above that of the application of the sole tithonia at the Kakamega site. At Bukura, none of the OMs/inorganic P fertilizer combinations gave yields that were significantly higher than the sole application of the OMs despite having an additional 40 kg P ha-1. Averaged across OMs at the P rate of 60 kg ha-1, the grain yield at Kakamega, as affected by the inorganic P sources, followed the order TSP > MPR > BPR. At Bukura the order was MPR > TSP > BPR. Averaged across inorganic P sources, the grain yield as affected by the OMs followed the order tithonia > FYM > urea at both sites.

At Bukura, none of the OMs/inorganic P fertilizer combinations gave yields that were significantly higher than the sole application of the OMs despite having an additional 40 kg P ha-1. Averaged across OMs at the P rate of 60 kg ha-1, the grain yield at Kakamega, as affected by the inorganic P sources, followed the order TSP > MPR > BPR. At Bukura the order was MPR > TSP > BPR. Averaged across inorganic P sources, the grain yield as affected by the OMs followed the order tithonia > FYM > urea at Kakamega, and tithonia > FYM > urea at Bukura.

Economic analysis

The highest added costs were obtained with the tithonia treatments while the least costs were obtained with FYM treatments (Table 3).

Table 3 : **Effect of phosphorus sources and organic materials on added costs (USD ha-1)**					
Treatment	fert. cost*		labor # cost	Total added costs	
	KK	BK	KK & BK	KK	BK
1. Control (no input addition)	-	-	-	-	-
2. Tithonia (20 kg P ha-1)	0	0	605	605	605
3. FYM (20 kg P ha-1)	0	0	26	72	72
4. MPR (60 kg P ha-1)	276	295	3	279	298
5. BPR (60 kg P ha-1)	250	270	3	253	273
6. TSP (60 kg P ha-1)	298	344	2	300	346
7. Tithonia (20 kg P ha-1)+ MPR (40 kg P ha-1)	108	108	607	715	715
8. Tithonia (20 kg P ha-1)+ BPR (40 kg P ha-1)	91	91	607	698	698
9. Tithonia (20 kg P ha-1) + TSP (40 kg P ha-1)	122	141	606	728	747
10. FYM (20 kg P ha-1)+ MPR (40 kg P ha-1)	154	154	28	182	182
11. FYM (20 kg P ha-1)+ BPR (40 kg P ha-1)	137	137	28	165	165
12. FYM (20 kg P ha-1) + TSP (40 kg P ha-1)	168	187	27	195	214

KK = Kakamega; BK = Bukura; FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock. *Added fertilizer costs; # Added labor costs

Tithonia applied with TSP gave the highest net financial benefits while BPR applied with urea had the least at both sites (Table 4). The net benefits for the OM/inorganic P combinations appeared to be site specific and depended on the input combination. For example, at Kakamega, combining tithonia with TSP or MPR resulted in net benefits that were higher than the sole use of TSP, MPR or application of tithonia alone. However, combining tithonia with BPR at this site led to lower net benefits than sole application of tithonia. At Bukura, however, combining tithonia with any of the inorganic P sources resulted in net benefits that were higher than the sole application of the tithonia or inorganic P sources. The benefit cost ratios (BCRs) for all treatments, apart from those with FYM were, however, generally low. The highest BCR at Kakamega (1.1) and Bukura (4.5) were obtained with FYM applied with MPR and FYM alone respectively.

Table 4. **Net financial benefits (USD ha-1) and benefit-cost ratio (BCR)**				
Treatment	Kakamega		Bukura	
	Net benefit	BCR	Net benefit	BCR
1. Control (no input addition)	-	-	-	-
2. Tithonia (20 kg P ha-1)	-2	-0.03	144	0.23
3. FYM (20 kg P ha-1)	35	0.50	323	4.50
4. MPR (60 kg P ha-1) + urea	1	0.03	-51	-0.17
5. BPR (60 kg P ha-1) + urea	-329	-1.3	-248	-0.90
6. TSP (60 kg P ha-1) + urea	146	0.50	-228	-0.65
7. Tithonia 20 kg P ha-1 + MPR (40 kg P ha-1)	58	0.08	327	0.47
8. Tithonia 20 kg P ha-1 + BPR (40 kg P ha-1)	-145	-0.20	172	0.25
9. Tithonia 20 kg P ha-1 + TSP (40 kg P ha-1)	300	0.41	405	0.54
10. FYM 20 kg P ha-1 + MPR (40 kg P ha-1)	194	1.10	223	1.22
11. FYM 20 kg P ha-1 + BPR (40 kg P ha-1)	-130	-0.79	100	0.61
12. FYM 20 kg P ha-1 + TSP (40 kg P ha-1)	139	0.71	138	0.64

FYM= Farmyard manure; TSP= triple superphosphate; MPR= Minjingu phosphate rock; BPR= Busumbu phosphate rock; BCR is the benefit cost ratio

Discussion

Effect of phosphorus sources on maize yields

The good response of maize observed due to the application of tithonia when combined with inorganic P sources, especially TSP, is consistent with results of similar studies in East Africa (Ikerra *et al*., 2006). The failure of maize to respond to the inorganic P sources, when applied in combination with urea at Bukura, suggests that some other factor had a more profound effect on maize yields than P availability at this site. In fact, higher maize yields were obtained with tithonia and FYM when applied at a lower P rate of 20 kg P ha^{-1}. The Al saturation (23%) in the soil, which was above the critical value of 20% that has been reported to cause Al toxicity in maize (Farina and Chanon 1991), points to a possibility of Al toxicity at this site. At Kakamega, where the Al saturation was 7.2%, maize responded to TSP but not MPR and BPR whose solubility is low and thus could have resulted in low P availability. The combination of TSP with OMs, gave higher maize yields than combination of OMs with MPR or BPR because of the higher solubility of TSP. Presumably the OMs were able to remove the Al toxicity and allow maize to respond better to applied inorganic P input where they were used in combination.

Economic analysis

The added costs of using tithonia were very high because of its bulkiness. At the rate of 20 kg P ha-1 used in this study, almost 30 t ha-1 of fresh tithonia biomass were applied. Added costs for use of FYM were relatively lower than tithonia's because of its higher P content and lower moisture content hence the FYM applied was less bulky. The other advantage of FYM, which it shared with tithonia, compared with inorganic P sources, was its ability to provide N in addition to P thus making use of FYM less costly than the inorganic P sources which had to be combined purchased urea to provide N. Although tithonia applied with TSP had the highest added costs, it recorded the highest net benefits at both sites because it effected the highest yield increases above the control. All the BPR treatments at Kakamega had negative net financial benefits because BPR generally tended to depress maize yields at this site. Tithonia applied alone at this site also had negative net benefits because of the very high labour costs which were not offset by the additional maize yield accruing from its use. However at Bukura, tithonia applied alone gave positive benefits because of its ability to effect a large increase (126%) in yield over the control. The decision by farmers to adopt nutrient inputs depends on their profitability but as a general rule, a BCR of at least 2:1 is attractive to farmers (FAO, 2006). The BCRs in the present study were generally low and only FYM when applied alone at 20 kg P ha-1 met this criterion.

Conclusions and recommendations

Use of inorganic P sources in combination with urea was not agronomically effective but maize responded to them when applied with OMs. Averaged across OMs, the grain yield at Kakamega, as affected by the inorganic P sources, followed the order TSP > MPR > BPR. At Bukura the order was MPR > TSP > BPR. Averaged across inorganic P sources, the grain yield as affected by the OMs and urea followed the order tithonia > FYM > urea at both sites. At Kakamega, none of the tested technologies was economically attractive while at Bukura, only FYM when applied alone at 20 kg P ha-1 achieved a benefit cost ratio of 2 and thus the most likely to be adopted among the tested nutrient sources and combinations. Differences in response by maize to the different P inputs at the two sites indicate that P recommendations for maize cannot easily be transposed among diverse soils of western Kenya.

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On-station evaluation of maize genotypes for nutrient and water use efficiencies in the semi arid lands of coastal Kenya

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Abstract

About 75% of the land in coastal Kenya is arid and semi-arid. Crop failure, especially for maize, is very common in the region. Despite this situation, farmers persistently plant maize every season. Rainfall in this region is usually low, erratic and unevenly distributed. Crop yields are extremely low due to inadequate soil moisture and declining soil fertility. This therefore calls for integrated technological interventions to address the problem. In the sub-humid regions of coastal Kenya, 24% of land receives enough rainfall to sustain crop production during the long rains (LR) season. However, during the short rains (SR) season, low amount of rainfall is received, and crop failure is common. In a normal year, two thirds of the total annual rainfall is received during the LR season. Despite the prevailing situation, farmers continue growing maize during the SR season and therefore risk crop failure. Some farmers also plant maize varieties meant for the LR season, hence increasing the risk of crop failure. The study was therefore designed to evaluate the performance of different maize varieties under different water harvesting technologies in order to come up with a recommendation on the suitable maize varieties for planting under the relatively harsh environments. The results indicated that rainwater harvesting was not critical when the season was wetter than normal. Despite the excellent performance of PH4, CCM and Mdzihana, these maize varieties cannot be recommended for the semi-arid areas since the high yields were realized under above normal rainfall. There is a need for further research to identify maize varieties that are appropriate for the areas that normally receive low rainfall.

Key words: Semi-arid areas, crop failure, water harvesting method, maize varieties, low rainfall.

Introduction

Soil fertility management in semi arid areas is mainly constrained by inadequate moisture and lack of resources for the purchase of inputs, particularly the very expensive inorganic fertilizers that are usually imported. This problem is usually compounded by the nutrient removals which in turn exacerbate the problem of soil fertility decline. The nutrient removals arise from continuous cropping without adequate replenishment and soil erosion. Continuous cultivation of land exposes soil organic matter (SOM) to oxidative processes since in most cases there is reduced biomass input (Shepherd *et al*., 1996) and failure by users to judiciously manage soil nutrient reserves. Decomposition of organic matter has an impact on the capacity of the soil to retain nutrients. SOM plays an important role in soil fertility replenishment, but the linkages between degradation and soil carbon sequestration and nutrient retention are complex. Some forms of tillage practices, particularly in arid and semi-arid areas encourage oxidation of organic matter throughout the profile resulting in the release of carbon dioxide to the atmosphere rather than its build up in the soil (Nabhan etal., 1997).This leads to reduced biomass production from crops to pastures and lower carbon inputs to the soil in subsequent periods (because less root matter, leaf litter and less crop residues are returned to the soil). Many of the soils in the semi- arid zones of Eastern and Southern Africa are deficient in some essential nutrients, especially Phosphorus (P) and Nitrogen (N) (Okalebo etal., 1987). Low soil fertility, especially P and N deficiencies, is a major biophysical constraint to successful agriculture in semi–arid areas of East and Southern Africa (Yates, 1992). A better understanding of nutrient imbalances induced by pH?PH and other applied nutrients is therefore important in managing soil fertility.

In Kenya, the semi-arid agricultural areas receive very low bimodal rainfall, with recordings as low as 342 mm per annum (Nadar and Faught, 1994). The probability that the rainfall is less than two thirds of the potential evaporation in the rainy season varies between 60 and 80% equaling to two thirds of the potential evaporation (about 347 mm in a four months' growing season). This is the minimum required by annual crop plants like maize and beans with a growing period of three months. Rainfall amounts that are less than half of the potential evaporation (approximately 275 mm within 4 months) in the growing season will lead to crop failure (Nadar and Faught, 1994). The probability of crop failure in semi-arid regions may therefore be quite high during years of below average rainfall.

Farmers in the East and Southern African region use various water capturing strategies aimed at reducing run-off on the soil surface and increasing infiltration. These include terracing on steep slopes, particularly but not exclusively, in Kenya, contour bunds including dead level contours, storm drains and other water harvesting techniques such as tied ridges and basins constructed in a field of growing crops to encourage water retention and infiltration. Tiffen *et al*. (1993), elaborated on the excellent progress made in Kenya (Machakos) in reducing soil erosion through contour banks and terracing. Terracing of the croplands using hand-dug contour trenches and banks was long adopted by farmers in Kenya and is popularly known as 'fanya juu' terraces (Simpson, etal., 1996). Tiffen *et al*.(1994) further elaborated that any deleterious effects of changes in the nature of the base (due to cultivation and cropping) have been more than offset by improvements due to terracing and other conservation measures and that farmers have learned to manage the resources better .The conservation of soil and water has led to an increased supply of soil moisture and hence increased the potential for the mining of the remaining soil nutrients by crops (Simpson *et al*., 1996). With inherently low soil fertility, most of the soils in the semi- arid areas of East and Southern Africa may produce short term gains in crop yields when appropriate water harvesting techniques are used, but will accentuate the problem of low soil fertility in the long term.

Optimization of soil water use for increased crop production in dry land agriculture is dependent on agronomic practices that result in an increase in the amount of water stored in the soil and efficient utilization of that water. This, therefore, calls for the need for crop genotypes that can utilize the limited water resources to sustain their growth for the benefit of mankind. The crop genotypes should also have the ability to efficiently utilize the lower nutrient amounts available in those soils since farmers in the arid and semi-arid areas are resource-poor and cannot therefore afford inorganic fertilizers. The two major pathways of water loss are evaporation from the soil surface and run off. Losses due to evaporation of water from the soil surface can be as high as 66% of the season's rainfall (Smets etal., 2011). This brings in the idea of carrying out some tillage practices that can conserve water and reduce the rate of evaporation as well as run off.

Coastal Kenya is located between latitudes 10o and 4o south and longitudes 38o and 41o east. It covers an area of about 84,000 km2 and is subdivided into seven administrative districts namely Kilifi, Kwale, Mombasa, Malindi, Tana River, Lamu, and Taita Taveta. The largest part of the region lies in the coastal lowlands (CL), which is subdivided into five agro-ecological zones (AEZs), namely; CL2, CL3, CL4, CL5 and CL6. The high potential areas comprise CL2 and CL4 While CL5 and CL6 form the arid and semi-arid lands (ASALs). The region receives a bimodal rainfall with annual averages raging from 1400 mm in CL2 to less than 400 mm in CL6. Rainfall is distributed over two distinct seasons; the long rains (April to July) and the short rains (October to December). The most common food crops grown in the region are maize, cassava and cowpeas. The average yield of maize is about one tonne of grain per hectare. The region is a food deficit area, producing only 20% of its food requirements. Agricultural production is constrained by low inherent fertility of the soils and their poor water retention. The problems associated with low soil fertility and low water holding capacity have been aggravated by practices that cause net losses of nutrients and soil water. Increasing population pressure has resulted in reduced farm sizes and more intensive farming in the high potential areas (CL3 and CL4) without substantial replenishment of plant nutrients. Farms in these areas cannot be left fallow as was the tradition in the past. This has led to soil nutrient depletion and low crop yields.

In order to address the problem of food deficit in the region, there is need to open up more land for agriculture. The arid and semi arid areas of Coastal lowland Kenya could therefore offer an alternative site to supplement the high potential areas since they form 75% of the coastal region. However, rainfall in the arid and semi-arid areas is usually low and erratic and unevenly distributed. In most cases the total amount of seasonal rainfall can occur in just a few days leading to both soil and water losses. Crop yields are extremely low due to inadequate soil moisture and low soil fertility. Despite this situation, farmers persistently grow maize every season (Mangale *et al*., 2003).This calls for integrated technological interventions so as to make proper use of the low rainfall amounts in these areas for crop growth. The main objectives of this studywere to identify and verify maize genotypes that are efficient in nutrient and water use, verify water harvesting technologies in arid and semi-arid areas and to identify/verify the nutrient and water use efficient maize genotypes with water harvesting technologies to the farmers.

Materials and methods

Study area

The study was conducted on station at Kenya Agricultural Research Institute (KARI) Mariakani, Kilifi County in coastal Kenya for two seasons in 2005. The site is 200 m above sea level. Soils at the centre are sandy loams. They are deep, well drained and have a fairly high water holding capacity. The rainfall pattern at the centre is bi-modal with peaks in May and November during the long and short rains, respectively. The average annual rainfall is 500 mm. The mean monthly maximum and minimum temperatures are 35 and 28oC, respectively.

Experimental procedures

Land was prepared manually to establish the various water conservation structures after bush clearing and removal of stumps. A plot measuring 65 x 50 m was subdivided into 3 blocks of 19 x 48 m separated by a 2 m path. The blocks were further sub-divided into 4 sub-blocks measuring 10.8 m x 19 m separated by a 1 m path between them. Each sub-block was again sub-divided into 6 plots (3 from either side) measuring 3.6 x 9 m separated by a 1 m path. The sub-blocks were randomly assigned the water harvesting methods (shallow tillage, tied ridges, deep tillage and zai pits) and all the plots within the sub-block were prepared according to the particular water harvestingmethod. Six maize varieties (PH1, DHO2, CLS3, PH4, CCM, and a Local check) were planted and tested for nutrient and water use efficiencies. The water harvesting technologies that were tested included tumbukiza or Zai pits (60cm long x 60 m wide x 15 m deep), deep tillage (using the long handle big hoe or oxen plough) and tied ridges. The usual farmer's practice of shallow tillage was used as a control. All the plots received farm yard manure (FYM) at a rate of 5 tonnes per hectare. Since the work was meant to solve the problem of farmers in the marginal areas, a suitable site was identified at KARI-Mariakani sub-centre which has similar climatic conditions. A split plot experimental design (SPD) was used with water harvesting technologies forming the main plots while the maize varieties occupied the sub-plots. These were randomized and replicated 3 times.

Data analysis

The corded data were analyzed using the statistical package SAS What is SAS? Significance was tested at 95% level. In areas where there were significant differences, the means were separated using LSD.

Results and discussion

The first season was characterized by a moderate amount of rainfall that saw the crop perform quite well. However, a few weeks before harvesting, it was severely damaged by rogue elephants that had strayed from the nearby game reserve. This made it difficult to obtain the yield data. The experiment was repeated during the short rains season, which was characterized by very low amounts of rainfall which resulted in the crop drying up after flowering stage. Data collected included plant height and stover yield.

The results showed that water harvesting method had significant ($p< 0.05$) effect on maize plant height and stover yield (Table 1). Zai pits and deep tillage increased the maize plant height by 19-20% as compared to shallow tillage. Maize under deep tillage practice was 1.3 times taller than that under shallow tillage. Tied

ridges on the other hand were not significantly superior to shallow tillage in their effect on maize plant height and stover yield.

Table 1 **: Effect of water harvesting technologies on maize stover yield and plant height- SR 2005**		
Water harvesting technology	Stover yield (t ha-1)	Plant ht (cm)
Deep tillage	0.95a	39.5a
Tied ridges	0.84ab	36.4ab
Zai pits	0.84ab	39.4a
Shallow tillage (using traditional hoe)	0.71b	33.0b
LSD0.05	0.178	3.71
CV (%)	31.8	21.4

Results of the LR 2006 indicated that water harvesting methods had no significant effect on grain yield (Table 2). This was probably due to the excessive amount of rainfall in May and June. The excessive rains caused waterlogging in the zai pits. Some of the pits were also filled with silt. The waterlogging conditions led to a reduction in the growth rate of maize in the zai pits. This explains the low stover yield in the zai pits compared to the stover yield obtained from maize grown under tied ridges.

Table 2 : Effect of water harvesting technologies on maize stover yield and plant height during LR 2006		
Water harvesting technology	Grain yield (t ha-1)	Stover yield (t ha-1)
Deep tillage	3.80	5.5b
Tied ridges	3.95	6.5a
Zai pits	3.67	5.6b
Shallow tillage (using traditional hoe)	3.83	5.8ab
LSD0.05	NS	0.75
CV (%)	22.7	19.0

Table 3 shows that maize variety had a significant ($P<0.05$) effect on maize plant height and stover yield. The dry land hybridmaize variety (DHO2) was 11, 39, 53 and 81% taller than CCM, Mdzihana, PH1, PH4 and CLS3, respectively. The DHO2 maize seemed to grow faster than the rest of the maize varieties, but the high rate of growth was not reflected in the variety's stover yield. The coastal hybrids (PH1 and PH4) were 20-27% shorter than CCM, but were at the same time not significantly different from the local variety (Mdzihana) in their heights. Again, the varieties Mdzihana, PH1, CCM and DHO2 did not differ in their stover yields. Maize variety, PH4, was 29 and 39% taller than PH1 and CLS3, respectively.

Results of the LR 2006 showed that variety had a significant effect on maize grain and stover yields. In PH4, CCM and Mdzihana had higher grain and stover yields than DHO2, PH1 and CLS3. However, these maize varieties cannot be recommended for the semi-arid areas despite their excellent performance since their high yields were realized due to the above normal rainfall that was experienced in the region during the time of the experiment. There is a need therefore to repeat the experiment at the same site with low moisture levels so as to determine the appropriate maize varieties for the semi-arid areas.

Table 3 : **Effect of maize variety on stover yield and plant height - SR 2005**		
Water harvesting technology	Stover yield (t ha-1)	Plant ht (cm)
Pwani hybrid 4 (PH4)	0.97a	32.2c
Coast Composite Maize (CCM)	0.93ab	44.4b
Dry land Hybrid maize (DH02)	0.84abc	49.3a
Mdzihana (Local maize)	0.83abc	35.4c
Pwani hybrid 1 (PH1)	0.75bc	32.2c
Coast Lowland Synthetic 3 (CLS3)	0.70c	27.2d
LSD0.05	0.218	4.55
CV (%)	31.8	21.4

Recommendation and way forward

The results from the experiment indicated that rainwater harvesting for crop production in the coastal semi-arid areas is not critical when the season is wetter than normal. Despite the excellent performance of PH4, CCM and Mdzihana, these maize varieties cannot be recommended for the coastal semi-arid areas because the high yields were realized when the region received above normal rainfall during that particular season. There is a need for further experimentation so as to identify the varieties that are suitable for the area that is characterized by low amounts of rainfall.

Recommendation and way forward

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Factors influencing the adoption of conservation agriculture as an adaptation strategy to climate change - A case study of Ngata Division, Nakuru County

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Abstract

Soil degradation as a result of poor ploughing methods is one of the major challenges in agricultural production in many parts of the world, especially in developing nations like Kenya. Data was collected from selected smallholder farmers using a proportionate stratified random sampling. In the first stage, the Locations were stratified into five stratas based on the degree of conservation agricultural extension efforts. A total of 120 household heads were selected randomly using probability proportional to size of the location. Data were collected from sampled households using structured interview schedule. The structured interview schedule was pre-tested, revised and then administered by well-trained enumerators recruited from the study area.

Descriptive statistics such as mean, standard deviations and frequencies were used to summarize the data while t test and chi square was used to test the hypotheses.

The results indicate that age, education, farm size, frequency of contact with extension agent and frequency of participation in field days had positive and significant influence on adoption of conservation agriculture while family size, sex, farm experience did not affect adoption. Based on these key findings, there is need for more extension effort in extension service so as to encourage farmers to adopt conservation agriculture. Improving smallholder farmers' access to farm credit through government interventions will also help smallholder farmers ensure food security at household level.

Key words: adoption, conservation agriculture, socio-economic factors, institutional factors.

Introduction

Majority of people in sub-Saharan Africa live and work in the rural areas, where they depend directly or indirectly on agriculture as a source of livelihoods. Agriculture employs these rural population and continues to be a fundamental instrument for sustainable development, poverty reduction and enhanced food security in developing countries. It is a vital development tool for achieving the Millennium Development Goals (MDG), one of which is to halve by 2015 the share of people suffering from extreme poverty and hunger (World Bank, 2008).

Currently, agricultural productivity growth in sub-Sahara Africa (SSA) lags behind that of other regions in the world, and is well below that required to achieve food security and poverty goals. Small-scale farming in Africa faces a double challenge: to increase production and preserve natural resources simultaneously. This is not an easy challenge, but one which many people think is key to the development of the African continent, playing a vital role in fighting hunger and poverty.

In an attempt to increase agricultural productivity and improve food security, efforts have been taken to generate and disseminate improved agricultural technologies among smallholder farmers. Conservation Agriculture is one of the technologies promoted for enhancing sustainable agriculture and includes several practices such as no or minimum tilling, soil cover and crop rotations.

Despite the governments effort to systematically disseminate CA, very few empirical evidence has been presented as to what factors affect the adoption of conservation agriculture technology. Only a few studies (Natalie *et al*., 2009;) have reported on the status and effects of CA in the country.

The objective of the current study was to determine the factors which influence the use of Conservation Agriculture by smallholder farmers in Ngata Division of Nakuru county.

Materials and methods

Data was collected from selected smallholder farmers using a proportionate stratified random sampling. In the first stage, the Locations were stratified into five stratas based on the degree of conservation Agriculture extension efforts. Finally, a total of 120 household heads were selected randomly using probability proportional to size of the Location. Quantitative data were collected from sampled households using structured interview schedule. The structured interview schedule was pre-tested, revised and then administered by well-trained enumerators recruited from the study area. Descriptive statistics such as mean, standard deviations and frequencies were used to summarize the data while t test and chi square was used to test the hypotheses.

Results and discussions

Age:Age is one of the factors which is useful in describing households and age structure of a sample and indeed the entire population. In most adoption studies age is taken to affect adoption positively due to farming experience old farmers have which make them easily adopt new technologies. Based on this fact, age was hypothesized to have positive relationship with adoption of conservation agriculture

The mean age of household head for adopters and non-adopters is 38.9 and 43.6 years, respectively. An independent t-test was conducted to test if there was significant difference in the mean age of adopters and non adopters. The t-value (t=2.262) showed statistically significant difference in the mean age of adopters and non-adopters .The non adopters mean age was greater than that for the adopters and is significant at $P<0.010$ and the result is provided in Table 1. This clearly indicates that as the farmers grow older, they become reluctant to embrace technologies that they are not used to. The result agrees with the findings of Green and Ng'ong'Ola (1993) who in their study on adoption of fertilizer technological package in Malawi, found that age had a negative influence on adoption but contradicts the findings of Adesina and Baidu-Forson (1995) who reported a positive influence of age on adoption of sorghum in Burkina Faso.

Table 1. Association between farmers' characteristics and adoption (n=120)

	Adopters		Non adopters			
Variables	mean	SD	mean	SD	T test	Significance level (2-tailed
Age	38.9	8	43.6	6	2.621***	0.010
Farming experience	10.45	8.67	9.75	5.05		0.43ns
Family size	6.59	1.95	5.94	1.57		.630ns
Education					1.490***	.000

Ns-non significant,*** significant at p<0.01,**significant at P<0.05

Family size

Family size in the study is considered as the number of individuals who reside in the respondent's household. Large family size assumed as an indicator of labour availability in the family. Based on this fact this variable was hypothesized to have positive and significant relationship with adoption of conservation agriculture.

The respondents mean family size is 6.9 and 5.9 for adopters and non-adopters, respectively. It ranges from two to eleven members of the family. The finding on the mean difference of both categories is provided in Table 1. The result shows that the mean family sizes of adopters are greater than non adopters. The results show that there is no significance mean difference among the adopter categories (t= 0.483, p=0.630). This is because of the fact that most farmers have experienced shared labour to overcome labour shortage.

Farm experience

Farm experience is one of the factors which influence adoption, For this particular study, farm experience did not affect adoption. There is no statistically significant mean difference between adopters and non-adopters. The mean year of experience for the adopters is 10.45 years while for non adopters its 9.75 years Table 1. From this we can conclude that having experience alone cannot make a farmer adopt conservation agriculture. The result agree with the work of Chilot *et al*., (1996) who indicated that farming experience does not matter in the adoption of improved wheat and coffee technologies. However it disagrees with Tesfaye's (2004) who in his study on adoption of in organic fertilizer on maize in Amhara, Oromia, and southern regions, explained that farm experience significantly influencing adoption of chemical fertilizer

Education

Education is very important for the farmers to understand and interpret the agricultural information coming to them from any direction. A better educated farmer can easily understand and interpret the information transferred to them by a development agent.

From Table 2, the total number of farmers who had secondary school level of education and above was 76% for adopters' and 21.5% for non adopters. Education was found to be significant ($p<0.01$), implying that farmers who have education are more likely to accept technologies than those who lack education. This shows that the education level of adopters of conservation agriculture is higher than non-adopters of the technology, implying the influence of the variable in making adoption decisions. This provides support for the hypothesis that better education levels are associated with greater information on conservation measures and in turn results in a greater adoption.

Table 2. Education of household (n=120)

	Adopters		Non adopters	
Variables	mean	%	mean	%
None	3	6	15	21.4
Primary	9	18	40	57.1
Secondary	22	44	12	17.1
Tertiary	14	28	2	3.0
University	2	4	1	1.4
Total	50	100	70	100

T-test = 1.49 P= 0.010

High level of education enhances the understanding of instructions given and should also improve the farmers level participation in agricultural activities. This is so because education enables one to access information needed to make a decision to use an innovation and practice a new technology. Education increases managerial competence and therefore enhances ability to diagnose, assess, comprehend, and respond to financial and production problems.

The findings of this study are in agreement with the studies of Tom (2006), Chitere and Dourve (2000) who found that education is a significant factor in facilitating awareness and adoption of agricultural technologies. However, the findings disagree with the study of by Tesfaye (2003), on soil and water conservation practices in Wello, Wolaita and Konso areas of Ethiopia revealed that there is no variation between literacy and illiteracy rates in terms of soil and water conservation.

Economic variables

Economic factors can play important role in determining the adoption of Conservation agriculture. The main and significant economic factors considered in this study are the area of farm size, labor availability and off farm activities of the household.

Farm size

Table 3 clearly indicates that, the average farm size for non-adopter group was 6 ha with (SD 4.96) while adopters were 13.9 ha and 10.6 standard deviation. Farm size affects adoption negatively. The results of independent sample t-test (with value of t=-2.609) shows a statistically significant mean difference between adopters and non-adopters at 1% significant level. This study is in agreement with the study of Taha 2007.In his study, he illustrates clearly that small land area may provide an incentive to adopt a technology especially in the case of an input-intensive innovation. In that study, the availability of land for agricultural production was low, consequently most agricultural farms were small. Hence, adoption of land-saving technologies seemed to be the only alternative to increased agricultural production.

Labour

Availability of labour did not influence adoption of conservation Agriculture. The average labour availability in terms of man equivalent for sample household was 3.07 with standard deviation of 1.5 for adopters and 2.5 and 1.3 for non adopters Table 3. The analysis (t= 1.396 and P = 0.247) shows the absence of significant mean difference between adoption categories, the result of this study confirms the findings of Pandey and Mishra (2004) who found no association between adoption of zero tillage and the family's ability to access labor and disagrees with the findings by Baudron *et al*., (2007) who argued that due to the paucity of family labor, more farmers will likely turn to technologies that save labor like reduced tillage systems if they are accessible and affordable.

Table 3: Association between economic variables with adoption (n=120)

	Adopters		Non adopters			
Variables	mean	SD	Mean	SD	T-test	Significance level (2-tailed
Farm size	13.9	10.6	6.0	4.9	-2.609	0.010**
Labor	3.07	1.5	2.5	1.3	1.396	0.247

Off farm activities

From this study, there is no significant relationship between adoption and participation in off farm activities. The fact that one does not participate does not make them adopt this technologies. The finding of this study agrees with the studies carried out by but disagrees with the studies of Mulugeta *et al*. (2001)who indicated positive relationship between off farm activies and adoption and Techane (2002) who in his study on determinants of fertilizer adoption in Ethiopia reported the negative influence of participation in off-farm income on farmers' adoption of chemical fertilizer.

Table 4: Association between off farm activities and adoption(n=120)

	Adopters		Non adopters		X2	P
Off farm activities	N	%	N	%		
Yes	10	95.8	12	20.5		
No	40	4.2	58	79.5		
Total	50	100	70	100	= 2.884	0.144

Institutional factors

Contact with extension agents. Extension plays a great role in promoting conservation agriculture. During the interview, it was clear that farmers in the area had directly got assistance from the extension officers in the district.. As shown in (Table 5.6), 68 % of the adopters contacted with extension agent. The contact of these farmers with the extension officers helps them to know more about the technology and helps them to practice conservation agriculture more effectively. The chi-square result ($\chi 2$=7.651 and P=0.053) shows there was statistically significant difference between adopters and non- adopters with respect to farmers' contact with extension agent. This shows that the farmers who frequently visit extension agent get more acquaintance with technology and tends to decide adoption of the technology than those who don't. This agrees with the study carried out by Kidane (2001).

Table 5: Association between contact with extension agent and adoption (n=120)

	Adopters		Non adopters		X2	P
Contact with extension agent	N	%	N	%		
Yes	45	95.8	15	20.5		
No	5	4.2	55	79.5		
Total	50	100	49	100	= 7.651	0.053

Field day participation

Field day is one of the most popular methods of transfer of technology .Conducting field days on farmers' field is a good way of convincing other farmers to adopt new technology. In field day neighboring farmers will get an opportunity to observe how the new technology is put in to practice in the field. This situation may facilitate the adoption process. Table 6 indicates that few farmers attended the field days compared to those who never attended. To determine the relationship between field days with the adoption of conservation agriculture chi-square analysis was conducted.

Table 6: Relationship of field day attendance and adoption of Conservation Agriculture (%)

	Adopters		Non adopters		X2	P
Field day	N	%	N	%		
Never	20	52.6	49	52.3		
Sometimes	13	25.0	15	34.0		
Total once a week	10	13.2	2	4.54		
Most often	7	9.21	4	9.09		
Total	50	100	44	100	18.83	0.027**

The chi-square analysis showed ($\chi 2$=18.837, p=0.027) that there existed a significant relationship between them at 5 % probability level (Table 6).This study is in agreement with the earlier works of makokha 1999 who observed that farmers characteristics such as Participation in field days had significant influence on perception and hence adoption decision of farmers.

Access to credit

Access to credit facilities is an important component as far as agricultural production is concerned. It is thus believed that a lack of adequate access to credit may have significant negative consequences on various aggregate and household level incomes, including technology adoption, agricultural productivity, food security, nutrition, health and overall household welfare .

From this study, there is a significant relationship between adoption and access of credit. ($\chi 2$ = 12.674, P = 0.005) as shown in Table 7 This can also be confirmed in distribution of percentage of respondents where

only 25 of non adopters have access to credit while the percentage difference between adopters is not as high as the one between non adopters.

Table 7: Association between access of credit and adoption (n=120)						
	Adopters		Non adopters		X2	P
Response of farmers	N	%	N	%		
Yes	30	42	12	24		
No	41	58	37	76		
Total	71	100	49	100	= 12.674	0.005

Information sources

The study also looked at ways through which farmers in the area get informed about conservation agriculture. In this particular study we looked at sources of extension services and teaching methods

Sources of agricultural extension services. As revealed in Table 8, all interviewed farmers reported government extension workers as main providers of extension services followed by non-governmental extension staff (63%). Fellow farmers (50%) and farmer-based organizations (8%) were also cited as sources of extension services. From this results, farmer based organisations had the least percentage. This is so because farmer based organisation which can carry out extension services are still few.

Table 8: Respondent-farmers' sources of agricultural extension services in the study area

Source of extension service	Frequency	%
Government extension staff	120	100
NGOs	75	62.5
Research institutions	40	33.3
Farmer based organizations	10	8.33
Fellow farmers	60	50
N=120		

These results shows clearly the important role that government extension workers play in the dissemination of agricultural technologies and hence the need for government to build more capacity for them to effectively carry out extension work

Extension teaching methods experienced by farmers. In this study, farmers were also asked to identify the extension teaching methods used by extension workers in the dissemination of conservation agriculture. The findings in Table 9 show the distribution of extension teaching methods identified by farmers. All the farmers (100%) identified method training as an extension teaching method used by extension workers followed by field day (83%) as another common extension teaching method used in the area. Other extension teaching methods were result demonstration (50%), leaflets (25%), posters (18%), and radio (12%). Farm magazine was the least mentioned extension teaching method constituting 5.8% probably because of the language used. Most of farmer magazines are written in English. Most of the farmer are semi literate and this makes them get difficulties in reading this magazines.

Table 9. Respondent-farmers' extension methods in the study area

Extension method	Frequency	%
Field days	60	50
Demonstrations	100	83.33
Leaflets	30	25

Training	120	100
Radio	14	11.66
Posters	22	18.33
Farmer magazines	7	5.83
N=120		

Training was ranked the highest as a method through which farmers get informed. This is due to the fact that several farmer field schools were set up in the area in order to teach farmers on conservation agriculture.

It is thus very important that appropriate extension teaching methods be used to pass across appropriate technologies given the nature of the technology to disseminate

Conclusion

Education levels of households head were found to be positively and significantly influencing adoption decision of Conservation Agriculture. The educated farmers easily understand the basic land management practices and they also know the advantage that is obtained from conservation Agriculture as compared to conventional tillage. Hence, it is appropriate for research, agricultural extension and NGOs to target them during on-farm research and CA promotion as they can easily understand about the technology which, in turn, helps them convince others to adopt the technology. The research can also identify and document the existing Indigenous Technical Knowledge of farmers to integrate valuable ITK into conservation agriculture.

From this study, frequency of contact with extension agents has positively and significantly influenced adoption of conservation agriculture which clearly suggests the

need for more targeted and continued extension services. Thus, there is need to strengthen the extension system operating in the areas and elsewhere so as to increase the flow of information for rural development. Clear messages on conservation agriculture should be included in the normal extension packages and training of both extension workers and farmers should be emphasized so as to improve their understanding and skills.

It was found that credit is strongly influencing adoption of conservation Agriculture. Non adopters were not using the existing credit in the area due to high interest rates. The government, research, extension, NGOs, and Private Sectors can look for ways of providing credit to these farmers at reduced interest rates.

Recommendations

Appropriate Education policies will be good to stimulate and increase the adoption of conservation Agriculture since it affected the probability of Adoption of conservation Agriculture Extension services should be strengthened to help overcome the problem of lack of information since it is evident that they provide technical information to farmer's hence increasing the probability of adoption of conservation Agriculture. However these should go hand in hand with financial support to enable farmer's get capital for purchasing farm inputs. This would also address the problem of lack of credit which was a major constraint facing farmers.

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Effect of enrichment and rate of cattle manure on nitrogen uptake and yield of tea

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Abstract

Tea (*Camellia sinensis*) is one of the most important cash crops in Kenya. The economic yield, two leaves and a bud are periodically harvested hence placing a lot of demand for the nutrients. Inorganic fertilizer NPK(S) 25:5:5:5 is generally recommended for the optimum supply of nutrients and crop yield. Non-judicious use of the inorganic fertilizer however acidifies the soil and pollutes the environment. Integrated soil fertility management, the combined use of organic and inorganic fertilizer, is recommended for improved crop yield and soil health. An experiment was carried out to determine the effect of enriching cattle manure with inorganic fertilizer 25:5:5:5s and varying the application rate on nitrogen uptake and yield of tea. Enriched and sole cattle manure up to a rate of 150kg N/ha increased the level of N in mature leaf. The N content in the mature leaf was highest under inorganic fertilizer NPKS 25:5:5:5 application. Enriching cattle manure with inorganic fertilizer significantly increased the crop yield.

Key words: cattle manure, enrichment, yield tea *Camellia sinensis*

Introduction

Tea (*Camellia sinensis*) one of the leading cash crops in Kenya can remain in production for up to 100 years. The regular harvesting of the crop (two leaves and a bud) however implies that nutrients are continuously mined from the soil. Nitrogen is one of the most important nutrients for tea production. A yield of 4000 kg made tea per ha removes about 160-200 kg N, 12-15 kg P_2O_5 and 84-100 kg K_2O from the soil (TRFK, 2010). Replacement of the lost nutrients is crucial for sustainable production of the crop.

In Kenya, a fertilizer rate of 100-200 kg N/ha in form of NPKS is recommended for optimal yield of tea. Many farmers use more than the recommended rates in a bid to realize high crop yield (Owuor *et al.,* 2000). The high fertilizer rates are expensive, acidify the rhizosphere and pollute the water masses (Killpack and Buchholz, 1993). Continuous use of the inorganic fertilizer however threatens the sustainability of the system (Baruah *et al.,* 2013). Cattle manure, one of the alternative nutrient sources is limited in quality and quantity (Gupta *et al.,* 2004; Lekasi *et al.,* 2001). Integrated soil fertility management (ISFM) the combined use of organic and inorganic fertilizers is recommended because of the synergistic effects that result in high crop yield and improved chemical, physical and biological soil conditions (Mishra *et al.,* 1991; Vanlauwe *et al.,* 2001). The benefits of ISFM have been demonstrated especially in the annual crop systems, but the challenge is how much, in what proportions and when the different fertilizer types are to be used. An experiment was carried out to determine the effect of enriched cattle manure rates on nitrogen uptake and yield of tea.

Material and methods

Site description

A field experiment was established in the year 2000 at Kangaita, Latitude, 0° 26′ S, Longitude 37° 15′ E, and altitude of 2020 m above sea level on the slopes of Mt Kenya at East of Rift Valley, Kenya. The soils are red clay classified as *humic Acrisols* (Kebeney *et al.,* 2010).

Treatments

A high yielding clone TRFK 31/8 was used in the experiment. The treatments were included:

- Inorganic fertilizer NPKS 25:5:5:5
- Cattle manure
- Enriched cattle manure (cattle manure: NPKS 25:5:5:5 at a ratio of 2:1)

Each of the treatments was applied at equivalent rates of 0, 75, 150 and 225 kg N ha^{-1} $year^{-1}$ Cattle manure was sourced from the nearby farmers' fields and standardized using the N content. The fertilizers were applied during the first week of September 2010 and 2011.

Experimental design

The trial was a 3 by 4 factorial experiment laid out in a Randomized Complete Block Design (RCBD) and replicated three times. Each plot was (10.98 by 5.46) m^2. The net plot comprised of (7 by 14) bushes spaced at (1.22 by 0.61) m^2.

Laboratory analysis

Cattle manure was ignited at 550^0C and organic carbon determined by oxidation using concentrated sulphuric and potassium dichromate according to Nelson and Sommers (1975) and titrated against Ferrous ammonium sulphate. Nitrogen in the cattle manure was determined using Kjeldahl method by digestion using concentrated sulphuric acid with hydrogen peroxide as an oxidant and selenium as a catalyst at 330^0 C. Total nitrogen was then determined by distillation in the presence of sodium hydroxide then titration (Okalebo *et al.,* 2002).

Nitrogen uptake

Leaf analysis has been used for a long time as a diagnostic tool in many perennial crops. Fifty mature leaves per net plot were sampled oven dried for 24 hours at temperature 105°C and milled using the coffee miller (®Ramtons). Leaf Nitrogen was determined using Kjeldahl method by digestion using concentrated sulphuric acid with hydrogen peroxide as an oxidant and selenium as a catalyst at 330^0 C. Total nitrogen was determined by distillation in the presence of sodium hydroxide then titration. Total P was determined colorimetery with ammonium molybdate/ammonium vanadate mixture and p-nitrophenil as an indicator and K by the flame photometer (Okalebo *et al.,*2002).

Yield of tea

Tea was plucked at 7-10 days interval and the weight per plot recorded at every plucking round. The yields were converted to kg made tea per hectare per year (kgmt/ha/y) using the following equation: (n*a*0.225)/b. Where: n is green leaf yield per plot, a is plant population per hectare, 0.225 is the factor converting green leaf to made tea (TRFK, 2002) and b is the number of plants per plot.

Statistical analysis

Data was subjected to Analysis of Variance (ANOVA) using SAS version 9.0 statistical software package. Means were separated by Student- Newman-Keuls (SNK). Soil data with high coefficient of variations (CV) was transformed using $\log_e$ (x +1).

Results and discussion

Nitrogen uptake

The N content in the mature leaf did not differ significantly with fertilizer type (Figure 1a and 1b). Kamau *et al*. (2008) and Kwach *et al*. (2012) noted comparable N content. The results show that of the N applied, less than 30% is recoverable in the mature leaf. The low amounts may be reason for the lack of significant difference. Moreover, irrespective of source, tea prefers the ammonium form of N (Li *et al.,* 2013; Ruan *et al.,* 2007) hence even when nitrate form applied it undergoes nitrification.

Fertilizer rate significantly increased the N content, especially at higher rates. Kamau *et al*. (2003) also noted an increase in N content in the mature leaf with increase in fertilizer rate. Increasing fertilizer rates under

cattle manure resulted in lower N content compared to NPKS and enriched manures probably because of the release of nutrients (Gupta *et al.,* 2004). Enriched cattle manure resulted in increased the N content in mature tea leaf especially in 2011.

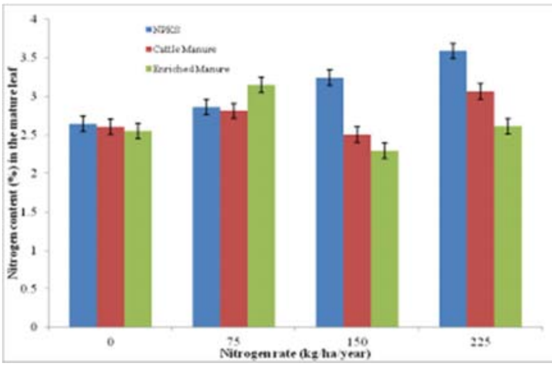

Figure 1a: Effects of fertilizer type and rate on the N content of the mature leaf in 2010

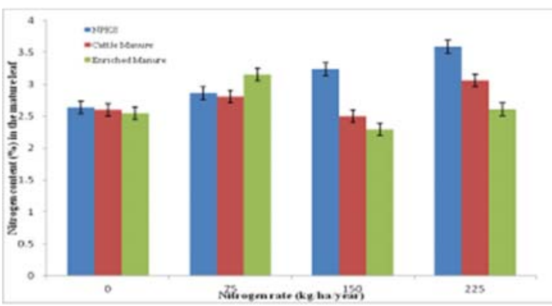

Figure 1b: Effects of fertilizer type and rate on the N content of the mature leaf in 2011

The results suggest that organic manure alone cannot supply adequate N for sustainable tea productivity.

Crop yield

Crop yield varied significantly with year, fertilizer type and rate (Figure 2). The annual crop yield variation is a common characteristic in tea where several factors including temperatures, amount and distribution of rainfall vary (Owour *et al.,* 2008). In 2011 lower rainfall was received which resulted in lower yields compared to year 2010. The crop yield was thus generally higher in 2010 than in 2011. Cattle manure had the lowest yield probably because of the lower nutrient content. In 2010, inorganic fertilizer (NPKS) had the highest yield (3014 kg made tea/ha) followed by enriched cattle manure (2959 kg made tea/ha) and lastly cattle manure with 2572 kg made tea/ha. Enrichment increased crop yield by about 36%.

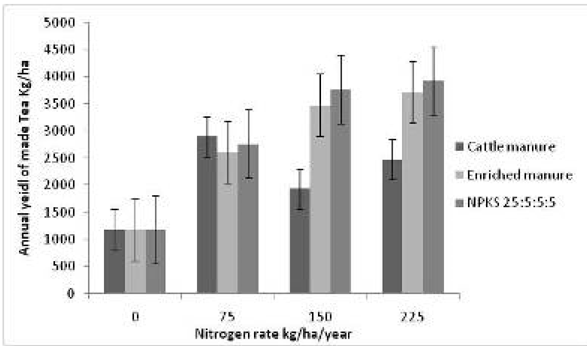

Figure 2a: Effect of fertilizer type and rate on annual crop yield in 2010

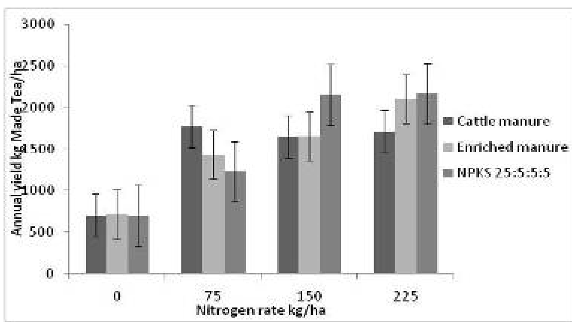

Figure 2b: Effect of fertilizer type and rate on annual crop yield in 2011

In 2011, inorganic fertilizer (NPKS) had the highest yield (1661 kg made tea/ha) followed by enriched cattle manure (1604 kg made tea/ha) and lastly cattle manure with 1363 kg made tea/ha. Enriched manure had comparable yield to NPKS the positive control.

Crop yield increased with increasing fertilizer rate. The response of tea yield to the increase in N fertilizer rate has also been reported in several studies (Kamau *et al.*, 2011; Wanyoko, 1997).The increase in yield with enriched manures is probably because of the effect on biological and physical soil properties that results in improved nutrient retention and nutrient release patterns and ultimately yield (Vanlauwe *et al.*, 2001). The slow release of nutrients from cattle manure coupled with influence on pH and other properties maybe responsible for the low yields (Phukan *et al*. 2008). This shows that enriched manures can be used to substitute for inorganic fertilizers.

Conclusions

Use of organic manure resulted in higher P and K in the mature leaf. Although enriched manures showed lower K in the mature leaf, use of enriched manures resulted in higher, higher crop yield and P in the mature leaf. Enriched manures showed higher nitrogen uptake. Enriched manures can thus be used substitute the inorganic fertilizer (NPKS) enhanced tea production.

Acknowledgement

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Screening some promissing rice cultivars for rooting ability in low management condition

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Abstract

Rainfall reduction in West Africa adversely affects water supply for rainfed rice production. There is a need to improve water use efficiency by rice varietal rooting ability in order to mitigate water stress. Therefore, the rooting ability of some interspecific (*O. sativa* (V11) × *O. Glaberrima* (V12)) rice cultivars named NERICAs (V1, V2, V3, V4, V5, V6, V7, V8, V9 and V10) was assessed compared to their parents under two rates (0 $kgha^{-1}$ (N0) and 30 kg ha^{-1} (N1)) of nitrogen-N in a split-plot design. Profile method of root study was used. Highest root densities (1700 m^2) were observed for cultivars V1-NERICA 1 and V2-NERICA 2 with 0 $kgNha^{-1}$ compared to that of 30 kg N ha^{-1}, meanwhile, the highest overall mean value of root density (4000/m^2) was observed for N1 (30 kg N ha^{-1}) especially in the top soil (0-20 cm). The cultivar-V11 (*O. sativa*) has the highest root density in the topsoil indifferently to N-rates while NERICA 2 (V2), 4 (V4) and 8 (V8) have similar characters in subsoil 20-40 cm and 40-60 cm likewise for the parent *O. Glaberrima* (V12) in 40-60 cm depth. Varietal difference of rooting ability was under different management options and NERICA 1 and 2 was recommended for drought mitigation under limited N-supplying condition while NERICA 4 and 8 are for low-N supplying condition.

Key words: NERICA rice cultivar, root density, drought, nitrogen, soil.

Introduction

Annual rainfall reduction in West Africa (CNRS, 2000) is a threat of rainfed rice (*Oryza sativa* L.) production that account for 80% of rice cultivated surface (Audebert *et al.*, 1999). Enhancing water use efficiency by morphological traits as root development can improve rice production in the sub-region. Thus, varietal difference in rooting ability was assessed under low input management condition to indentify some cultivars for drought stress mitigation in small farmers’ fields. The aim was to identify cultivars some presuming drought tolerant NERICA cultivars that can develop highest root density for the improvement of water use efficient under no- and/or low-nitrogen fertilizer effect.

Material and methods

Study area

The study was carried out in 2006 in southern Benin (6º 28′ N, 2º 21′ E, 15 m elevation) at Abomey-Calavi. The experiment was laid out on the summit of the plateau landscape with a slope of about 0-2%. Three years of fallow dominated by *Imperata cylindrica* preceded the experiment under a bimodal rainfall pattern with a short dry season from July to August. The soil was Acrisols free of morphological constraints such as gravels and hardpan.

Experiment layout

Ten interspecific rice cultivars considered as New Rice for Africa (NERICA) released by Africa Rice Center after crossing *O. glaberrima* and *O. sativa* from Africa and Asia respectively, was used for the trial. The rooting ability of NERICAs was assessed compared with that of their parent *O. sativa* (V11) and *O. glaberrima* (V12) using NERICA 1 (V1) to NERICA 10 (V10) in successive order. Two rates of nitrogen, N0 (0 kg N ha^{-1}) and N1 (30 kg N ha^{-1}) were combined with 50 kg k ha^{-1} and 50 kg P ha^{-1} as basal fertilizers respectively according to the fertilizer treatments in a split-plot design. The land was previously ploughed using a hand-held hoe before laying out 15 m^2 (3 x 5 m) plots. In the first week of June, rice varieties were seeded sown at the rate of three grains per hill at 20 x 20 cm spacing.

Data collection

At rice flowering period, destructive sampling was done for root study. Two opposite profiles (70 × 70 cm) were done in each plot (treatment) for root study as described by Tardieu et Manichon (1986) using a grid of 60 × 30 cm in dimension including cells of 5 × 5cm. The observation was done within the 60 cm depth. The number of root impact was counted in each cell (25 cm^2) of the grid that was placed twice from zero to 60 cm depth.

Statistical analysis

Counted data were transformed by root square method before processing analyse of variance to generate mean values of root density for each cultivar and for 0-20 cm, 20-40 cm and 40-60 cm depths respectively. GenStat discovery was used for these purposes.

Results

There is no significant effect of nitrogen rate on root density contrasting with variety and depth effects as well as for their interactions. But nitrogen has significant interaction with each of these factors whereas no significant effect is observed for the full factors interaction (Table 1).

Table 1: Treatment effects on root density

	Df	Probabilty (F)
N	1	0.56
Var	11	0.05
Depth	2	<0.001
N.Var	11	0.03
N.Depth	2	0.03
Var.Depth	22	0.006
N.Var.Depth	22	0.10

GM (Numb.m^{-2}) 1516; CV(%) 20

Highest root densities are observed for NERICA 1 (V1) and NERICA 2 (V2) with no nitrogen fertilizer (0 kg N ha^{-1}) while significant highest densities occurred for NERICA 6 (V8), NERICA 10, *O. sativa* (V11) and *O. glabberima* (V12) when 30 kg N ha^{-1} was applied (Figure 1).

Figure 2 shows that the highest significant root density as observed under 30 kg N ha^{-1} occurred especially in the topsoil (0-20 cm).

However, highest root density was observed for NERICA 2 (V2), NERICA 4 and NERICA 8 in subsoil (20-40 cm and 40-60 cm). Similar observation was done for V12 (the parent O. glabberima from Africa) in 40-60 cm (Figure 3).

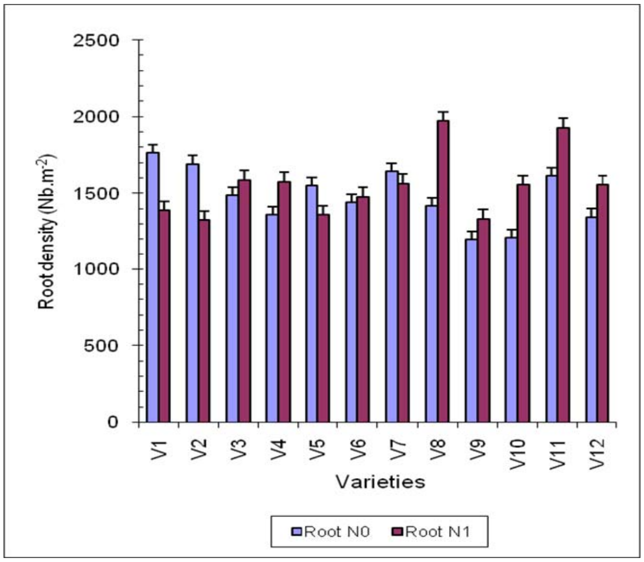

Figure 1: Root density mean values of rice varieties according to N-fertilizer levels

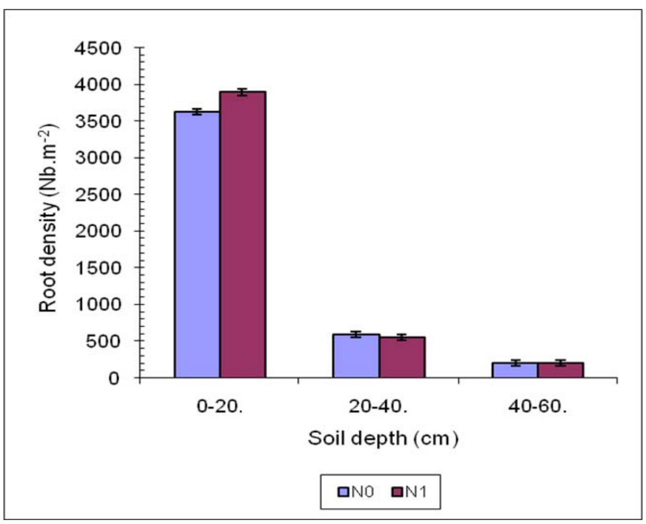

Figure 2: Effect of N-levels on root density in 0-20 cm, 20-40 cm and 40-60 cm of soil depth (bars are standard errors)

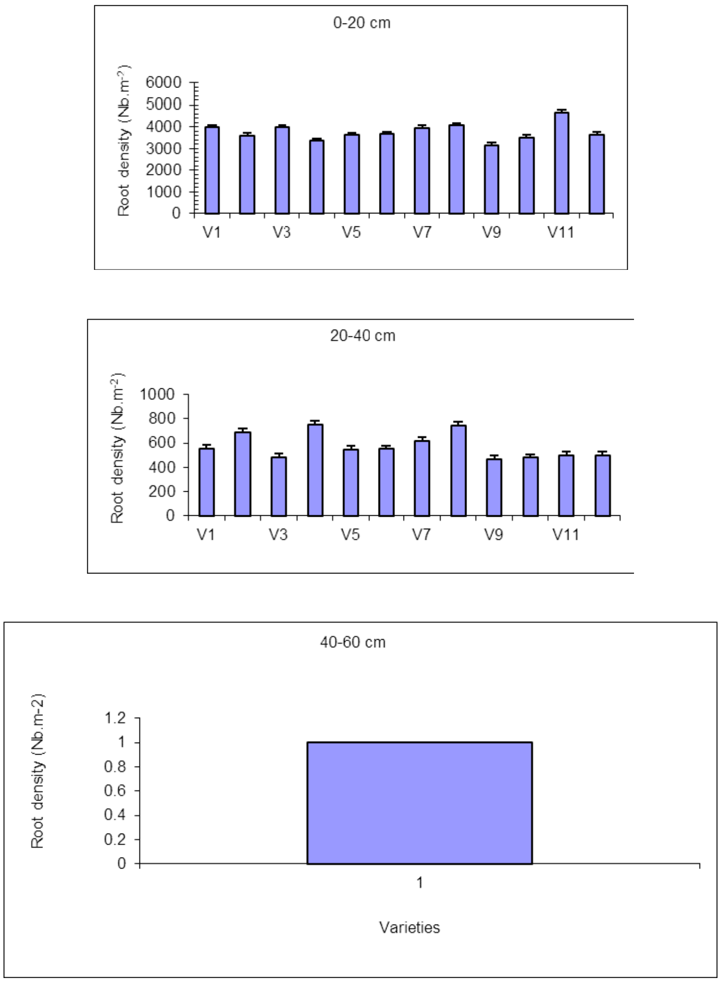

Figure 3: Varieties root density each soil depth (0-20 cm (a), 20-40 cm (b), 40-60 cm (c)) in the profile

Discussion

Oryza glabberima as the parent of NERICA cultivars originated from Africa, was found to have deepest rooting ability in the studied agroecology. This genotype has probably significant influence in the rooting ability of NERICA 2, NERICA 4 and NERICA 8 which have consistently developed highest root density in the subsoil (20-60 cm). Furthermore, the varietal difference observed under N-rates could be explained by nitrogen effect in root ramification (Kouamé *et al.,* 2013) which could be also dependant on cultivars. The highest root density recorded for NERICA2, NERICA 4 and NERICA 4 can justify their high potential for soil exploration, thereby, improving their water use efficiency in drought-prone area. But, in soil deficient in nitrogen, NERICA 1 and NERICA 2 are recommendable for this purpose.

Conclusion and recommendation

Our study showed a varietal difference in rooting ability on Acrisols under low nitrogen management condition. Among the NERICAs tested, those who are likely to be more influenced by *O. glaberrima* genotype are the recommendable in limited water supplying condition.

In mid-season drought-prone area of West Africa, NERICA2, NERICA 4 and NERICA 8 are recommended for upland rice cropping, meanwhile, in N-deficient condition NERICA 1 and 2 are preferred for this.

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Soil fertility status, quality of available manure and its implication on soil fertility maintenance in the peri-urban areas of semi-arid eastern Kenya

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Abstract

A study of nutrient status of cropland soils and the quality of farmyard manure applied on the farms was undertaken in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County in semi-arid eastern Kenya. The objective of the study was to recommend appropriate soil fertility maintenance strategies for enhancing productivity of vegetables and fodder crops in crop-livestock production systems in the two peri-urban areas. Soil and manure samples were collected from 54 farms in the two areas and analysed at the National Agricultural Research Laboratories, Nairobi. Results of soil analysis indicated that with the exception of nitrogen, phosphorus, organic carbon and zinc, the other nutrient elements analyzed for were above critical levels. Results of manure analysis indicated that with the exception of nitrogen, phosphorus and zinc, the other nutrient elements analyzed for were above critical levels. It was concluded that due to the low levels of nitrogen (< 2% N) in the farmyard manure and the insufficient quantities available on farm, application of manure alone cannot maintain soil fertility for sustainable crop and livestock production. It was, therefore, recommended that the available quantities of farmyard manure should be augmented with inorganic nitrogen fertilizers. Intensification of legume production in order to increase N pool in the soil, through N_2 fixation, was also recommended.

Keywords: semi-arid areas, peri-urban, farmyard manure, soil fertility, nutrients.

Introduction

There has been increased land pressure in the semi-arid lands of Kenya due to the rapid increase in population, brought about by high population growth and influx of people from the high potential areas in search of new farmlands. This has led to intensive land use without adequate replenishment of nutrients, resulting in the depletion of soil nutrients, hence the decline in soil fertility. In most of these areas, the soils have low organic matter content and are deficient in nitrogen (N) and phosphorus (P) (Nadar and Faught, 1984; Ikombo, 1984; Okalebo *et al.,* 1992; Okalebo *et al.,* 1996; Okwach *et al.,* 1999; Gachimbi *et al.,* 2005; De Jager *et al.,* 2005). The outflow of nutrients in most farms exceeds input flows (Smaling *et al.,* 1993; Gachene *et al.,* 2000; Gachimbi *et al.,* 2005; De Jager *et al.,* 2005). Organic matter depletion affects soil behaviour physically and chemically by causing loss of water-stable structure and reduced water conductivity, which are manifested as slaking of cultivated seedbeds, reduced infiltration rates and increased proportion of rain lost as runoff (McCown and Jones, 1992). Thus, increasing soil fertility requires increasing soil carbon, N and P. Farmyard manure is the principal source of nutrients for crop and fodder production in these areas. Its use is also the main method of recycling nutrients and, where animals have access to forage outside the farm, a means of collecting nutrients from surrounding areas. Manure is the best amendment for increasing soil fertility as it provides carbon, prevents acidification and generally provides the balance of all nutrients (Pichot *et al.,* 1981; Nambiar and Abrol, 1989, cited by McCown and Jones, 1992). A survey of nutrient status of cropland soils and the quality of FYM applied on the farms was undertaken in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County in semi-arid Eastern Kenya, where farmers are engaged in dairy and vegetable production, with the aim of recommending appropriate soil fertility maintenance strategies for enhancing the productivity of these enterprises.

Materials and methods

Study areas

The study was conducted in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County. Wote town is the main urban centre in Makueni County while Wamunyu market is one of the fast-growing urban centres in Machakos County and is 40 km southeast of Machakos town along Machakos-Kitui road. Wote town is in the transition zone between Lower Midlands (LM) 4 and 5 at 1100 m. Wamunyu market is in LM 4 at 1190 m (Jaetzold *et al.,* 2006). The two areas have a bimodal rainfall pattern, which is almost evenly distributed between the long rains (March-May) with a peak in April, and the short rains (October-December) with a peak in November. The main soil types in the two areas are Cambisols and Ferralsols (Jaetzold and Schmidt, 1983). The farms from where the soil and manure samples were collected were within 15 km radius of the two urban centres. These farms had been selected earlier for a baseline survey of a crop-livestock integration project using a purposive sampling procedure, where the main criterion was possession of at least one cross breed or high grade dairy animal.

Soil sampling, collection of manure samples and analysis

Soil sampling and collection of manure samples were undertaken in April 2012. Soil samples were taken from the 0-30 cm layer from 24 farms in Wamunyu area and 30 farms in Wote area. On each farm, soil sampling was carried out only on the terraces where farmers indicated they intended to grow vegetables and fodder. At least 5 samples were randomly taken in each terrace, composited and then sub-sampled. One manure sample was also collected from each farm and together with the soil samples analysed at KARI-Kabete. Complete analyses were carried out for soil and manure samples. In soil analysis, total N was determined by the Kjeldahl method (Hinga *et al.,* 1980). Organic carbon by calorimetric method, Soil pH was determined in a 1:1 (w/v) soil-water suspension with a pH meter. Phosphorus, potassium, calcium, magnesium and manganese were determined by the Mehlich Double Acid method (Hinga *et al.,* 1980). Copper, iron and zinc were determined by Atomic Absorption Spectrophotometer (AAS). For manure analysis, the samples were determined by the digestion method where digestion is carried out in tubes with sulphuric acid-salicylic acid-hydrogen peroxide and selenium. Total N was then measured by distillation then titration with standard 0.01NHcl, phosphorus was determined calorimetrically on spectrophotometer, potassium was determined by flame photometer and calcium, magnesium, copper, zinc, manganese and iron were determined using AAS.

Results and discussion

Soil pH

The range and mean of pH (H_2O) values of the soils of the study areas are shown in Figure 1. The pH ranged from 5.83 to 7.96, with an overall mean of 6.96 (sd.±0.53). Except on eight farms, where the soil pH was slightly alkaline (>7.0), the soil pH of the soils from the other farms was generally neutral, indicating that, on all the sampled farms, the pH was satisfactory for the growth of crops and fodder.

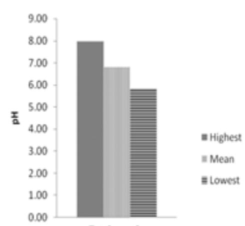

Figure 1: Range and mean of pH values of the soil samples collected in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County

Soil nutrients and organic matter content

Results of soil analysis indicated that with the exception of nitrogen (N), phosphorus (P), organic carbon (Org. C) and zinc (Zn), the other elements analyzed for, i.e. potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), and iron (Fe), were above critical levels. The lowest, highest, mean and critical levels of total N, P, Org. C and Zn for all the farms sampled are presented in Figures 2, 3, 4 and 5, respectively. Total N ranged from 0.07 % to 0.16%, with a mean of 0.09% (Sd.±0.02) and was below the critical level (0.2%) on all the farms. Organic carbon ranged from 0.51% to 1.29%, with a mean of 0.91 (Sd. ±0.19) and was below the critical level (2.0%) on all the farms. Phosphorus ranged from 1.0 mg/kg to 109.0 mg/kg, with a mean of 27.60 mg/kg (Sd.±26.70) and was above the critical level (20 mg/kg) on 15 farms. Zinc ranged from 0.91 mg/kg to 9.54 mg/kg, with a mean of 3.47 (sd.±2.59) and was above the critical level (5 mg/kg) on 10 farms. Low organic matter content and N and P deficiencies have been reported in other areas in this region (Nadar and Faught, 1984; Ikombo, 1984; Okalebo *et al.,* 1992; Okalebo *et al.,* 1996; Okwach *et al.,* 1999; Gachimbi *et al.,* 2005; De Jager *et al.,* 2005). Nutrient monitoring studies in this region have shown that the outflow of nutrients in most farms far exceeds input flows (Smaling *et al.,* 1993; Gachene *et al.,* 2000; Gachimbi *et al.,* 2005; De Jager *et al.,* 2005). This scenario has been attributed to continuous cultivation without adequate replenishment of nutrients, removal of crop residues for livestock feed and loss of nutrients through erosion, leaching and runoff. There have been no reports of widespread zinc deficiencies in the semi-arid areas in the past. However, the results of this study indicate that with time, zinc is likely to become limiting.

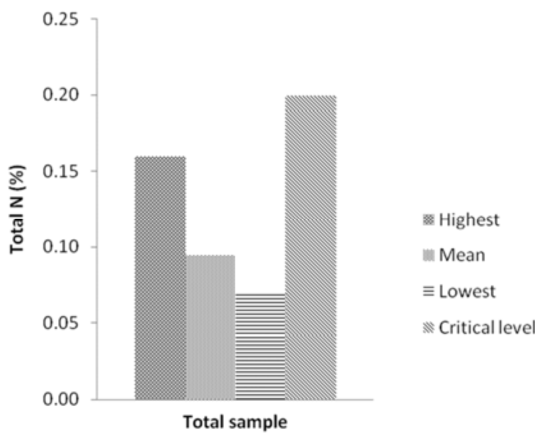

Figure 2: Range and mean of total N from sampled farms in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County

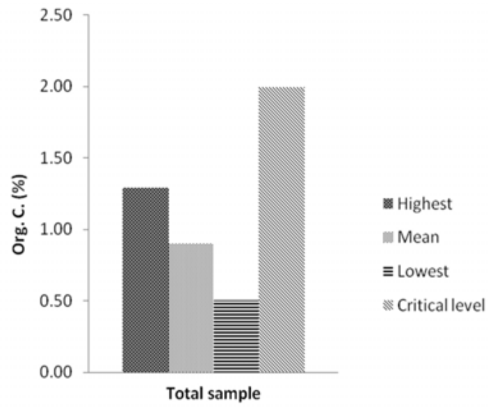

Figure 3: Range and mean of organic C. from sampled farms in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County

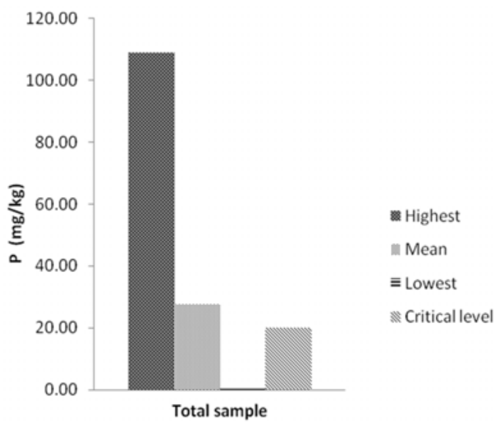

Figure 4: Range and mean of P from sampled farms in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County

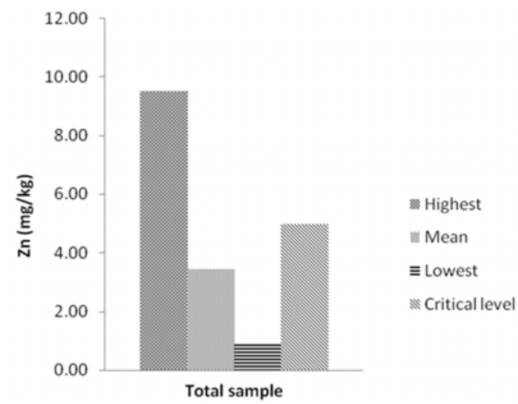

Figure 5: Range and mean of total Zn from sampled farms in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County

Levels of N, P and Zn in the manure applied on the farms

Results of manure analysis indicated that with the exception of N, P and Zn, the other elements analyzed for, i.e. K, Ca, Mg, Cu, Mn and Fe, were above critical levels. The lowest, highest, mean and critical levels of N, P, and Zn for all the farms sampled are shown in Figures 6, 7 and 8, respectively. The N contents ranged from 0.1 to 2.1%, with a mean of 0.91% (sd.±0.47) and were below the critical level (3.0%) on all the farms. P levels ranged from 0.16 to 0.51%, with a mean of 0.28% (sd.±0.89) and were below the critical level (0.2%) on only two farms. Zn levels ranged from 11.2 to 118 mg/kg, with a mean of 44.44 mg/kg (sd.±25.2) and were below the critical level in 10 farms. Low levels of N in manure produced on smallholder farms in this region have been reported by a number of investigators (Probert *et al.,* 1992; Watiki *et al.,* 1999; J. R. Okalebo, unpublished data). Low levels of N in manure produced in smallholder farms have been reported from other places in Africa. For instance, Mugirwa and Shumba (1986) reported N levels of 0.98% and 1.05% from Chiota and Svose communal areas, respectively, in Zimbabwe. Mokwunye (1980), working in West Africa, reported N levels ranging from 0.48 to 1.95%. The low levels of N have been attributed to mixing of manure with soil when scooping manure from *bomas*, which in most cases do not have a concrete floor, denitrification, brought about by wet conditions in the *bomas*, leaching and volatilization when manure is heaped outside after it has been removed from the *bomas* and left uncovered (Probert *et al.,* 1992).

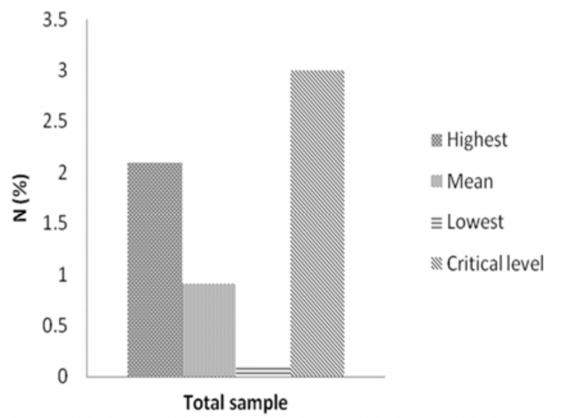

Figure 6: Range and mean of total N from manure samples obtained in farms in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County

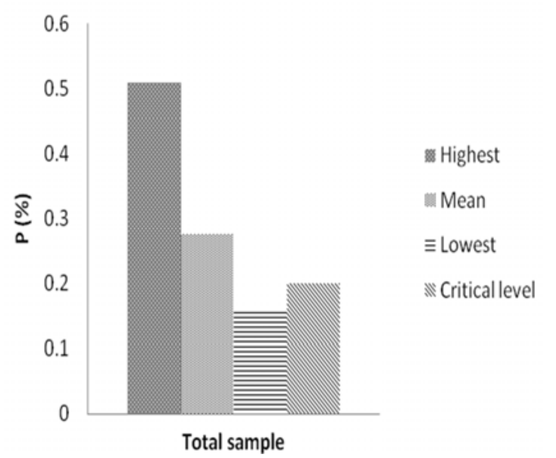

Figure 7: Range and mean of P from manure samples obtained in farms in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County

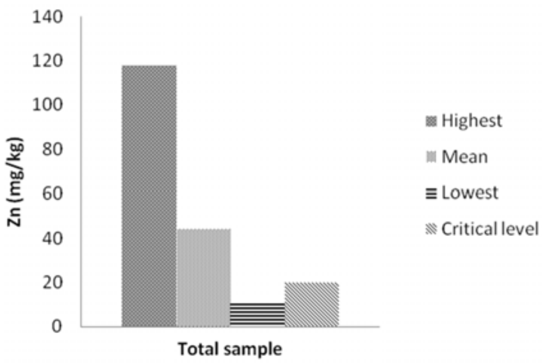

Figure 8: Range and mean of N from manure samples obtained in farms in the peri-urban areas of Wote town in Makueni County and Wamunyu market in Machakos County

Implication of the manure quality on soil fertility maintenance

The assertion that farmyard manure is capable of maintaining soil fertility in resource-poor smallholder crop-livestock farming systems presupposes that adequate quantities of good quality manure are available on farm. However, as shown by the analysis, the manure produced on these farms is of poor quality. It is particularly deficient in N and to some extent P. Past research findings have also indicated that most of the farmyard manure in the semi-arid areas of Kenya contains only one third of the N and P expected from fresh animal manure (Probert *et al.*, 1992; Lee, 1993). A much more important constraint in the utilization of farmyard manure is the insufficient quantities available on farm. For instance, a recent survey (Itabari *et al.*, 2013) showed that the average amount of animal manure produced on the farms in the peri-urban areas of Machakos town was 5.1 tonnes (s.d ±2.8) per season while that produced in the peri-urban areas of Wote town was 5.6 tonnes (s.d ±4.4) per season. The recommended application rate for maize is 8t/ha of good quality manure (Ikombo, 1984). This clearly indicates that, given the poor quality of the manure, these amounts are not sufficient to apply to even one hectare of cropland. However, Probert *et al.* (1992), working in the same region reported estimated rates of application of between 38 to 168 t/ha, but this was on farms where farmers practised a policy of applying manure to different terraces each year. For instance, one farm had applied manure to one out of ten terraces and another had applied to half of a terrace out of three. Thus, manure is not adequate to apply to the whole cropped area and presumably, farmers were applying these high rates so as to provide adequate nutrients to their crops. From the foregoing, it is evident that while manure is essential for soil fertility maintenance, the available supplies are of poor quality and insufficient and hence cannot maintain soil fertility. Maintenance of soil fertility for sustainable crop and livestock production in these areas is, therefore, only possible by augmenting manure with inorganic fertilizer, with manure supplying organic matter, phosphorus and micronutrients and inorganic fertilizer supplying mainly nitrogen.

Conclusions and recommendations

N was particularly deficient in all the soils of the surveyed areas and levels of Zn were below the critical level in most of the farms. Organic matter contents were also very low in all the farms surveyed. There is, therefore, a need to improve the levels of these soil nutrients and organic matter content. One way of addressing this problem, especially low organic matter content, is through application of adequate quantities of good quality manure. The N content of the manure, which is the principal source of nutrients in the region was very low, hence there is a need to sensitize/train farmers on strategies for mitigating N losses from manure so as to improve its content. However, due to the low levels of N in the farmyard

manure and the insufficient quantities available on farm, application of manure alone cannot maintain soil fertility for sustainable crop and livestock production. There is, therefore, a need to augment the available quantities of farmyard manure with inorganic nitrogen fertilizers. There is also a need to intensify production of legumes so as to increase N pool in the soil through N_2-fixation.

Acknowledgement

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Modelling nitrogen dynamics in tea soils

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Abstract

Nitrogen fertilization is important in tea cultivation due to high removal from the soil through crop harvesting. Field investigation was conducted for one year in tea plots at Tea Research Foundation of Kenya (TRFK), Kangaita station in Kirinyaga, Central Kenya, to assess dynamics of nitrogen. In order to support nutrient management in tea, a simulation model which considers the temporal dynamics of nitrogen in the tea environment was used. The model N-Vino was validated to reproduce the nitrogen dynamics in tea soils. Seventy percent of the simulated soil minimum N values ranged within the standard deviation of the observed soil minimum N values. Ninety percent of the soils water content, another variable used for the model validation could be reproduced at this level of accuracy. The results however, are considered sufficient for practical use in tea fertilizer management.

Key words: nitrogen, simulation model, crop growth.

Introduction

In recent years, sustainable agriculture has become a concern due to the pressures of the increasing nitrogen (N) fertilizer costs and increased focus on environmental protection. Any intensification on the use of nitrogen fertilizers in agriculture already has and will continue to have major detrimental impacts on the diversity and functioning of the non-agricultural neighbouring bacterial, animal, and plant ecosystems. There is greater attention being paid to the efficient use of N fertilizers (Hezhong *et al.,* 2010). The need to optimize fertilizer inputs to meet crop requirements have also increasingly been identified as priorities for research in feedback from tea stakeholders.

Nitrogen is the major nutrient of tea plant, *Camellia sinensis* without which it would not be feasible to achieve the commercial level of production (Venkatesan *et al.,* 2005). It plays an important role in increasing the agricultural production and as a constituent of protein, it increases the tea quality (Kalaiselvi and Mahimairaja, 2010). Application of N depending on its form and compound it containes, undergoes a series of transformation including hydrolysis, volatilization, nitrification, denitrification and mineralization.

Nutrient dynamics mainly affect nutrient budget in tea soil. The nutrient budget is partly affected by processes such as fertilizer application; plant uptake and removal by harvesting, accumulation or storage in the standing plant and recycling through litter fall and stem flow (Dang, 2005). Nutrient uptake by plants is inherently inefficient and nutrients remaining in the soil after uptake can cause negative soil, air and water resource impacts depending on their fate. The study of nitrogen dynamics in tea cultivation is therefore required to understand the fate and potential threats of these elements.

Description of the model

The model, in which the plant growth subroutine for *Camellia sinensis* was embedded, was previously presented by Kersebaum (1989, 1995). It considers the main nitrogen turnover processes net mineralization and denitrification as well as transport of nitrate by water and N uptake by plants. To meet the requirements of practical application the model is specially designed to work under conditions with restricted input data. It has been successfully used to assess fertilizer recommendations in Northern German agriculture in the last decade. Detailed description of the sub models for calculating the water balance as well as the transport and turnover of nitrogen were given by Kersebaum (1989, 1995). The plant growth sub model Kersebaum (1985, 1995) used in the model is based on the SUCROS model of Van Keulen

et al. (1982). Plant growth is expressed by daily dry matter production, which is calculated from global radiation and temperature. Photosynthesis response to temperature is taken from Groot (1987). Assimilate demand for organ-specific maintenance respiration is subtracted according to Penning de Vries & van Laar (1982) in dependence of plant dry mass to be maintained. The crop phenological development is divided into different stages, each depending on effective phenological thermal time. The calculation of the thermal time was first realized for winter wheat according to Weir *et al.,* (1984), taking temperature, vernalisation and day length into account. Partitioning of assimilates to different plant organs depends on the phenological development. Furthermore, plant growth can be restricted either by water stress, determined by the ratio of actual to potential transpiration, or by nitrogen deficiency. The crop nitrogen balance is controlled by a thermal time dependent function of critical and maximum nitrogen content of the above-ground plant organs. It is connected to the soil nitrogen balance by an empirical function of root dry matter distribution by depth (Gerwitz and Page, 1974).

Materials and methods

Experimental site

This study was conducted at Tea Research Foundation of Kenya, Kangaita substation in Kirinyaga, Central Kenya. Kangaita (37^{o}, 17.8′ E; 0^{o}, 19.8′ S; 2130 metres above sea level) is located on the slopes of Mount Kenya.

Soil

The experimental soils were acidic clay (montmorillonites) humic loam with high fertility, taxonomically grouped under humic NITISOLS (Jaetzold *et al.,* 2006).

Micro-meteorological variations

The local climate is humid subtropical with annual rainfall which ranges between 1700-2150 mm while temperature ranges between 14.5-17.8^{o}C. A summary of the major values of micro-meteorological parameters during the experimental period i.e. September, 2010 to August, 2011 is shown in Table 1.

Table 2: Monthly total rainfall, maximum, minimum and mean air temperature, soil temperature and relative humidity at Kangaita for September, 2010 to August, 2011

Month	Total rainfall (mm)	Max. air Temp. (°C)	Min. air Temp. (°C)	Mean Air Temp. (°C)	Soil Temp. (°C)	RH (%)
Sep	41.6	19.2	9.9	14.6	18.1	87
Oct	148.9	20.8	11.4	16.1	20.1	83
Nov	146.4	20.2	10.4	15.3	18.9	90
Dec	48.4	21.4	9.3	15.4	20.9	77
Jan	29.7	21.9	8.7	15.3	21.6	67
Feb	15.0	21.0	10.3	15.7	21.8	56
Mar	76.2	22.0	12.8	17.4	22.4	62
Apr	290.7	20.7	15.1	17.9	19.6	69
May	486.5	20.9	15.1	18.0	17.7	77
Jun	57.7	15.0	12.3	13.7	17.9	88
Jul	46.5	18.8	11.7	15.3	17.6	74
Aug	110.3	17.6	12.0	14.8	16.3	75
Mean	124.8	20.0	11.6	15.8	19.4	75.4

N-Vino model inputs

Input data were organized according to project, which means they are located in the project folder (Figure 1).

Figure 1: Data structure of N-Vino model

A project is defined by a common location (same latitude and weather station). The model demands input for soil properties, soil management, weather, crop management and fertilizers.

The simulation period as well as some options (output interval, evapotranspiration method, and precipitation correction) can be defined in the driver file for each project. Within a project folder separate folders are available for annual weather data (\WEATHER\) and output files and measured values (\RESULT\).

Input and validation data

The validation procedure for the N-Vino model involved separately validating the different modules i.e. site data, fertilizer parameters and management (Nendel, 2004). The growth parameters for tea were obtained from the field observations of other ongoing research projects in the Tea Research Foundation of Kenya. Model default values for fraction (%) of organic N that was not considered being recalcitrant and thus was available for daily N mineralization, dormancy and bud break were used in the simulation. Since the model was not parameterized for tea crop, the option provided for non-parameterized crops was used to input basic data required for the simulation of plant water and N uptake.

The weather information required by the model were daily mean air temperature (°C) at 2 m above soil level, daily air temperature (°C) at 2 p.m. at 2 m above soil level, daily sum of precipitation (mm), relative air humidity (%) at 2 p.m., and daily sum of global radiation (J cm^{-2}) was obtained from weather stations of the Tea Research Foundation of Kenya.

The scatter diagrams and regression analysis of the observed and simulated data for the tea cropped plot are presented in Figures 2 and 3 respectively for soil minimum nitrogen content at 0-30 and 30-60 cm.

Figure 2: Comparison between observed and simulated soil minimum nitrogen content at 0-30 cm depth

Figure 3: Comparison between observed and simulated soil minimum nitrogen content at 30-60 cm depth

For both Figures, soil minimum nitrogen contents at 0-30 and 30-60 cm depths, the fit between observed and simulated data was more accurate in the lower than in the higher depth. Nevertheless, the medium correlation coefficients (above 0.4) between the simulated and measured soil minimum nitrogen content at 0-30 and 30-60 cm soil depths indicated that the calibration of the model was relatively accurate.

The other variable used in the calibration was soil moisture content. Nitrogen transport in the soil is strongly determined by soil water movement. The scatter diagrams and regression analysis of the observed and simulated data for the tea cropped plot during the monitoring period are presented in Figures 4 and 5 respectively for 0-30 and 30-60 cm.

Figure 4: Comparison between observed and simulated moisture content at 0-30 cm depth

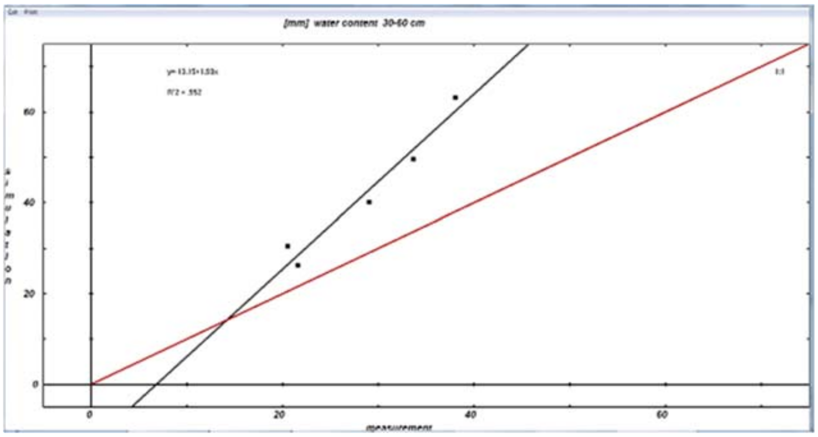

Figure 5: Comparison between observed and simulated moisture content at 30-60 cm depth

The clustering of the observed and simulated soil moisture around the 1:1 line and the high correlation coefficient (0.9) in Figure 5 indicate that the N-Vino model was quite accurate in simulating time changes of the soil moisture. The ability of the model to reproduce the soil water content with some degree of correctness determines the success in simulating N dynamics. From the Figures, simulation seems to overestimate the water content slightly throughout the whole simulation period and stronger in deeper layers. The simulation reveals a better match of simulated and observed water content in the 0-30cm depth.

Results and discussions

It is difficult to measure the depth and time distribution of fertilizer N which undergoes transformation in tea cultivation, therefore simulation studies were performed with N-Vino model. N-Vino was used to simulate the depth and time distribution of nitrogen in the root zone after it was validated using the measured data from the field experiment.

Mineral nitrogen content

The results of the soil minimum N simulations are presented in Figure 6. The monthly simulated soil profile nitrogen content (kg ha^{-1}) behaved almost the same way for depth 0-30 and 30-60 cm.

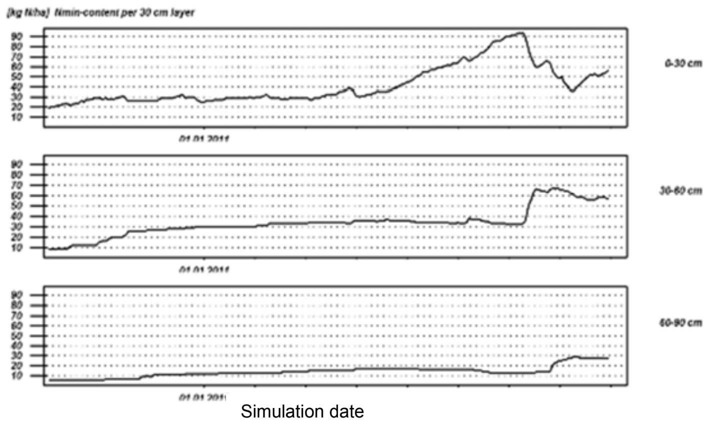

Figure 5: Monthly simulated soil profile minimum N content (kg ha^{-1}) between September, 2010 and August, 2011

For the top profile, simulated nitrogen content stagnated averagely at around 30 kg ha^{-1} from September, 2010 up to May, 2011 when it started rising almost linearly to 90 kg ha^{-1} at July, 2011 and later dropped gradually. For second profile of 30-60 cm, simulated minimum nitrogen content rose slightly from 10 to almost 30 kg ha^{-1} between September and October, 2010, stagnated averagely between 30 and 40 kg ha^{-1} from October, 2010 up to July, 2011 when it started rising sharply up to almost 70 kg ha^{-1} and later dropped slightly. The soil N dynamics show a pattern of increase in the top soil up to July, 2011, which might be due to N mineralization (Figure 9), and a subsequent translocation down the soil as per the second and third depths, where a part of it is consumed by tea roots. With a little time lag the behaviour in the top layer minimum N content affects the deeper layers as well, but not in the same order of magnitude. From this it can be concluded that the peak might be only a short-term mineralization flush, caused either by the organic or by any other external disturbance of the microbial biomass. The released nitrogen was then presumably immobilized again during the following month.

Water percolation

Water percolation in 200 cm depth was simulated as shown in Figure 7.

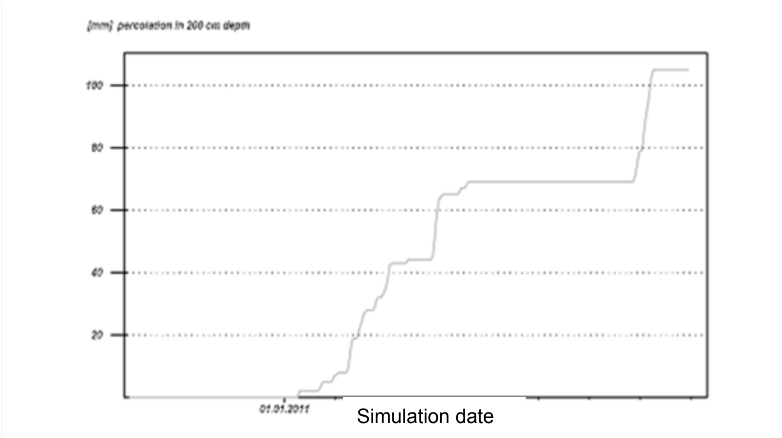

Figure 6: Monthly simulated percolation within 200 cm soil profile between September, 2010 and August, 2011

From the simulation there was no percolation from September, 2010 up to January, 2011 when it started rising gradually up to around 105 mm by August, 2011 with little stagnation after 40mm and extensive stagnation at around 70mm. The simulation did not show percolation at first, this might suggest that precipitation although high were proportional to plant water uptake.

Nitrogen leaching

N-leaching within 200 cm depth was simulated as shown in Figure 8.

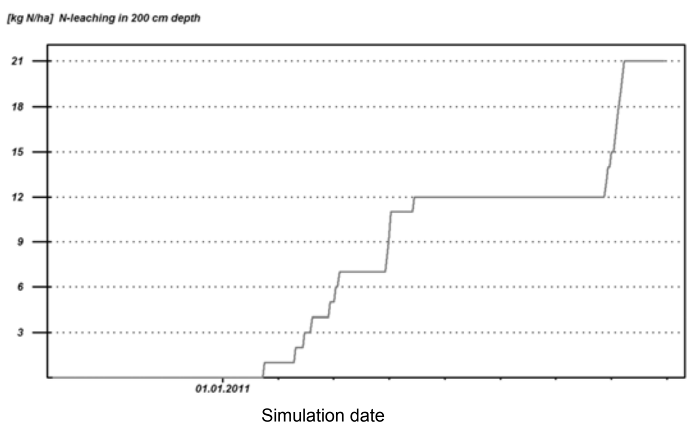

Figure 7: Monthly simulated leached N (kg ha^{-1}) within 200 cm soil profile between September, 2010 and August, 2011

From the simulation, there was no nitrogen leached from September, 2010 up to almost February, 2011 when it started rising gradually up to 21 kg ha^{-1} by August, 2011 with small stagnation along the simulated

leaching line up to 12 kg ha^{-1} where extensive stagnation occurs between April and July. The residual nitrogen in soil which is present in the form of nitrate is commonly lost through leaching (Figure 8), or denitrification (Figure 10), or a combination of these. Nitrate is easily dissolved in water and once it enters the water solution, it moves with the water, down into the water Table. Proper fertilizer management in terms of selection of fertilizer type, timing and method of application determines the availability of fertilizer N in the root zone for leaching (Prunty and Greenland 1997).

Nitrogen mineralization

Nitrogen mineralization was simulated as shown in Figure 9.

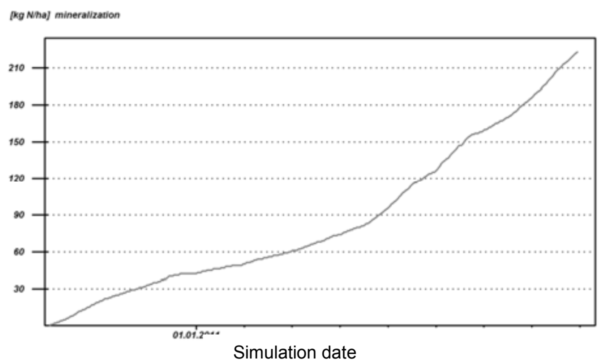

Figure 8: Monthly simulated mineralized N (kg ha^{-1}) within 200 cm soil profile between September, 2010 and August, 2011

From the simulation, nitrogen mineralization rose exponentially from zero at September, 2010 to almost 220 kg ha^{-1} at August, 2011.

Nitrogen denitrification

Denitrification of N per hectare was simulated as shown in Figure 10.

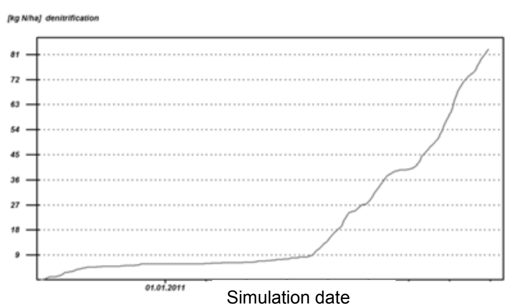

Figure 9: Monthly simulated N denitrification (kg ha^{-1}) within 200 cm soil profile between September, 2010 and August, 2011

From simulation, nitrogen denitrification rose very slowly up to 9 kg ha^{-1}at April and started rising almost linearly to 80 kg ha^{-1} at August, 2011.Figure 11 illustrates simulation behaviour of minimum nitrogen content for soil depth profile.

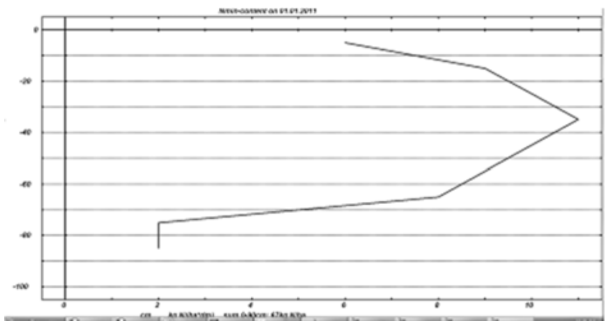

Figure 10: Simulated minimum N content (kg ha^{-1}dm^{-1}) along a 100 cm soil profile

Between surface and 10 cm, simulated nitrogen content was 6 kg ha^{-1}dm^{-1} and increased slowly up to 9 kg ha^{-1}dm^{-1} around 15 cm. It increased further drastically between 15 and 35 cm up to 15kg ha^{-1}dm^{-1}. Simulated nitrogen content along the depth profile started decreasing from 15 to 8 kg ha^{-1}dm^{-1} between 35 and 65 cm. It decreased further slowly between 65 and 75 cm from 8 to 2 kg ha^{-1}dm^{-1} then stagnated at 2 kg ha^{-1}dm^{-1} till end at 85 cm.

The increase in simulated nitrogen content between the soil surface and the 35 cm depth might have been due to leaching and accumulation of N fertilizers (Figure 11).

Conclusion

The following conclusion may be drawn from the results of the N-Vino N simulation in tea. As previously shown for cereals (Kersebaum, 1995), the validated model for *Camellia sinensis* as well produces sufficient results for practical use in tea fertilizer management. The plant growth sub model, simulated amount and dynamics of monthly nitrogen in tea giving a useful support for the description of the general nitrogen dynamics. Although tea nitrogen uptake varies from about 75 to 150 kg N ha^{-1}, N-mineralization and transport seem to determine the nitrogen dynamics mainly in tea land.

Acknowledgement

The study was carried out at the Tea Research Foundation of Kenya field with established tea, research facilities and personnel. C. Nendel, Germany Centre for Agricultural Landscape and Land Use Research provided the model and support. This research has been supported by the National Council for Science and Technology through a research grant.

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Economic suitability of selected phosphorus sources on soybean yield in central highlands of Kenya

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Abstract

Soybean is an important legume compatible with the smallholder farming systems in central highlands of Kenya. However, low P and N, which is prevalent in the central highlands of Kenya has limited its performance. This study assessed the economic suitability of different phosphorus sources in soybean production. The study areas were Kigogo in Meru County and Kamujine in Tharaka Nithi County. The trial was laid out in randomized complete block design (RCBD), having 13 treatments with four replications each on a 4.0 m by 4.5 m plot size. The P sources were Triple Super Phosphate (TSP), Minjingu rock phosphate, Mavuno fertilizer, diammonium phosphate (DAP), animal manure and fortified manure (animal manure with Minjingu fertilizer at 1:1 ratio) all providing 30 kg P ha^{-1}. Diammonium phosphate (DAP) was reference input as it has both P and N and was the farmers' choice in the study area. Data collected were biomass and grain yields and soybean and fertilizer market prices. Data was analyzed using analysis of variance (ANOVA) and means separated using t-test and Least Significant Difference (LSD) ($P<0.05$). The study used value cost ratio (VCR) to assess economic suitability of the various P sources. The most costly was CAN-Manure with the least being DAP at Ksh. 1583.31 (US $ 17.02) and Ksh. 273.06 (US $ 2.94) per kg of P, respectively. Therefore DAP was recommended with consideration for liming to address possible reduction in soil pH.

Key Words: Cost benefit analysis, economic suitability, P sources, ISFM, soybean production , Value Cost Ratio.

Introduction

Studies have shown that the central highlands of Kenya have negative nutrient balances (Gitari *et al.*, 1999; Maingi *et al.*, 2006; Mugendi *et al.*, 2010). To address this, several studies recommend the use of legumes for soil improvement (e.g. Dobereiner, 1997; Crews and Peoples, 2004; Albareda *et al*, 2009), incorporation of organic inputs (Place *et al.*, 2003), increased use of mineral fertilizer (Tilman *et al.*, 2002) and integrated soil fertility management (ISFM) (Sanginga and Woomer, 2009a, b; Chianu *et al.*, 2011) as possible solutions. Use of commercial fertilizers to address low fertility status in smallholder farmers remains minimal due to the high fertilizer prices (Crew and Peoples, 2004; Sanginga and Woomer, 2009a, b).

Few studies have assessed the locally available P sources in regard to their contribution to soil characteristics while addressing their cost effectiveness to soybean production in central highlands of Kenya. This study therefore assessed both mineral and organic P sources' contributions to the improvement of soil chemical characteristics and soybean yield while estimating biological N fixation. The study identified the least cost P sources in soybean production before recommending them to farmers in the study area and similar agro ecological zones. The study also assessed the relevance of using starter N for improved biological fixation and higher soybean yields.

Materials and methods

The study was conducted at Kigogo Primary School (00^0 23′ 08.6′′S, 37^0 38′ 0.3″ E) in Tharaka Nithi county and Kamujine site (00^0 06′19.4″N, 037^0 54′ 49.7′′E) in Meru County, in the Central Highlands of Kenya (Figure 1), respectively. Treatments were a combination of P sources with or without starter nitrogen totaling to 13 treatments including the control. The experiment was arranged in randomized complete block design. Treatments were replicated four times in plots measuring 4.0 m x 4.5 m, with a net plot area of 10.5 m ^{2}. Sources of P were Minjingu phosphate rock, Mavuno basal fertilizer, TSP, DAP fertilizer, manure only and fortified manure (manure + Minjingu phosphate fertilizer) each providing 30 kg P ha^{-1}. The manure used was a mixture of goat and cattle manure. Calcium Ammonium Nitrate (CAN) was the source of starter nitrogen. With DAP as a P source containing a substantial amounts of N (18%), it did not receive starter N. For this study, the amount of 10 kg N per ha was identified to be adequate as a starter N to effectively meet the requirement of the soybean crop at its initial stages before BNF can commence. This amount was chosen following as reported by Chen *et al*. (1992) and Starling *et al*., (1998) and the studies of Albareda *et al*., (2009) who had used 50 kg per ha and found that this amount reduced biological nitrogen fixation. On the other hand, Anon (2004) in Melekeberhan (2007) found that farmers in Brazil applied 8 kg ha^{-1} with crops improving BNF fixation.

To assess the profitability of the various P sources, value-cost analysis (VCR) was calculated and rated against the benchmark of VCR ≥2 for acceptable profitability (Heerink, 2005). The VCR of the different treatments was based on the 2011 and 2012 market values. Value-Cost ratio is defined as the sales value of the extra yield produced by using fertilizer divided by the cost of that fertilizer. Normally, a VCR of at least two is considered suitable, although a VCR of this level is risky if there is a danger of drought, disease or crop prices falling. In that scenario, a higher VCR of four is considered enough to mitigate the risks. It is given by the following formula:

$$\boldsymbol{VCR} = \left(\frac{\textit{Product Price}(Kg)}{\textit{Fertilizer Price}(Kg\ \ Nutrient)}\right) * \textbf{Fertilizer Response Rate } \boldsymbol{i.e.}\left(\frac{Kg\ Yield}{Kg\ Nutrient}\right)$$

In calculating VCR, data regarding market prices of the P sources, the prevailing market price of soybean and the yields of soybean from the various P sources in kg/ha was collected. Calculation of VCR used a conservative soybean price of Ksh. 60 (US$ 0.645), which was the market price of soybean in the region at the time of study.

Results

Tables 1 and 2 show the price attributes of various treatments in the study in the Long Rains Season of 2011 (LR 2011) and Short Rains Season of 2011 (SR 2011) respectively. Considering the price of P source per kg, TSP was the most expensive [Ksh. 455.10 (US $ 5.06)] with the least costly being manure [Ksh. 4.00 (US $ 0.043)]. In terms of cost per kg of P, manure however is a bulky and poor quality fertilizer, costing Ksh. 972.80 (US $ 10.46). The most costly source was CAN-Manure treatment with the least being DAP at Ksh.1583.31 (US $ 17.02) and Ksh. 273.06 (US $ 2.94) per kg of P, respectively. As a P source, TSP was the most expensive probably because of factors mainly related to market dynamics such as its international prices, international PR and H_2SO_4 supply, demand from major markets, transportation costs both in the high seas and inland, taxes and or lack of subsidies e.t.c. (Heerick, 2005; Cordell et. al., 2009; Vaccari, 2009; UNEP, 2011). Such costs are passed on to consumers (Beert, 2005). For this reason and due to its single nutrient supply, the fertilizer demand is low with few quantities ordered. The low orders in turn exercerbate its price. This is where DAP becomes a popular fertilizer for Kenyan farmers (Mutsotso *et al*., 2011). It is cheaper than TSP yet with nearly equal amounts of P per kg. Added to this, it also contains 18% N. The fertilizer has consistently improved yields making farmers demand more of it. Traders order more knowing their stocks will sell thereby increasing its availability and is cheaper due to competition and economies of scale (Chianu *et al*., 2011).

Table 1: Costs of various fertilizers and their corresponding soybean yields at Kamujine and Kigogo sites during the LR 2011 season

Treatment	Fert. used ha^{-1} (Kg)	Kamujine Yield (Kg)	Kigogo Yield (Kg)	Fert. Price	Unit(Kg)	Cost of $fert.ha^{-1}$ (Ksh.)	Fert. Price Kg^{-1}	Price of P Kg^{-1}	P used Ha^{-1}
Control	0j	714.9c	723.9b	0	0	0	0.00i	0k	0
CAN_Fortified	3810.96c	1332.4abc	951.8ab	9600	1100	33272.38b	8.73f	1109.08b	30
CAN_Manure	7334.46a	1184.7bc	1010.4ab	6800	1050	47509.07a	6.48g	1583.64a	30
CAN_Mavuno	267.46e	1957.0a	1123.5ab	5400	100	14523.84f	54.00d	484.13f	30
CAN_Minjingu	267.46e	1451.7ab	1130.3ab	5600	100	15061.76e	56.00c	502.06e	30
CAN_TSP	190.16g	1142.2bc	1046.0ab	7300	100	13991.18g	73.00b	466.37g	30
DAP	151.7h	1210.0bc	706.3b	2700	50	8272.80j	54.00d	275.76j	30
Fortified	3772.5d	1199.5bc	994.1ab	6800	1050	24441.14d	6.48g	814.70d	30
Manure	7296b	1269.4abc	1156.0ab	4000	1000	29190.00c	4.00h	973.00c	30
Mavuno	249f	1108.2bc	1123.5ab	2600	50	13026.00i	52.00e	434.20i	30
Minjingu	249f	1054.8bc	922.5ab	2800	50	14028.00g	56.00c	467.60g	30
TSP	151.7h	1098bc	961.3ab	4500	50	13788.00h	90.00a	459.60h	30
LSD	0.31	703.94	473.06	-	-	58.76	0	1.96	-

One USD = KES 93 (March 2011). Means with the same letter along the column are not significantly different

Table [illegible] various fertilizers and their corresponding soybean yields at Kamujine and Kigogo sites during the SR 2011

Treatment	Fert used ha^{-1} (Kg)	Kamujine Yield (Kg)	Kigogo Yield (Kg)	Fert. Price	Unit(Kg)	Cost of fert.ha^{-1} (Ksh.)	Fert. Price Kg^{-1}	Price of P Kg^{-1}	P used Ha^{-1}
Control	0j	542.5d	689.2cde	0	0	0	0.00i	0k	0
CAN_Fortified	3810.96c	1456.3a	837.0bc	9600	1100	33272.38b	8.73f	1109.08b	30
CAN_Manure	7334.46a	1235.6abc	938.6ab	6800	1050	47509.07a	6.48g	1583.64a	30
CAN_Mavuno	267.46e	1072.6abc	895.5ab	5400	100	14523.84f	54.00d	484.13f	30
CAN_Minjingu	267.46e	1106.6bcd	1084.5a	5600	100	15061.76e	56.00c	502.06e	30
CAN_TSP	190.16g	955.9bcd	7922.0bcd	7300	100	13991.18g	73.00b	466.37g	30
DAP	151.7h	1340.1ab	689.0cde	2700	50	8272.80j	54.00d	275.76j	30
Fortified	3772.5d	1179.1abc	782.8bcd	6800	1050	24441.14d	6.48g	814.70d	30
Manure	7296b	1224.9abc	558.9e	4000	1000	29190.00c	4.00h	973.00c	30
Mavuno	249f	1038.7abc	902.3ab	2600	50	13026.00i	52.00e	434.20i	30

One USD = KES 93 (March 2011). Means with the same letter along the column are not significantly different.

Manure was the cheapest P source because of its availability in farming sytems as a by-product of mixed farming. However, it has low quality, requiring large quantities for sufficient supply to meet crop nutrient requirements (Mugwe *et al*., 2007b). In Kigogo, manure was among the least responsive fertilizers (Table 1). Its use also increases cost of production, as more labour is required to apply it compared to other fertilizers (Place *et al*., 2003). When combined with CAN, it became the most expensive given CAN did not sufficiently improve yield to warrant its additional cost.

Table 1 shows response rates of various treatments to the yields of soybean in Kamujine and Kigogo. In Kamujine, during the LR 2011, CAN-Mavuno had significantly ($p<0.001$) higher response rates than all treatments except CAN-fortified manure, CAN-Minjingu and manure while CAN fortified was significantly ($p<0.001$) more responsive than CAN-TSP (31.86) and TSP (28.59) during the SR 2011. In Kigogo, during the LR 2011, mavuno had a significantly ($p<0.001$) higher response rate than DAP. In SR 2011, CAN Minjingu was significantly ($p<0.001$) more responsive than all treatments except CAN-manure, CAN-Mavuno and Mavuno treatments (Table 2). Treatments had higher response rates in Kamujine than in Kigogo.

Table 3: Fertilizer Response and VCR at Kamujine and Kigogo sites during the experimental period

Treatment	Kamujine				Kigogo			
	Fert. Response Rate		**VCR**		**Fert. Response Rate**		**VCR**	
	LR 2011	**SR 2011**	**LR 2011**	**SR 2011**	**LR 2011**	**SR 2011**	**LR 2011**	**SR 2011**
Control	[illegible]	0d	0g	0f	0c	0f	0d	0g
CAN_Manure	39.49b	41.19abc	1.50fg	1.56ef	33.68ab	31.29ab	1.28cd	1.19f
CAN_Mavuno	65.26a	35.76abc	8.08ab	4.43bc	37.45ab	29.85ab	4.65a	3.70bc
CAN_Minjingu	48.39ab	36.89abc	5.78bc	4.41bc	37.68ab	36.15a	4.50	4.32ab
CAN_TSP	38.07b	31.86bc	4.90cde	4.10bcd	34.87ab	26.40bcd	4.49a	3.40c
CAN Fortified	44.41ab	48.54a	2.40efg	2.63de	31.73ab	27.90bc	1.72c	1.51ef
DAP	40.53b	44.67ab	8.78a	9.71a	23.54b	22.97cde	5.12a	5.00a
Fortified	39.98b	39.30abc	2.95def	2.90cde	31.14ab	26.09bcd	2.44bc	1.92e
Manure	42.31ab	40.83abc	2.61defg	2.52de	38.53ab	18.63e	2.38bc	1.15f
Mavuno	36.94b	34.62abc	5.1cd	4.78b	39.89a	30.08ab	5.51a	4.16b
Minjingu	35.16b	38.69abc	4.51cde	5.00b	30.75ab	26.56bcd	3.94ab	3.41c
TSP	36.62b	28.60c	4.77cde	3.73bcd	32.04ab	20.40de	4.18a	2.66d
LSD	**23.17**	**14.55**	**2.70**	**1.70**	**15.05**	**6.63**	**1.69**	**0.72**

Means with the same letter along the column are not significantly different

The most profitable P source in Kamujine site was DAP (Table 3). Its value-cost ratio of 9.71 in SR 2011 was more than 2.43 times the recommended threshold value of 4.0 VCR considered profitable in risk prone African farming systems (Heerink, 2005). Given the minimum recommended VCR of two for returns to cost of input, CAN-Manure combination was unprofitable having VCR of 1.50 and 1.56 in LR 2011 and SR 2011, respectively (Table 3). In Kigogo site, only DAP, CAN-Minjingu PR and Mavuno met the high threshold of 4.0 VCR. Considering the lower threshold of two, CAN-fortified, CAN-manure in both seasons, and fortified manure and manure in SR 2011 were not profitable at this site.

The high response rate of CAN-Minjingu in Kigogo may have been due to the site's low P and micronutrients levels whose supply made crops respond well to it. Crops responded poorly to manure because of its low P levels and possible slow release rates of both the P and micronutrient levels (Vlek *et al*., 1997). The better response in Kamujine compared to Kigogo may be due to initial poor nutrient status in Kamujine than in Kigogo (Results not shown). Being also cheaper and higher yielding, and with high amounts of N and P, in a site where both are deficient, DAP had among the highest response rates and making it the most profitable fertilizer in Kamujine. Manure on the other hand was not profitable due to its low response, its high cost per kg of P and its rather low yields compared to other treatments. Addition of CAN in manure compounded its cost factor. Kigogo site may have have responded better with P than with starter N because it already had sufficient soil N but poor in P, and micronutrients (Cu, Mg and Fe). Soybean requires these nutrients in large amounts and so their faster delivery by DAP (P), CAN-Minjingu PR and Mavuno (N, P, K and micronutrients) made them profitable in that site. With increased availability of P and micronutrients, crops may have demanded more N and so fertilizers that also included N ensured adequate nutrient supply to crops.

Conclusion and Recommendation

Use of TSP for Soybean production was not economically advantageous over other sources of P. The cost of CAN-Fortified manure was also prohibitive. Using DAP was most economical and therefore the fertilizer was recommended for use while considering its acidifying effects through liming and supplementing with organic amendments

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Applicability of hand-held X-ray fluorescence analyser for rapid characterisation of soil elemental compositions

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Abstract

Chemical analysis is a crucial but often expensive and time consuming step in the characterisation of soils. Laboratory analysis has many chemical, physiochemical and physical methods that can be used to characterise and evaluate soil fertility and quantify pollutants. Developments in analytical techniques have enhanced the use of multi-nutrient extractants, allowing for a shift towards multi-element analyses, and a decrease in detection limits by several order of magnitude. Chemical methods are being replaced by reliable physical or physiochemical methods that are more sensitive, faster and more selective, making it possible to determine the very low concentrations of elements. One such technique is hand-held X-ray fluorescence (HHXRF) spectroscopy which can provide information about the quantities of individual elements in soil that are essential for the growth of crops such as copper and those that may be undesirable such as lead. This paper describes how HHXRF analysis can provide results comparable in accuracy with total element composition measured using a bench top X-ray fluorescence (TXRF) method for various elements, with the possibility of either replacing or enhancing them. The results indicated that determination of element concentrations in soils with HHXRF were comparable for most elements with those of total element concentrations measured using total X-ray fluorescence spectroscopy (TXRF). Compared with the TXRF technique, the HHXRF method determined total element concentrations of the elements Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn and Pb accurately (model slope close to 1:1 line, and R2 > 0.80) over a wide range of soil samples while V could not be estimated with an acceptable precision (R2 < 0.65) compared with TXRF. Thus, HHXRF could be used to directly analyse total element composition of soils in the field and on prepared samples and may provide a basis for low cost soil chemical characterisation and mapping.

Introduction

Nutrient contents in food are determined by their content level and availability in soils on which the food plants are grown; the amounts and quality of soil organic- and mineral matter. Soil clay minerals strongly influences the water holding capacity and the supply of nutrients while the amounts of micronutrients in the soil affect plant growth and the nutritive value to consumers. Hence, under conditions of nutrient deficiency in soil, the content in food crops can be increased by the application of fertiliser. However, in spite of increased use of fertilisers, more nutrients are being removed annually from the soil than the amount applied as mineral fertilisers, especially in the less developed parts of the world, where nutrient balance is likely to remain negative (Vijayakumar *et al.*, 2011). A dysfunctional food system that cannot deliver enough essential nutrients to meet the requirements for plants, human and animals may easily result in a global crisis in malnutrition. Cost-effective methods for the direct analysis of soil in the field and on prepared samples for mineral and total elemental compositions could be applied to achieve an economical detailed screening analysis and mapping of soils across individual fields.

Conventional multi-element techniques for determination of soil and plant element compositions such as the inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectrometry (ICP-AES) have been used for routine determinations. However, the conventional methods are not without problems for determination of various elements, and thus, there is need for new,

rapid, low cost and for routine testing or screening tools for diagnosing soil micronutrient deficiencies for crop, livestock and human health. Recent developments of the X-ray Fluorescence (XRF) technology have made this technique suitable for on-site analysis (miniaturisation of XRF systems [X-ray tube], the optimisation of the calibration programmes and the improvement of the detectors [Holschbach-Bussian and Vanhoof, 2010]). The XRF technique relies on the fluorescence at specific energies of atoms that are excited when irradiated with X-rays and the detection of the specific fluorescent photons enables the qualitative and quantitative analysis of elements in a sample (Viscarra Rossel *et al.,* 2011). Portable, hand-held XRF technology has become popular as an analytical approach in the environmental community, particularly for rapid measurement of metal contaminants (Viscarra Rossel *et al.,* 2011). For example, Palmer *et al*. (2011) used field-portable XRF analysers for rapid screening of toxic elements in FDA-regulated products and demonstrated in their work that XRF analysers are an exceedingly valuable tool for routine and nonroutine elemental analysis investigations, both in the laboratory and in the field. The United States Environmental Protection Agency (US EPA) has tested hand-held energy-dispersive X-ray fluorescence (EDXRF) systems on their capability for the on-site analysis of heavy metals in soils and sediments (USEPA, 1998; Stosnach, 2005). Because the sensitivity and energy resolution of these instruments is technically limited a second approach for field-portable benchtop X-ray fluorescence (XRF) systems was started by the US EPA (USEPA, 2007; Stosnach, 2005).

Recent instrument improvements have increased the quality of measurement results. The Bruker S1 Turbo SD LE hand-held X-ray fluorescence (HHXRF) spectrometer (Bruker AXS GmbH) is commercially available as a rapid, specific mining instrument or as an additional calibration suitable for other similar type of materials, such as cement and minerals, ceramics, glass (mid-density matrix), restricted materials, multi-purpose calibration, and soil calibration and thus should be a method of choice but needs further testing and validation for possible "in situ" measurements. The Bruker S1 Turbo SD LE HHXRF spectrometry has the potential to provide information about the quantities of individual elements in soil that are essential for the crops (e.g. copper) and those that may be undesirable (e.g. Lead).

This paper demonstrates that HHXRF analysers are valuable tools for routine and non-routine elemental analysis investigations, both in the laboratory and in the field, with emphasis on the use of a battery driven hand-held Bruker S1 TURBO^{SD} LE spectrometer. The S1 Turbo SD LE instrument features an improved light element performance (Mg, Al, Si), but the factory "mining" calibration models (GeoChem Trace and Geochem General) are empirical and are based on standards, which are representative of samples to be measured. The factory calibration covers 41 elements namely Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Ce, Hf, Ta, W, Pt, Au, Hg, Pb, Bi, Th, and U, and reports only the elements in the calibration as matrix with less accuracy. Therefore, due to the complex nature of the universal calibration, it is important to check the feasibility of the application with soil and plant samples.

The objectives of this study was to:

- develop and test an analytical method for the direct quantification of total element concentrations in soils using the Bruker S1 TURBO^{SD} LE spectrometer
- test the ability to validate against total element composition measured using a bench top X-ray fluorescence (TXRF) method for a range of elements using a set of soil samples and standard reference materials

Materials and methods

Ninteen soil samples were selected based on the Kennard-Stone sample selection algorithm (Kennard and Stone, 1969) using a principle component analysis (PCA) of Total X-ray Fluorescence (TXRF) total element concentration data from a set of 603 samples associated with the Africa Soil information Service (AfSIS) project (www.africasoils.net), taken from nineteen 100-km^2 stratified random sites across Africa (AfSIS, 2013). The soil samples were selected from a wide range of soils in the sub-Saharan Africa tropics

and textures as well as elemental ranges and used to develop a generalisable approach. The soil samples were air-dried and passed through a 2-mm sieve. Five grammes of the air-dried soil was sub-sampled and ground to less than 73 micron using an RM 200 Retsch grinder. The samples were analysed using a battery driven light weight Bruker S1 TURBO^{SD} LE hand held X-ray Fluorescence (HHXRF) spectrometer and an S2 Picofox TXRF spectrometer (Bruker AXS Microanalysis GmbH, Germany).

The S1 TURBO^{SD} LE spectrometer from Bruker used in the current study contains an X-ray tube which irradiates the sample and using a thin film ultralene window, detection of light elements such as Mg, Al and Si is possible. In addition, the S1 TURBO^{SD} LE can be conFigured with calibrations that are optimised for a variety of materials-including a wide range of soil samples. The principle of the HHXRF technology is based on the fact that the incident rays eject electrons from the atoms of the elements in the sample, resulting in the emission of X-rays with energies that are characteristic of the elements present. The emitted rays are analysed using a silicon drift detector. The results are immediately displayed and stored. The hand held results are obtained utilising a devise that would hold the gun rather than have an operator hold it. This approach eliminates human error and creates an optimum setting, since an operator may not always keep the gun extremely still during the measurement period. The S1 TURBO^{SD} LE provides rapid and accurate analysis on elements such as Calcium (Ca), zinc (Zn) etc. and restricted elements such as lead (Pb), mercury (Hg), chromium (Cr), and cadmium (Cd) at part per million levels; however quantification of elements depends on the X-ray source and sample matrix.

For HHXRF analysis the 73 micron ground samples were loaded in to a Fluxana 32 mm double open ended sample cup covered on one end with a 4 µ polypropylene X-ray film, by scooping several spatula-full of the soil to half-fill a sample cup (about 5 g soil). The sample cup was closed on the open end with a lid then placed over the ultralene examination window and IR proximity sensor. The sample compartment was covered using a lid to prevent scattering of X-ray radiation. The S1 TURBO^{SD} LE trigger at the back of the instrument was pulled to begin analysis. Measurements were conducted for 120 s using the Geochem general Method.

For TXRF analysis a further milling to 20-53 µm using a McCrone micronising mill for all the samples was done. For validation purposes, 45.0 mg of each milled sample were weighed in clean-labelled vials and 2.5 ml of aqueous Triton X 100 solution added into the vial followed by internal standard of 40 µl of 1000 ppm Se solution using a pipette. The mixture was agitated to a homogenous solution, which involved placing them in a water bath and applying Sonics for 15 min. This was followed by pipetting 10 µl of the suspension onto the centre of siliconised quartz sample carrier and dried for about 5 min on a hot plate at 50° C to form a thin film of sample. Twenty-four loaded sample carriers were assembled onto a sample cassette where 1ppm mono-element standard was placed in the first position for gain correction. The samples were then analysed using an S2 Picofox TXRF spectrometer (Bruker AXS Microanalysis GmbH, Germany) and quantified using a deconvolution routine (SuperBayes) of the SPECTRA software which uses measured mono-element profiles for the evaluation of peak intensities (Bruker, 2007).

In addition, four certified reference materials; montana soil, check soil, soil 7 and river clay soil were also analysed in a similar procedure using the two techniques for validation purposes. Regression and multivariate analyses were performed using R statistical software (R Development Core Team, 2013).

Results and discussion

The soil samples were measured using the two spectrometers, and the relative abundance of each line was determined (Figure 1). The HHXRF technique offers a rapid measurement (in 1-2 minutes) compared to 10-13 min with the TXRF method. The X-ray fluorescence lines of the individual elements were stored in the instrument software in the form of an atomic library and later identification of the elements was done by an interactive comparison of the observed spectra lines and measured spectrum.

Percent recovery values were examined using two standard reference materials (soil 7 and river clay soil) taking into consideration the elements K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn and Ga (Table 1). There was a wide recovery range observed for the TXRF spectrometer between 38 and 189%, in average around 96% for Soil 7 and 33-121%, average 81% for River clay, respectively (Table 1). Similarly, the percent recovery ranged widely for the HHXRF determined results for the elements Mg, Al, K, Ca, Ti, Cr, Mn, Fe, and Cu ranging from 58 and 110%, in average around 80% for Soil 7 and one and 103%, in average 64% for River clay, respectively (Table 1).

Table 1: Percent recovery values calculated for two standard reference materials (Soil 7 and River clay soil) measured using TXRF and HHXRF spectrometers

	Soil 7			River clay		
Element	Ref value (ppm)	Txrf Value (ppm)	% recovery TXRF	Ref value (ppm)	Txrf value (ppm)	% recovery TXRF
K	12100	11844.3	97.9	23725.5	19500	121.7
Ca	163000	198726.6	121.9	15419.6	13800	111.7
Ti	3000	2170.3	72.3	3764.5	4300	87.5
V	66	41.4	62.8	48.3	80.9	59.7
Cr	60	42.3	70.5	66.9	89.6	74.7
Mn	631	476.6	75.5	794.1	1000	79.4
Fe	25700	21713.6	84.5	26941.8	29700	90.7
Ni	26	49.3	189.8	30.9	37.9	81.7
Cu	11	4.2	38.3	12.9	20.1	64.4
Zn	104	74.1	71.2	79.4	96.1	82.7
Ga	10	17.4	174.4	4.4	13.6	32.6
Av. (%) recovery			96.3			80.6
Element	Ref value %	HHXRF value %	% Recovery	Ref value %	HHXRF value %	% Recovery
Mg	1.1	0.7	64.5	0.9	0.5	59.1
Al	4.7	4.2	88.4	5.9	3.2	54.4
K	1.2	1.3	110.5	2.0	2.0	103.6
Ca	16.3	16.5	101.0	1.4	1.3	96.9
Ti	0.3	0.2	66.0	0.4	0.3	73.5
Cr	0.0	0.0		0.0	0.0	1.1
Mn	0.1	0.0	58.1	0.1	0.1	64.7
Fe	2.6	1.9	72.2	3.0	2.2	73.0
Cu	0.0	0.0		0.0	0.0	49.8
Av. % recovery			80.1			64.0

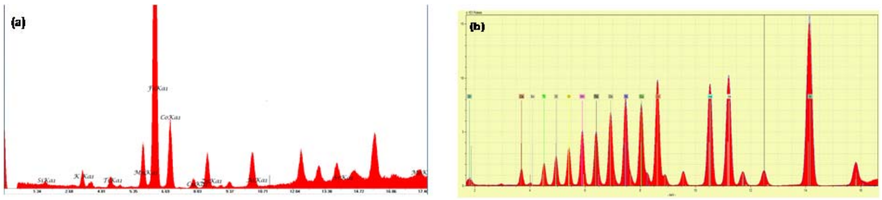

Figure 1: Spectra of a soil standard reference material (SRM) measured using (a) the HHXRF and (b) the S2 PICOFOX TXRF spectrometer showing peaks and the abundance of each line determined for all elements

The results indicated that the HHXRF spectrometer results were comparable for most elements to those of the total element concentrations measured using the TXRF technique (which was recalibrated using the international standard method - ICP-MS as described by Towett *et al*. 2013) (Table 2). Some elements were either over- or underestimated using the HHXRF compared to the TXRF methods. However, on performing a regression of the HHXRF and TXRF results, compared with the TXRF technique, the HHXRF method determined total element concentrations of the elements Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, and Pb accurately (model efficacy/slope close to 1:1 line, and $R^2 > 0.80$) over a wide range of soil samples (Figure 2). Vanadium could not be estimated with an acceptable precision ($R^2 < 0.65$) compared with TXRF and was generally somewhat underestimated (Figure 2). These results are expected because the HHXRF instrument has been recalibrated using the TXRF analytical results and the TXRF is as good as ICP-MS for elements such as Ti, V, Ca, Vr, Mn, Ni, Zn, Pb and Fe (Towett *et al*., 2013). Values of R^2 close to one indicate that MIR is almost as good as the TXRF and ICP-MS techniques against which it is calibrated. Soil matrix recalibration and additional appropriate adjustments of the soil matrix calibration to improve the accuracy of the results of the HHXRF instrument may be done using TXRF results as reference data for Cu, and Zn and additional reference results using ICP-MS are required. It is necessary to optimise the calibration of the HHXRF instrument using a variety of soil materials with a wide range of possible matrix effects. Thus the HHXRF instrument recalibration is currently a work in progress.

In addition, samples used for HHXRF and TXRF analyses required minimal treatment and only a few grams of powdered, air-dry soil were required. Better analyses were obtained if samples were ground to less than about 50 microns particle size, but re-designed systems may avoid this and its associated costs, especially for field analysis. This use of a dry soil sample was advantageous in that expensive and toxic chemicals were not required, and artificial solutions used in some conventional extractions methods were avoided.

Table 2: Analytical results (in mgkg^{-1}) measured using HHXRF and TXRF for a set of 19 soil samples from across sub-Saharan Africa as well as 4 soil standard reference materials (SRMs)

Sample names	HHXRF Results										TXRF Results										
	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Pb	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Ga	Pb
icr002590	20400	14600	67	72	1680	59200	66	0	64	34	28299.4	12763.4	126.8	323.6	1384.5	60734.4	96	41.5	82.4	12.9	83.9
icr010038	2320	10800	67	181	1990	82500	89	12	64	0	2668.3	13212.3	152.2	128.6	1481.2	76700.5	110.3	47.7	69.2	11.2	109.9
icr010118	1090	10400	67	156	2260	79700	85	21	47	32	587.3	11660.1	119.5	77.3	1775.8	64166.6	96.5	49.1	40.1	12.5	109
icr011067	4280	7120	67	148	1410	82500	0	17	47	0	7756.7	6653.8	253.4	104.3	1401.8	111205.2	39.4	71.3	31.3	8.2	287.4
icr011164	1030	5430	308	371	1050	172000	0	0	47	107	858.6	4045.1	357.9	358.3	198.5	181690.6	9.7	37.7	16.4	0.2	639.1
icr011321	1760	11900	67	262	1380	114000	0	3	48	36	1490.6	8810.9	267.5	149.9	852.6	123895.3	14.5	51.8	25.9	4.8	303.2
icr014408	7170	4800	67	94	2080	45000	0	0	65	0	11910	3461.4	40.3	34.3	1568	39407.9	15	13.3	64.9	15.4	51.6
icr015472	1690	3090	67	0	387	13700	0	0	39	0	1264.8	2546.5	6	36.4	221.5	12956.7	6.7	7.7	16.2	9.3	11.6
icr023393	508	6170	67	32	588	34000	29	0	48	0	605.2	4739.7	35.2	75.7	288	27425.5	41.2	14.1	32.1	10.1	12.9
icr023433	2750	1660	67	0	369	7980	0	0	35	26	2930.3	1277.2	11.6	9.3	183.5	6086	3	5.6	11.3	5.6	20.3
icr023731	2770	1310	67	0	267	6030	0	0	37	47	3073.3	933.2	8.4	5.9	78.9	4279.5	1.7	3	7.7	7.6	36.9
icr030083	9060	17600	67	159	2080	79000	0	0	54	34	11240.4	16685.5	17.3	102.8	2051.1	83850.8	47.3	23.3	63.1	17.7	210
icr033407	17900	4200	67	0	784	24000	0	0	41	0	28262.3	4221.1	1.9	64.4	771.2	27380	20.3	17.4	34.2	12.3	11.6
icr033466	22100	3150	67	0	587	15800	0	0	35	0	36499.6	4603.7	1.4	49.5	668.3	23015.9	15	13.9	31.3	12.9	19.6
icr033714	10500	5000	67	0	692	31400	94	0	50	0	6505.9	10.1	1.1	1.1	53.8	82.3	8.2	2.6	2.6	0.2	0.5
icr049556	4380	4460	67	3	445	32700	20	0	59	0	5947.8	4304.7	46.6	82.6	210.8	34479.6	36.9	28.6	56.3	12.2	53.6
icr049655	2440	3550	67	0	382	30100	17	0	58	0	3967.6	3252.6	40	76.8	129.8	30829.3	34.6	22.4	53	12.3	28.1
icr049735	2240	3980	67	0	446	38400	0	0	52	0	3492	3417	40.5	80.8	122.4	40858.2	25.4	22.4	51.5	11.2	47.5
icr049755	2450	3710	67	0	379	28400	18	0	57	0	4497.6	3391.1	41.8	68.5	125.1	29201	40.3	28.8	52.9	10.9	31.3
Montana Soil	7070	2900	67	0	1530	32800	0	2390	1680	1900	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
River Clay	9320	3160	67	0	756	21200	0	0	57	0	13800	4300	80.9	89.6	1000	29700	37.9	20.1	96.1	13.6	ND
Soil 7	290000	4360	67	0	1220	30500	0	0	102	75	198726.6	2170.3	41.4	42.3	476.6	21713.6	49.3	4.2	74.1	17.4	ND
Soil check	3730	2940	67	8	2660	19100	0	113	271	312	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Key: ND = not determined																					

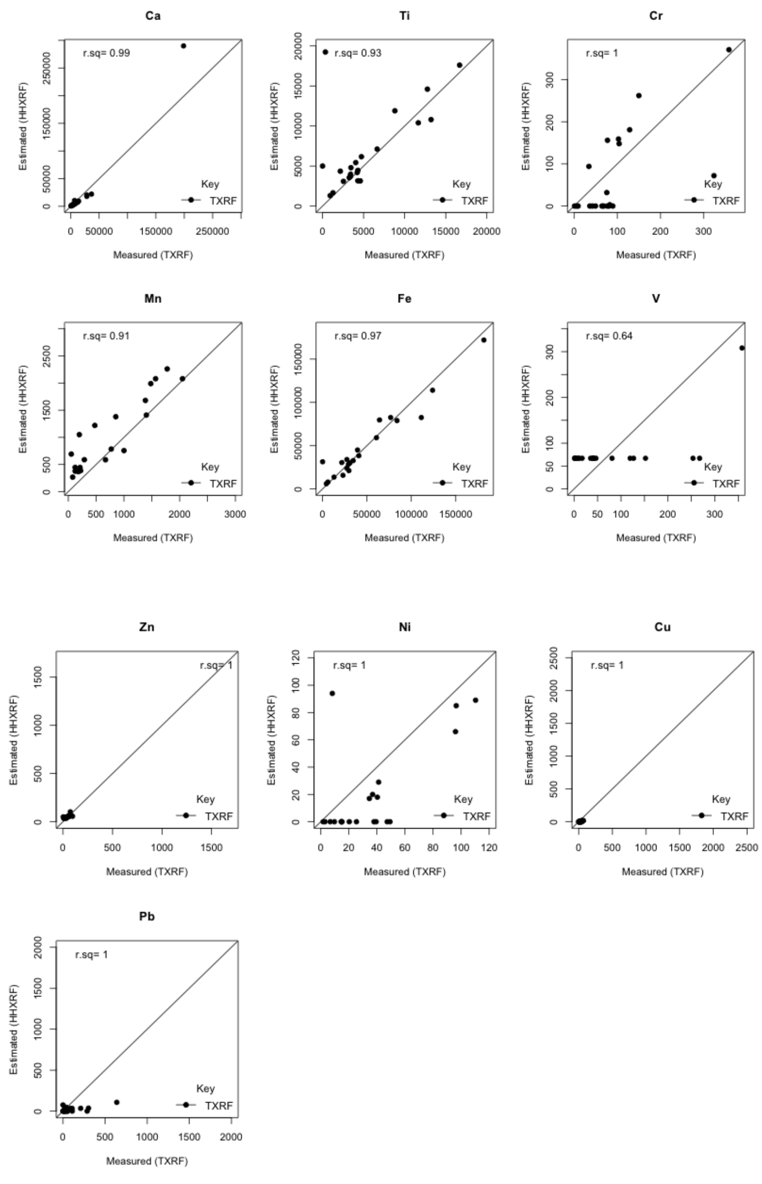

Figure 2: Total element concentrations (in mg kg^{-1}) measured using HHXRF versus concentrations estimated using TXRF for 19 soil samples used in this study

Conclusion

Hand-held XRF is a major innovation to an already important analytical technology and has been shown to be capable of detecting and determining total elemental compositions of soil samples. In addition, it offers a rapid measurement (1-2 min). XRF analysis is potentially much cheaper and faster than conventional soil testing, and a single spectrum can provide, simultaneously, useful information on total element compositions for multiple elements. On the basis of the results, it can be concluded that HHXRF spectrometry is suitable for the rapid on-site determination of selected elements, both heavy metals and light elements in screening processes. However, there were underestimations of all the elements analysed using the HHXRF instrument compared to the results measured using the desktop TXRF spectrometer indicating that the HHXRF instrument recalibration is necessary. Thus, it is necessary to optimise the calibration of the instrument using a variety of soil materials with a wide range of possible matrix effects. The matrix calibration of the handheld XRF instruments has an important effect on the quantification of the elements detected meaning that for specific samples an appropriate adjustment of the matrix calibration is required to improve the accuracy of the results. With proper calibration and sample preparation, the HHXRF technique will give quantitative results. Use of X-ray films with highest transmission percentages such as Proplene and ultralene to provide optimal analysing conditions for low atomic number elements such as Na and Mg is recommended.

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Utilising soil fertility replenishment measures for nutrient use efficiency in maize production in western Kenya

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Abstract

Soil acidity and fertility depletion, particularly nitrogen (N) and phosphorous (P) are major limitations to food production in sub-Sahara Africa. This on-farm experiment was done to determine the nutrient use efficiencies in maize production. Ten farmers were involved from each of Trans-Nzoia, Uasin-Gishu and Siaya Counties in Kenya. Fertiliser application rates were 75 kg N ha^{-1} plus 26 kg P ha^{-1}. The plots were arranged in an incomplete randomised block design and all the yield data subjected to one-way analysis of variance. The initial soils characterisation indicated that the soils were low in soil pH, available P (<10 mg P kg^{-1}), total N (<0.2%) and organic carbon(<4.0%). The agronomic nutrient use efficiency of nitrogen and phosphorous was in diamonium phosphate + lime treatment at an average of 14.41 kg grain/kg P and 5.14 kg grain/kg N while it was lowest in Minjingu plots at an average of 11.60 kg grain/kg P and 4.02 kg grain/kg N. Although there was no significant ($p<0.05$) effect, DAP + lime plot still gave the highest mean yields recorded at 5.56 t ha^{-1} while the Rotuba with ½ DAP plots had the lowest yields among the plots with treatments at a mean of 4.83 t ha^{-1}. There was no significant ($p<0.05$) difference in the yields of the treatments but there was a significant difference between the treatments and the control plots realising a mean of 1.75 t ha^{-1}. In conclusion, agronomic studies have shown that DAP does not perform better alone but increase yields when applied together with lime. In the experiments, DAP + lime or MPR + CAN performed better in both grain and stover yield. I would recommend that more studies be done to study the current relevance of DAP in farming in western Kenya in order to find ways to enhance its productivity.

Key words: soil acidity, nitrogen, phosphorus, rotuba, lime.

Introduction

Soil fertility depletion has been identified as the major cause for declining per capita food production in sub-Sahara Africa with the original fertile soils yield of 2-4 bags per hectare of maize into infertile soils hardly exceeding one bag per hectare (Ayaga 2003). In Kenya, main causes of low and declining maize yields are soil acidity and nutrient deficiencies. Nitrogen is a vital plant nutrient and a major yield determinant for maize production (Adediran and Banjoko, 1995).

Nutrient use efficiency is defined as yield per unit input. Various measurements have been used to assess the efficiency of nitrogen (N) and phosphorus (P) to determine crop response (Cassman *et al.*, 2002; Hussein, 2009). This is based on the difference in crop yield and total nutrient uptake above ground biomass between fertile and infertile control plots (Dobermann, 2005)

Mineral fertilisers tend to be rapidly solubilised to forms assimilated by plants while organic inputs have to be mineralised first then subjected to plant uptake or less from the soil. Nitrogen is limiting to crop production lost through uptake and removal by crops, volatilisation, leaching, denitrification and loss from soil surface through runoff. It is replenished through use of inorganic fertilisers, biological nitrogen fixation (BNF) and use of organic materials (Stoorvogel and Smaling, 1990)

Soil acidity causes manganese (Mn), iron (Fe) and aluminium (Al) toxicities to plant roots, low levels of basic cations; potassium (K), calcium (Ca) and magnesium (Mg) and deficiencies of nutrients like

manganese and boron (Eswaran *et al.,* 1997). Now that nutrient depletion has been the major cause of poor nutrient use efficiency hence affecting maize crop yield hence need for nutrient depletion to be addressed. This has been dealt with using Integrated Soil Fertility Management (ISFM) to replenish soil nutrients which involves application various soil fertility management options for productive and sustainable agro ecosystems to improve the agronomic nutrient use efficiency. This has led to low and unsustainable crop productivity in these soils. Nonetheless, substantial interventions to improve soil fertility have been done, especially in sub-Sahara Africa.

These have yielded crop increases, for example in western Kenya, where maize staple yield increases of 3-5 t ha^{-1} per season are as a result of fertiliser or with its combinations with organic inputs at on-farm level. However, most farmers, particularly smallholders who constitute about 90% of the farming communities, have not adopted the technologies.

The study aimed at improving adoption of fertilisers in maize production. Famers could choose from several recommended fertiliser options including chemical (Di-ammonium phosphates (DAP), $(NH_4)_2HPO_4$), organics and phosphate rocks. Because of the complexity in influencing adoption of the fertiliser recommendations by farmers, multidimensional strategies need to be used to influence farmers' decision making. Field trials were used to act as farmer field schools (FFS) which is an effective tool to extend knowledge to farmers (Pontius *et al.,* 2002).

The study was based on the broad objective of improving nutrient use efficiency in maize production for sustainable yields through use of fertilisers. The other objectives were to determine the effects of various treatments on soil pH, available P, organic carbon and total N, to determine the agronomic nutrient use efficiencies with respect to the various treatments applied and to determine the best combination of the inputs that gives maximum yields.

Materials and methods

Description

Soil acidity is attributed to the abundance of hydrogen (H+) and Aluminium (Al3+) cations in soils, at levels that interfere with normal plant growth. Soil acidity causes reduced maize yields on nearly 40% of the total arable land (Gudu *et al.,* 2005). In Kenya, 13% of the total arable land, covering about 7.8 million hectares is acidic. This covers the high agricultural potential areas characterised by high altitudes and high rainfall (Kanyanjua *et al.,* 2002). Western Kenya in particular has acidic and P-deficient soils occupying about 0.9 million hectares of land on which about 5million people cultivate (Woomer *et al.*,1997).

Study sites

To achieve the objectives, on-farm experiments were conducted in Siaya County (0°30″ and 0°20″N and 0°34″ and 34°30″E at 1140-1400 m) with bimodal rainfall distribution pattern encouraging two growing seasons in a year. The area is characterised by a mean minimum temperature of 15-17° C with a mean maximum of 27-30° C.The soils are developed from basalt volcanic rocks with the predominant soil being ferrasols, nitisols and acrisols.

Uasin-Gishu County (0°30′S and 0°55′N and 34°50′ E and 35°37′W at 1500-2100 m) receives 900-1100 mm rainfall which is unimodal and mean annual temperatures of 22° C.

The soils developed on intermediate volcanic and basement rock system with predominant soil types as nitisols, ferralsols and acrisols. Trans-Nzoia (0°52″and 1°18″ N and 34°38′ and 35° 23″E experiences highland equatorial climate with average fairly annual distributed rainfall of 1296 mm. The soils are deep, red and friable clays and sandy clays derived from the basement complex. Black cotton soils occur along Koitobos River in the Endebess plain (Jaetzold and Schimdt ,2006).

Experimental design and layout

Test maize H6210 suitable for Trans-Nzoia and Uasin-Gishu Counties and H513 were planted in an incomplete randomised block design (Figure 1).

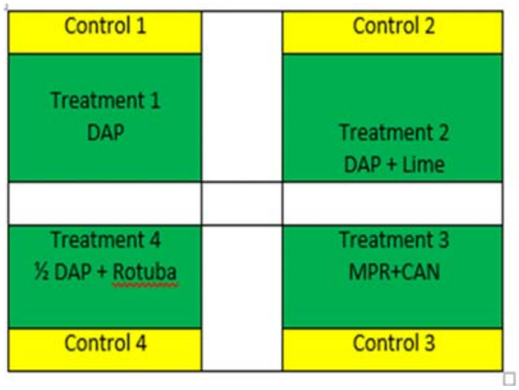

Figure 1: The experimental layout

Treatments were applied at 75 kg N ha^{-1}, 60 kg K ha^{-1} and 26 kg P ha^{-1} (FURP, 1994). Lime at 2 t ha^{-1} was also used (Kisinyo, 2011). MPR was applied at a blanket rate of 60 kg K ha^{-1} in all plots.

Results and discussion

The soils in Trans-Nzoia, Siaya and Uasin-Gishu were strongly acidic (pH 4.5 -5.0) with low total N content (<0.2% N), low organic carbon content (<0.4%C) and deficient in P (<10 mg P kg^{-1}) (Table 1).

Table 1: Initial soils characterisation

Soil parameters	Siaya	Trans-Nzoia	Uasin-Gishu
Soil Ph	4.84-5.06	4.50-4.62	4.75-5.16
Available P(ppm)	1.57-1.98	1.41-1.76	1.54-1.86
Total N (%)	0.15-0.17	0.17-0.19	0.16-0.18
Organic carbon (%)	1.32-1.65	1.57-1.82	1.49-1.77

Soil available P was low due to high rate of fixation caused by Al^{3+} and Fe^{3+} ions present in the acidic soils. The organic carbon was low due to continuous cultivation of land without nutrient replenishment. Burning of vegetation before tillage as a land preparation measure also contributing towards the low organic carbon content (Okalebo *et al.*, 2002).Since most N is derived from organic matter mineralisation, then low organic matter has also contributed to low soil N. The low N and P contents may also be due to inadequate fertilisers (Okalebo *et al.*, 2002).

After, DAP + lime had the highest contents of organic carbon content because lime reduces concentrations of H^{+}, Fe^{3+} and Al^{3+} ions responsible for soil acidity (The *et al.*, 2006). Phosphorus was also highest in this plot since lime decreased the exchangeable Al^{3+} ions that resulted to reduced sorption of the applied and the available P in the soil. Soil pH was greatly increased but Total Nitrogen remained constant in all the plots at 0.16% N. Plot 4 had the lowest pH and available P content while plot 3 had the lowest organic carbon content.

Organic carbon was generally low in all the sites and since it is a precursor of soil N, the total N content was generally low and was constant in all the treatments at 0.16%.

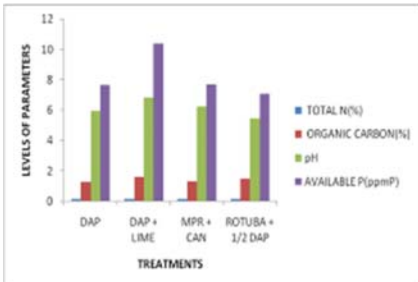

Figure 2: Effect of the various treatments on soil pH, available P, total N and organic carbon

The applications on agronomic nutrient use efficiencies showed DAP + lime having a significant effect ($p \leq 0.05$) in both agronomic P use efficiency (APUE) and agronomic N use efficiency (ANUE) by the grain giving a mean of 14.41 kg of grain per kilogramme P and 5.14 kg of grain per kilogramme N, respectively, followed by DAP at 13.26 of grain per kilogramme P and 4.60 of grain per kilogramme N then Rotuba at 12.20 of grain per kilogramme P and 4.28 of grain per kilogramme N and Minjingu which had the lowest effect on both APUE and ANUE had 11.60 of grain per kilogramme P and 4.02 of grain per kilogramme N (Figure 2).

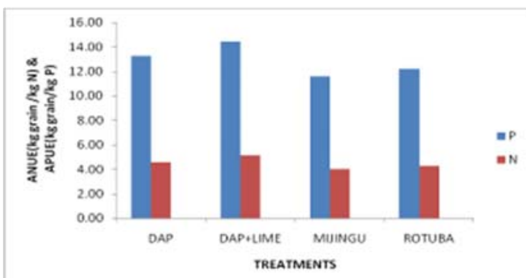

Figure 2: Effect of the various treatment applications on agronomic nutrient use efficiencies

The plot with DAP + lime had the highest yields at 5.564 t ha^{-1} followed by DAP (5.23), Minjingu (4.90), Rotuba (4.82) and the control (1.75).

Conclusion

The treatments enhanced seedlings growth which led to production of large cobs as compared to the control plots. The plot which recorded the highest yields was DAP + lime plot which had a mean of 5.56 t ha^{-1} while the lowest yield was in the control plots at 1.75 t ha^{-1}. This is because lime ameliorated the adverse soil conditions hence enhanced utilisation of nutrients hence increased crop yields. The initial low nutrient levels (N, P and organic carbon) and the high soil acidity are the major causes of low declining maize grain yield as evidenced by the wide difference in yield between the yield in the controls and the plots with treatments.

The DAP + lime treatment had the best combination as per the response to the soil chemical properties analysed: soil pH, organic carbon, total N and available P. It also gave the best response to the agronomic

N and P use efficiencies however, there was no significant ($p<0.05$) effect at between the treatments but there was a significant effect between the treatments and the control plots.

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Effect of selected soil amendments on growth and yield of beans in acidic Nitisol of Nyeri County, central Kenya

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Abstract

Common bean (*Phaseolous vulgaris* L.) is one of the most important grain legumes in Nyeri District. Dry grain yields have remained low (0.22-0.3 t ha) due to several biotic and abiotic factors. The main abiotic constraints are deficiency of nitrogen (N), phosphorus (P) and low soil acidity. This study was conducted to determine the effect of one-time application of organic and inorganic soil amendments on the soil pH. The treatments used were lime at 2 t ha^{-1}; Kelphos fertiliser at 375 kg ha^{-1}; diamonium phosphate (DAP) at 200 kg ha^{-1}; manure at 4 ha^{-1}; manure at 4 ha^{-1}+ Kelphos 375 kg ha^{-1}; manure at 4 ha^{-1}+ DAP 200 kg ha^{-1}, lime at 2 t ha^{-1} + DAP at 200 kg ha^{-1}, lime at 2 t ha^{-1} + Kelphos at 375 kg ha^{-1} and control. The experiment was laid out in a randomised complete block design with three replications. The after harvest soil analysis of the topsoil in each of the plots showed increase of soil pH by 0.27-0.78 units with lime and kelphos and manure contributing to the highest increase in that order. Above-ground dry biomass yield increased significantly than the control with lime + DAP having the highest yield followed by Kelphos, lime 4.17 and manure at 4.14 ha^{-1}. Dry grain yields increased from 0.66 ha^{-1} (control) to 1.83 ha^{-1} (lime + DAP), lime + Kelphos 1.6 ha^{-1} and manure 1.58 ha^{-1}. Manure gave the highest return to cost of amendment at 558.80% followed by lime with 420.28% and lime + DAP with 251.45%. Manure is recommended as amendment option for production of beans in acidic soils of Nyeri district.

Key words: acid soils, amendments, bean yield.

Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the most important grain legume that is grown for consumption and accounts for 50% for the grain legume consumed in the world (Wortman *et al.,* 1998). There are 55 known species in the genus Phaseoulus and five of these have been domesticated (Broughton *et al.,* 2002). In Kenya and most of eastern and central Africa, common bean is the most important legume. It is commonly grown by small-scale farmers as an intercrop with maize and as a monocrop.

The average annual production of common bean in Kenya stagnant at an average of 0.524 t ha^{-1} for the last 30 years (FAO, 1997). A six-year production trend (2004-2009) for Nyeri District indicates that the yield remained low at an average of 0.22 t ha^{-1} for intercrop and 0.30 t ha^{-1} for monocrop (DAO Nyeri, 2010). Low soil fertility is one of the limiting factors to bean production (FURP, 1994). In central Kenya highlands, continuous cropping without adequate nutrients replenishment is a major cause of low soil fertility (Kanyanjua *et al.,* 2002). Soils in the upper midland zone II and III are also inherently acidic with a pH of 3.4-5.5 (FURP, 1987). Beans are very sensitive to acidity and perform well only at pH 6.0 and 7.0 (FURP, 1994). The major causes of soil acidity in Kenya is high aluminium saturation and Ca and Mg deficiency (FURP 1987), (Kihanda and Gichuru, 1999). Application of lime and other ameliorating materials to raise the soil pH to levels where the crop performance is optimised is an important requirement. When this is done in combination with organic and inorganic fertilisers, there is a large increase in crop yield (Kihanda *et al.,* 2013).

The objectives of the trial was to evaluate the effect of organic and inorganic fertilisers on selected soil chemical properties and growth and yield of beans.

Materials and methods

The experiment was conducted at the Wambugu Agricultural Training Centre (ATC) 0°25 05′ and 36°57 E at 1710 m in agroecological zone upper midland II [UM2]). The soils are humic nitisols (UNESCO, 1977) well drained, extremely deep, dusky red to dark reddish brown nitisol with friable clay and an acidic humic top soil. The soil pH in water (1:2.5) is 4.8- 5.5 while base saturation is 10-20%. Cation exchange capacity (CEC) is 8-25 Cmol (+) and soil organic carbon is 25-33 t ha (FURP, 1987). The area receives an average annual rainfall of 928 mm while the temperature is 12.9-28.7° C. There are two cropping seasons, March to June (long rains) while the short rains are October to December (Jaetzold *et al*., 2006). The major agricultural activity is the surrounding area in mixed farming with coffee, dairy and maize production as the major enterprises.

Experimental materials

Agricultural lime. The agricultural lime was sourced from Athi River mining lid and it is a very fine grade product with retention of less than 15% on BSS mesh 100. It is highly soluble with a high acid neutralising value and a bulk density of 1.428-1.72 g / cc contains $CaCO_3$ (>75%) $MgCO_3$ (10%), S1 O_2 (0.50%).

Kelphos fertiliser. Kelphos is a basal single super phosphate fertiliser which contains 19% P_2O_5 (16% water soluble), 11% Sulfur and 21% CaO.

Cattle manure. The cattle manure used was-well decomposed and was sourced from the ATC's Zero grazing Unit. It had N = 0.70%, P = 0.36%, K = 1.58%, Ca = 0.79, Mg = 0.06%.

Diamonium phosphate. DAP (18-46-0) is a water soluble ammonium phosphate salt.

Bean variety KTX-56 which is determinate (35-40 cm high), with a potential grain yield of 1.4-1.8 t ha^{-1} was used as a test crop.

There were nine treatments -- DAP applied at 200 kg ha^{-1} of the fertiliser, Kelphos (SSP) applied at 375 kg ha^{-1}, Agricultural lime at 2 t ha^{-1} , Cattle manure at 4 t ha^{-1} , Cattle manure at 4t ha^{-1} plus DAP at 200 kg ha^{-1}, Cattle manure at 4 t ha^{-1} plus Kelphos at 375 kg $ha^{-1,}$, Agricultural lime at 2 t ha^{-1} plus DAP at 200 kg ha^{-1}, agricultural lime at 2 t ha^{-1} plus Kelphos at 375 kg ha^{-1} and the Control

Agricultural lime was broadcast and incorporated prior to cutting the bean furrows. Kelphos and DAP were drilled on the furrows and incorporated into the soil. Cattle manure was evenly spread on the furrows and thoroughly mixed with the soil. Planting furrows were made based on the recommended spacing of 0.5 m between rows and 0.10 m within the row (one seed per hill) giving a plant population of 200,000 ha^{-1}. All agronomic practices including weeding, insect control and rogouing were carried out as recommended.

The experiment was carried out during the long and the short rains. In both seasons the experiment was laid out as Randomised Complete Block Design (RCBD) with three replications. Data were recorded in the central two rows in an area of 1.0 × 1.5 m^2.

Select soil chemical analysis were determined at the start and the end of the experiment. These were:

- Soil pH in water (1:25)
- Soil P determined colorimetrically after extraction for 30 minutes and 1:20 w/v soil reagent ratio with 0.5 m $NaOHCO_3$ and adjusted to pH 8.5 (Anderson and Ingram, 1993)
- Total N in the soil and farmyard manure using the wet acid oxidation method as outlined by Bremner and Mulvaney, (1982).
- K by methods outlined by Anderson and Ingram (1993).

Data collection and analysis

Data were collected on:

- Soil parameters: these included changes in soil pH, P, N, K. The result on the soil analysis are expressed as a difference between the initial nutrient status at the start and at the end of the experiment
- Plant parameters included: plant height, flowering percentage, number of pods per plant, no of seeds per pod, above ground biomass and final grain yield
- Economic analysis was done by first computing the gross margin and finally return to cost of amendment

Data was analysed using the Statistical Package for Social Scientist (SPSS) soft were version 17.0. Means were separated using Duncan New Multiple range test at 0.05 percent confidence level.

Results and discussion

Soil characteristics

Soil pH.

In all the treatments, except the control and DAP, there was a significant increase in the soil pH within the three months the crop was in the field (Figure 1). Kelphos alone had the lowest increase of the soil pH of 0.25 while lime alone had the highest increase of 0.70. When the treatments were combined, there significant changes in soil pH for example, when lime was used in combination with Kelphos, there was an increase of 0.78 units but the increase in soil pH was significantly (P= 0.05) lower when lime was used in combination with DAP.

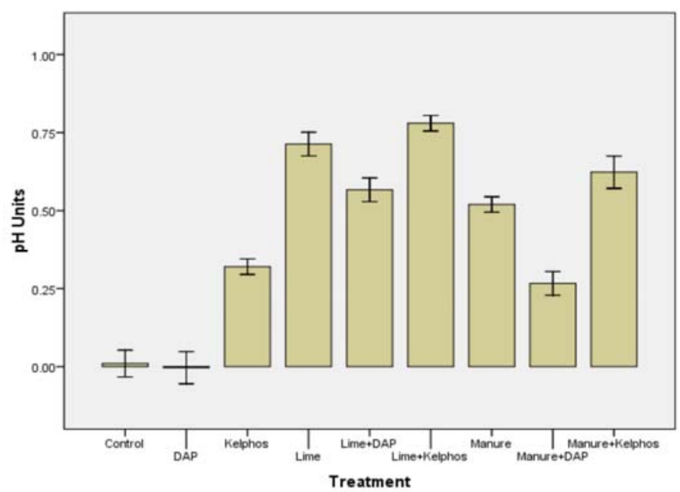

Figure 1: Changes in soil pH

The results indicate that inorganic and organic amendments either alone or in combination can increase the soil pH in one growing season. The main cause of low soil pH was high exchangeable H^+ although lime is an excellent source of N and P, it reduces soil pH due to the release of H^+ in the soil solution (Islam *et*

al.,1980). Application of lime, Kelphos which is high in CaO is able to neutralise H+ in the soil solution (Okalebo, 2002).The mechanism of manure reducing soil acidity is believed to be through complexation of organic residues with the H^+ (Murwira, 1994).

Soil P. The initial P in the soil solution was 69 ppm. At the end of the growing season the levels of P in the soil showed marked difference (Figure 2). This was attributed to addition of P to the soil and also plant uptake and fixing or release from the soil matrix. The results showed that after the growing season there were significant ($\alpha \leq 0.05$) changes in P levels in all the treatments.

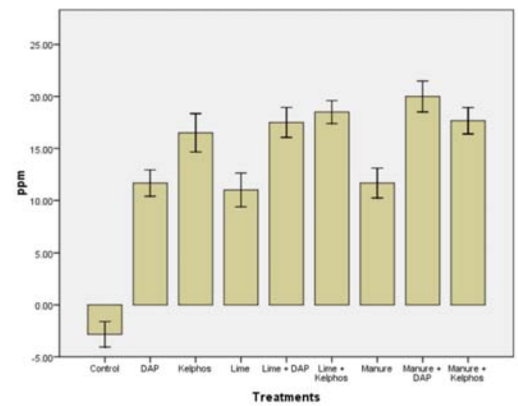

Figure 2: Changes in P levels as influenced by various treatments

The change in the level of P in plots treated with lime, DAP and manure were not significantly different. Lime, kelphos and manure increased the P by similar amounts while the highest increase in plots that received lime and kelphos. There was increase in P levels upon treatment of the soil with both organic and inorganic amendments when compared to the control. The control reported a decrease which could be attributed to plant uptake. Since Lime did not add P to the soil, the increase in the nutrient can be attributed to release of fixed P as lime increased the soil pH. The plots treated with Kelphos, Lime+DAP, Manure + Kelphos had means that were not significantly different. The means of manure + DAP and Lime + Kelphos were also not significantly different.

This increase could be attributed to release of the fixed P as the pH increased. Similar results were reported by Omenyo *et al.* (2010). Kelphos added more P to the soil than DAP though DAP has almost double the amount of P. This can be attributed Kelphos having had double effect on the soil. It increased the soil pH thereby increasing solubility of P due to its liming ability and also direct addition of P to the soil. Diamonium phosphate has acidifying effect on the soil and P is fixed at reduced pH. When DAP was used in combination with lime and also in combination with manure it increased P levels significantly similar to what was observed by Ndungu *et al.* (2003).

Nitrogen. The treatments had varied effect on the balance of N in the soil solution (Figure 3). The pre-planting level was 0.172% which was low. Soil total N content decreased in all the plots where the treatments did not add N to the soil. There was no significant (at $\alpha \leq 0.05$) difference in N reduction between the control and plots receiving Kelphos and lime. In plots that had N, there was slight increase in N in the topsoil. Manure increased the N level by 0.0240 ppm and DAP by 0.0350, which was the highest. Combination of manure + DAP increased level of N by 0.0263 ppm, manure + Kelphos 0.0282 ppm and lime + DAP by 0.0333 ppm. The results agree with those of Warren and Kihanda (2001). The means in the

plots treated with lime and Kelphos were not significantly different. Likewise, the means of plots treated with manure, manure + DAP and manure + Kelphos were not significantly different.

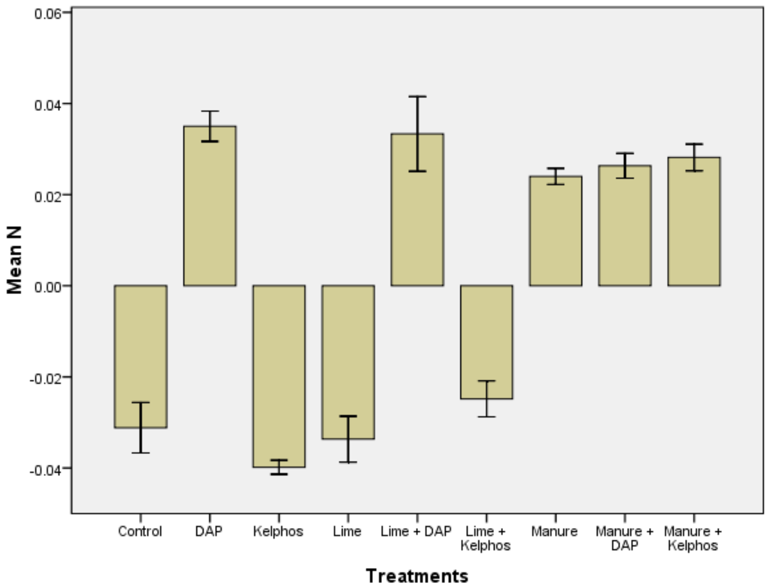

Figure 3: Changes in total nitrogen level as influenced by different treatments

Potassium levels. There were generally slight changes in K levels in the soil after harvest (Figure 4). Except for the manure treatments, the rest did not have significant effect on the level of potassium in the soil. There was a slight decrease in plots treated with manure Kelphos (-0.0262 ppm), DAP (-0.0140 ppm), Lime (-0.0222 ppm) and the control (-0.0192 ppm). There was a slight increase in manure plots (0.0344 ppm), manure + Kelphos (0.0370 ppm) and manure + DAP (0.0329 ppm). The three increases were, however, not significantly different.

Soils are generally well supplied in K and it is not a key ingredient in most inorganic fertilisers. However, manure analysis showed an adequate supply of potassium. Potassium is not a critical nutrient for beans since it is not deficient in soil and application of it is not likely to lead to increase in yield.

Plant height at 45 Days after Sowing (DAS)

Control, DAP and lime applied alone had significantly lower plant height at 45 DAS than other treatments. Plots treated with kelphos had the longest plants.

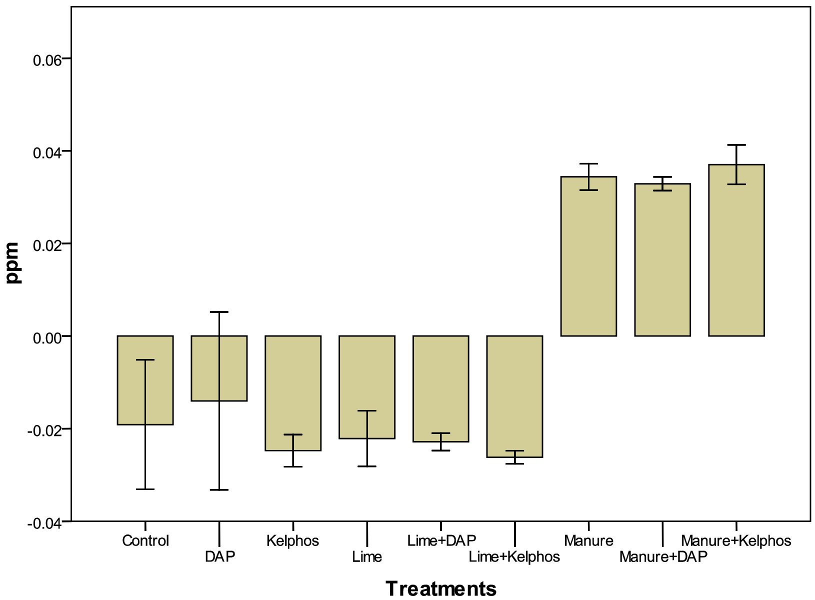

Figure 4: Changes in K levels as influenced by various treatments

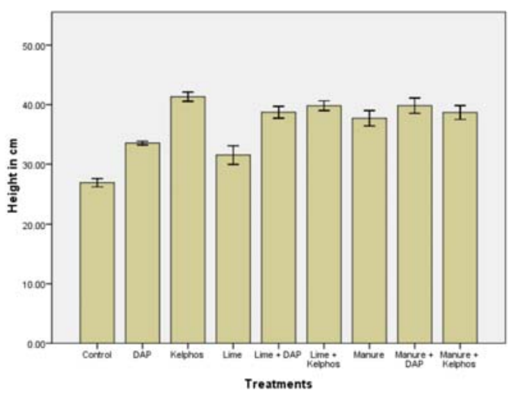

Figure 5: Height of plants 45 DAS as influenced by various treatments

Yield components

Number of pods per plant. Figure 6 shows the means of the effect various treatments on the number of pods per plant. The control had significantly (p=0.05) the least pods per plant than the rest of the treatments. The control had mean of 8.3 pods per plant compared to a 12,1 and 12.7 for plots treated with manure and lime, respectively. A combination of lime and DAP gave significantly (p=0.05) higher number of pods per plant (16.5) than the rest of the treatments.

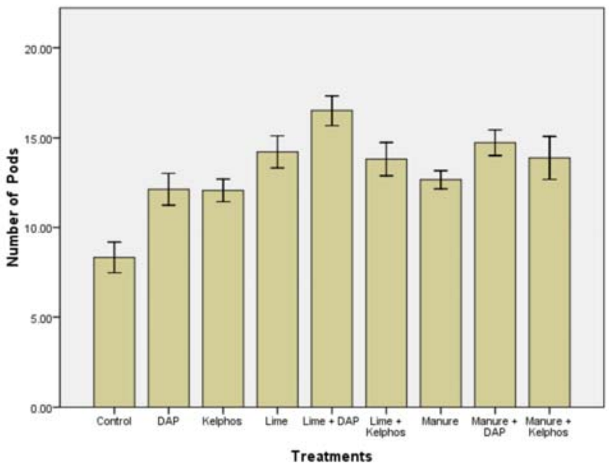

Figure 6: Number of pods per plant as influenced by various treatments

Biomass yield. The above-ground biomass yield was the total of the vegetative part and grains weight. Figure 7 shows the biomass yield for the various treatments. The control had significantly (p=0.05) lowest biomass yield (2.32 t ha^{-1}) than the other treatments. The highest biomass yield was produced by lime + DAP with 4.4 t ha^{-1} followed by Kelphos with 4.28 t ha^{-1}, lime with 4.18 and 4.14 t ha^{-1}. Diamonium phosphate had a low yield of 3.2 t ha^{-1}. Plant biomass from plots treated with manure, lime, Lime+Kelphos and Manure+Kelphos were not significantly (p=0.05) different.

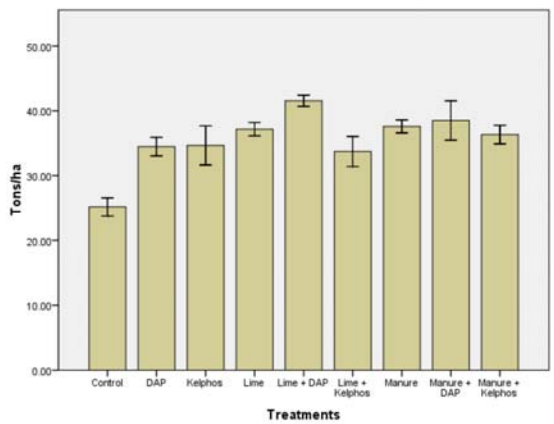

Figure 7: Biomass yield as influenced by various treatments

Grain yield. All the treatments significantly increased the dry grain yield (Figure). The lowest grain yield was recorded in the control while the highest yield was in the plots treated with lime + DAP at 1.83 t ha^{-1}. The results are consistent with those obtained by Kihanda (2013). The performance of Lime + DAP was followed by that of lime + Kelphos at 1.65 t ha^{-1}.

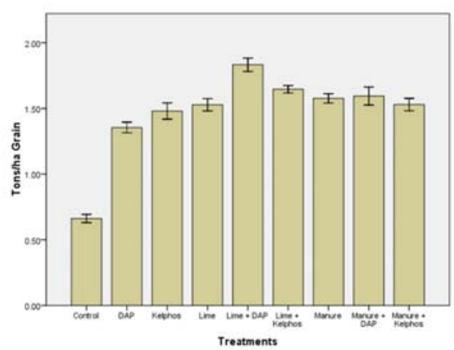

Figure 8: Grain yield as influenced by various treatments

The control yield in the control plots of 0.66 t/ha was higher than the average yields in Nyeri of 0.22-0.3 t ha^{-1}.

Economic analysis. Table 1 shows the gross margin (GM), accruing from the treatments. Lime + DAP had the highest GM (KES 107,990.40) followed by manure (KES 103,522.40) while lime (KES 98,076.60) was third. The control ranks the lowest (KES 47,642.40). Return to cost is calculated by subtracting the GM of the control from the GM of the treatment(s) and dividing this by the cost of the amendment. The result of this shows that Manure alone gave the highest return at 558.80% followed by Lime with 420.28%, with

DAP coming third with 315.9% (Table 2). The high returns from manure and lime were also reported by Kihanda *et al.* (2013) and Baraza *et al*. (2010).

Table 1: Economic analysis

Treatment	Treatment levels	Unit cost (KES)	Cost of Treatment	Grain yield (t ha^{-1})	Value of yield KES	GM (KES)
Control	-	-	-	0.6617	47,642	47,642.40
DAP	200 kg	60.0	12,000	1.3550	97,560	85,560
Kelphos	375 kg	42	15,750	1.4800	106,560	90,810
Manure	4 t	2.50	10,000	1.5767	113,522.40	103,522.40
Manure + DAP	4t + 200 kg	62.50	22,000	1.5950	114,840	92,840
Manure + Kelphos	4 t + 375 kg	44.50	25,750	1.5300	110,160	84,410
Lime	2 t	6.0	12,000	1.5283	110,076.60	98,076.60
Lime + DAP	2 t + 200 kg	66.0	24,000	1.8332	131,990.40	107,990.40
Lime + Kelphos	2t+ 375 kg	47.0	27,700	1.6467	118,562.40	90,862.40

The price of beans in Nyeri Market (May, 2011) is Kes 6,500 for 90 kg bag

Table 2: Return to cost of amendment

Treatment	Cost of treatment	GM (KES)	GM of treatment-GM of control	% return to investment of the amendment(s)
Control	-	47,642.40	-	-
DAP	12,000	85,560	37,917.60	315.90
Kelphos	15,750	90,810	42,537.60	274.08
Manure	10,000	103,522.40	55,880	558.80
Manure + DAP	22,000	92,840	45,197.60	205.443
Manure + Kelphos	25,750	84,410	36,767.60	142.79
Lime	12,000	98,076.60	50,434.20	420.28
Lime + DAP	24,000	107,990.40	60,348	251.45
Lime + Kelphos	27,700	90,862.40	43,220	156.0

Conclusion

- Lime, Kelphos and manure either alone or in combination raised soil pH by 0.3 to 0.8 units
- Soil amendment with lime, Kelphos and manure improved P availability by 10-20 ppm but changes in total N and K were variable
- The same amendments improved crop growth, crop biomass and final grain yield. The highest grain yield was obtained from plots receiving lime and DAP
- Economic analysis showed that it is profitable to amend acidic soils and the returns to investment puts manure as the best amendment for small-scale farmer.

Acknowledgement

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THEME 3: CROP /SOIL LIVESTOCK INTERACTIONS

Nutrient management practices for vegetable production in smallholder crop-livestock farming systems in the peri-urban areas of semi-arid eastern Kenya

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Abstract

Declining soil fertility is one of the major factors contributing to the current low productivity of crops in the crop-livestock production systems in the semi-arid areas of Kenya. This study was conducted in the peri-urban areas of Machakos and Wote towns in semi-arid Eastern Kenya with the aim of identifying nutrient management practices currently used in the smallholder crop-livestock production systems, with a view to developing appropriate nutrient management strategies for enhancing the productivity of vegetables. The target population consisted of smallholder farmers owning at least one dairy cow. In the peri-urban areas of Machakos town, a total of 60 farmers were interviewed while in the peri-urban areas of Wote town, 56 farmers were interviewed using structured questionnaires. An overwhelming majority of the households were male-headed, literacy levels were high and freehold system of land ownership was the most prevalent. The two major vegetables grown in the areas were kale and tomatoes. Farmyard manure was the principal source of nutrients for vegetable production. The use of inorganic fertilizers was low due to high cost. The two main methods of manure application were placement in the furrows and planting pits. Shortage of labour for transporting manure to the fields was the main constraint to its utilization. It was concluded that since farmyard manure is the main source of nutrients for vegetable production, enhancing integration of crop-livestock system has the potential to sustainably increase the productivity of the farms. There is also a need to sensitize farmers on the use of organic sources of nutrients other than farmyard manure and compost in combination with inorganic sources in order to optimize all aspects of nutrient cycling.

Key words: crop-livestock production systems, farmyard manure, productivity, soil fertility, smallholder farmers, nutrient cycling

Introduction

The semi-arid areas of Kenya are inhabited by smallholder farmers whose economy is mainly dependent on crop and livestock production. There is a strong interaction between livestock and cropping activities. Livestock provide manure and draft power for crop production while cropping activities provide crop residues for livestock feed. Livestock are also sometimes sold to raise cash for purchasing farm inputs. However, there is a significant conflict between livestock and soil fertility enhancing activities as crop residues which could be returned to the field to reduce runoff and provide nutrients for future crops are used as livestock feed.

Increased population pressure on the land has led to intensive cultivation without adequate replenishment of nutrients, leading to depletion of soil nutrients, hence the decline in soil fertility. In most of these areas, the soils have low organic matter content and are deficient in nitrogen and phosphorus (Nadar and Faught, 1984; Okalebo *et al.*, 1992; Gachimbi *et al.*, 2005).

Population growth in the urban areas, mainly as a result of people migrating from rural areas to seek wage-earning employment, has increased demand for livestock products, particularly meat and milk, and fresh vegetables. The increase in demand has, in turn, triggered a rise in the prices of these livestock products and fresh vegetables. This scenario has created an opportunity for the peri-urban smallholder vegetable farmers to increase their incomes and improve their livelihoods if appropriate nutrient management technologies are adopted to increase productivity.

The purpose of this study was to identify nutrient management practices currently used for vegetable production in the smallholder crop-livestock production systems in the peri-urban areas of Machakos and Wote towns in semi-arid Eastern Kenya, with a view to developing/identifying appropriate nutrient management strategies for enhancing the productivity of vegetables.

Materials and methods

The survey was conducted in the peri-urban areas of Machakos and Wote towns in Machakos and Makueni counties, respectively. Machakos town is the main urban centre in Machakos county while Wote town is the main urban centre in Makueni county. Machakos town (37°27'E; 1°52'S) is situated in the Upper Midlands (UM) 4 at an altitude of 1700 m while Wote town (37°37'E; 1 °47'S) is in the transition zone between Lower Midlands (LM) 4 and 5 at 1100 m (Jaetzold and Schmidt, 2006). Both have a bimodal rainfall pattern, which is almost evenly distributed between the the long and the short rains. The average annual rainfall for Machakos town is 767 mm while that for Wote town is 601 mm. In the two areas, the mean annual temperature ranges from 21 to 24 ^{0}C.

The major soil types in the two areas are Luvisols, Acrisols, Cambisols and Ferralsols. They are well-drained and their texture ranges from sandy clay to clay loams (Jaetzold and Schmidt, 2006). They have a tendency to harden when dry, but friable when wet and have low organic matter content, mainly due to the poor growth of the natural and human-modified vegetation and the removal of crop residues for livestock feed. They are shallow and hence have a low water-storage capacity, are generally acidic (pH 5.0 to 6.5) in the surface horizons; have a poor nutrient status, especially nitrogen and phosphorus; are saline and calcareous; and, due to poor structural development, are highly erodible and prone to surface sealing and capping through the energies of high-intensity rainfall and solar radiation (Muchena, 1975; Mbuvi and van de Weg, 1975).

Data collection and analysis

The survey covered 15 km radius around the two urban centres whose population consisted of smallholder farmers owning at least one cross-bred or high grade dairy cow. Proportional stratified sampling method was used and was based on geographical location of households within the urban centres. For this purpose, each site was divided into four clusters relative to the town; north, south, east and west. Farmers were selected from each of the four directions. Sixty and 56 farmers were interviewed from both the peri-urban areas of Machakos and Wote towns using structured questionnaires between February and July 2010. Data were collected on socio-economic characteristics of the farmers, their major sources of income, types of vegetables grown, sources of nutrients for vegetable production, methods of managing and application of manure, frequency of manure application, constraints in manure application and sources of information on vegetable production.

The collected data were coded and entered in a spreadsheet and analyzed using the Statistical Package for Social Sciences (SPSS) version 12.0 for windows (SPSS, 2003). The results are presented using descriptive statistics, tables and graphical illustrations.

Results and discussion

Socio-economic characteristics of the farmers

The socioeconomic characteristics of farming households are important. They influence farming decisions, choice and adoption of agricultural technologies (Omiti *et al.*, 1999). The socioeconomic characteristics of the farmers in the two areas are shown in Table 1. Male-headed households were more than female-headed ones (96.7% in Machakos and 91.1% in Wote). Literacy levels in both areas were high. The proportion of household heads with secondary education and above was 78.0% in Machakos and 85.5% in Wote. Thus the likelihood of uptake of new technologies for vegetable production is high as level of education has been shown to be positively correlated to adoption of improved technologies (Omiti *et al.*, 1999). Freehold land ownership was more prevalent in both areas (69.0% in Machakos and 87.3% in Wote) while ownership under customary law was 31.0% in Machakos and 12.7% in Wote.

The average farm size was 25.7 acres in Wote and 9.6 acres in Machakos. The larger average farm size in Wote may be attributed to the more recent settlement in the area. The average size of household was 4.2 and 4.6 in Machakos and Wote, respectively. A typical household consisted of a husband, wife and children. The size of a household could influence labour availability for various farm operations, e.g., transportation of manure. The household members involved in farming activities were 56.6% in Machakos and 50.2% in Wote. The main source of food for the households in Machakos was households' farms and purchasing (50.0%) while 66.7% of the households in Wote obtained their food from their own farms only. The major household heads' off-farm activity in Machakos was business (40.7%) while in Wote it was employment (28.6%). Off-farm activities are important sources of income in the two areas as farming is risky due to the low and unreliable rainfall. Earlier, 38% of the farmers interviewed ranked off-farm income as one the most important sources of income (Omiti, 1999).

Table 1: Socioeconomic characteristics of sampled farmers in the peri-urban areas of Machakos and Wote towns

Parameter	Site		Total sample
	Machakos	Wote	
	Mean	Mean	Mean
Age of household head	55 (12)	58 (12)	56.4 (12.0)
Farm size (Ha)	3.9 (3.5)	10.7 (10.3)	7.2 (8.3)
Household size	4.2 (1.5)	4.6 (2.0)	4.4 (1.7)
Number of years growing vegetables	13 (12)	4 (8)	7.6 (10.8)
Number of years keeping dairy cattle	9 (9)	13 (11)	10.8 (9.8)
Males	96.7(%)	91.1(%)	94(%)
Female	3.3(%)	8.1(%)	6(%)
Education level of household head			
None	5.1	1.8	3.5
Primary	16.9	12.7	14.9
Secondary	45.8	58.2	51.8
Tertiary	32.2	27.3	29.8
Major off-farm activity			
None	37.3	48.2	42.6
Business	40.7	23.2	32.2
Employed	22.0	28.6	25.2
Household members involved in farming activities			
Land tenure	56.6	50.2	53.3
Customary	31.0	12.7	22.1
Leasehold	0	0	0
Institutional	0	0	0
Rented	0	0	0
Freehold	69.0	87.3	77.9
Main source of food for household			
Own farm	46.4	66.7	56.4
Purchased	3.6	0	1.8
Own farm and purchased	50.0	33.3	41.8

Numbers in parentheses are standard deviations

The three major sources of income in the two areas are shown in Table 2. Livestock production ranked highest (54.2%) in the peri-urban areas of Machakos town while crop production ranked highest (46.4%) in the peri-urban areas of Wote town. Overall, livestock production ranked highest (46.6%) followed closely by crop production (45.7%). Small-scale business ranked third in the two areas.

Table 2: Major sources of income in the two areas

	Machakos		Wote		Total sample	
Source of income	Rank	Farmers (%)	Rank	Farmers (%)	Rank	Farmers (%)
Livestock production	1	53.3	2	48.2	1	46.6
Crop production	2	55.0	1	46.4	2	45.7
Business	3	25.0	3	14.3	3	19.8

The mean area allocated to crops in the peri-urban areas of Machakos town (1.97 ha) was greater than that allocated to pastures (1.65 ha) while in the peri-urban areas of Wote town, the mean area allocated to pastures (5.58 ha) was greater than that allocated to crops (3.80 ha, reflecting the relative importance of livestock in these areas.

Vegetable production

Table 3 shows the range of vegetables grown in the two areas, the percentages of farmers growing the various vegetables and the proportion of the total land area allocated to each vegetable type. Kales and tomatoes were the most preferred vegetables in the two areas.

Table 3: Type of vegetables grown in the two areas

	Machakos		Wote		Total sample	
Vegetable	Farmers (%)	Mean area (ha)	Farmers (%)	Mean area (ha)	Farmers (%)	Mean area (ha)
Kales	40.0	0.12 (0.08)	35.6	0.12 (0.09)	38.4	0.12 (0.08)
Tomatoes	30.0	0.29 (0.25)	26.7	0.18 ((0.20)	28.8	0.25 (0.24)
Cabbage	8.8	0.18 (0.11)	8.9	0.13 (0.05)	8.8	0.16 (0.09)
Onions	5.0	0.10 (0.00)	6.7	0.08 (0.03)	5.6	0.09 (0.03)
Spinach	2.5	0.00 (0.00)	8.9	0.00 (0.00)	4.8	0.07 (0.03)
Capsicum	5.0	0.10 (0.00)	4.4	0.07 (0.03)	4.8	0.14 (0.11)
Brinjals	3.8	0.08 (0.35)	2.2	0.17 (0.18)	3.2	0.07 (0.03)
Hot pepper	3.8	0.22 (0.18)	2.2	0.05 (0.00)	3.2	0.19 (0.15)
Amaranthus	1.3	0.02 (0.00)	0	0.10 (0.00)	0.8	0.02 (0.00)
Cowpea	0	0.00 (0.00)	4.4	0.15 (0.07)	1.6	0.15 (0.07)

Numbers in parentheses are standard deviations

Out of the sample farmers interviewed, 40.0% in Machakos and 35.6% in Wote grew kales while 30.0% and 26.7% grew tomatoes in Machakos and Wote, respectively. The third most preferred vegetable was cabbage, grown by 8.8% and 8.9% of the sample farmers in Machakos and Wote, respectively. The total area under different vegetables followed the same trend.

The percentages of farmers growing vegetables at various times of the year in the two areas are shown in Figure 1. The most preferred season for growing vegetables in Machakos was the dry season (32.5%) while in Wote, 33.3% of the farmers preferred growing vegetables during the dry and rainy seasons. The relatively lower percentage of farmers growing vegetables in the peri-urban areas of Machakos town during the wet and dry seasons could be attributed to its proximity to the rich agricultural areas of Central Province, which supply vegetables to Machakos town throughout the year.

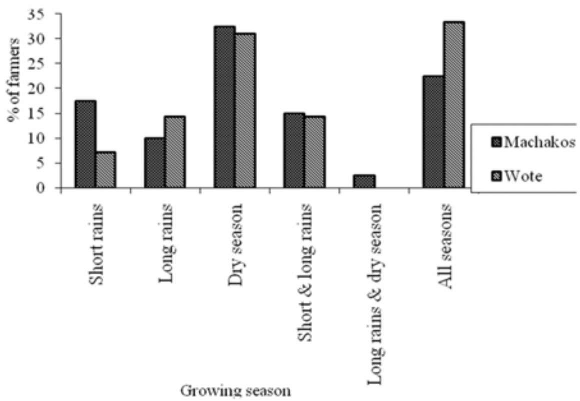

Figure 1: Vegetable production during different times of the year

Rotation of vegetable crops was practised by 80.4% of the farmers in Machakos and by 85% of the farmers in Wote. A majority of them (90.5% in Machakos and 59.1% in Wote) rotated crops after one season. The main reasons for practising crop rotation in the two areas were reported to be: control of soil borne diseases (76.2% and 61.8% of the farmers in Machakos and Wote, respectively), improvement of soil fertility (83.3% and 79.4% of the farmers in Machakos and Wote, respectively) and reduction of pest infestation (54.8% and 50.0% of the farmers in Machakos and Wote, respectively). Land shortage (77.8% and 40.0% of the farmers in Machakos and Wote, respectively) was reported to be the main reason for not practising crop rotation.

The major constraints in vegetable production reported for Machakos were pests (21.0%), low rainfall (20.8%) and diseases (20.3%) while in Wote, the three major constraints were diseases (25.0%), high cost of inputs (18.8%) and low rainfall (14.08%). The main cropping system for vegetables in the two areas was mono-cropping (74% in Machakos and 80.0% in Wote). Only 15.4% and 10.0% of the farmers in Machakos and Wote, respectively, intercropped vegetables.

66.7% of the farmers in Machakos and 78.9% in Wote reported growing vegetables for home consumption and sale while 28.2% and 10.5% of the farmers in Machakos and Wote, respectively, reported growing vegetables for home consumption only.

Nutrient management practices

Sources of nutrients for vegetable production. Sources of nutrients for vegetable production varied across the two sites (Figure 2). Out of the sample farmers, 28.8% and 38.1% used livestock manure in Machakos and Wote, respectively. A combination of manure and inorganic fertilizer was used by 46.3% of the farmers in Machakos and by 33.3% of the farmers in Wote.

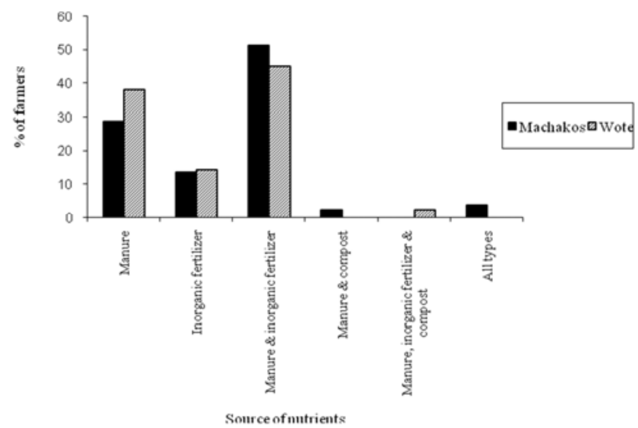

Figure 2: Sources of nutrients for vegetable production

Sources of manure for the production of vegetables and other crops are shown in Figure 3. The main source of manure in the two areas was cattle manure, which was used by 98.4% of the farmers in Machakos and by 97.1% of the farmers in Wote. Other sources of manure included poultry, goats, sheep, compost and pigs. Except for cattle manure, the percentages of farmers using other sources of manure were higher in Wote than in Machakos.

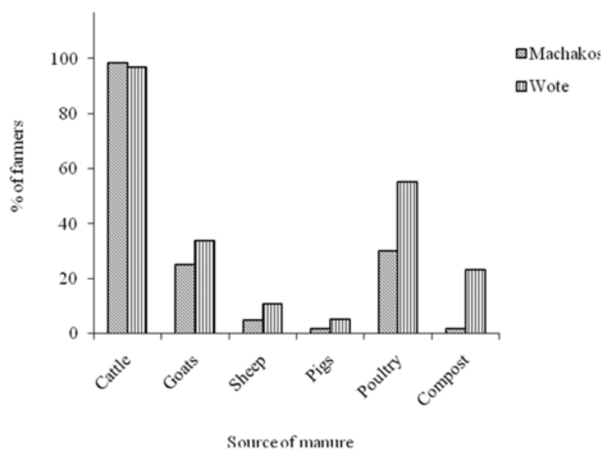

Figure 3: Sources of manure in the two areas

The average amount of animal manure produced on the farms in the peri-urban areas of Machakos town was 5.1 tonnes (s.d ±2.8) per season while that produced in the peri-urban areas of Wote town was 5.6 tonnes (s.d ±4.4) per season. The use of animal manure provides a means of recycling nutrients and where animals have access to forage outside the croplands, a means of collecting nutrients from surrounding

areas. Adding manure to the soil also improves soil structure, which promotes water infiltration, thereby reducing soil erosion. Its application is closely associated with ownership of livestock with the average quantity of manure available significantly correlated with the size of the livestock herd. The quality of farmyard manure depends on the type of animal, type of feed fed to the animal and the way the manure is stored. Most of the farmyard manure in the semi-arid areas of Kenya contains only one third of the N and P expected from fresh animal manure (Probert *et al.*, 1992; Lee, 1993).

Manure management

Manure management is a key factor in determining the quality of manure produced on the farms. The various methods of managing manure in the two areas are shown in Figure 4. In both areas, a majority of farmers heap their manure without covering it. In the peri-urban areas of Machakos town, composting manure before use was ranked second while heaping manure and covering it was ranked second in the peri-urban areas of Wote town. In both areas, direct application was the least common method of manure management.

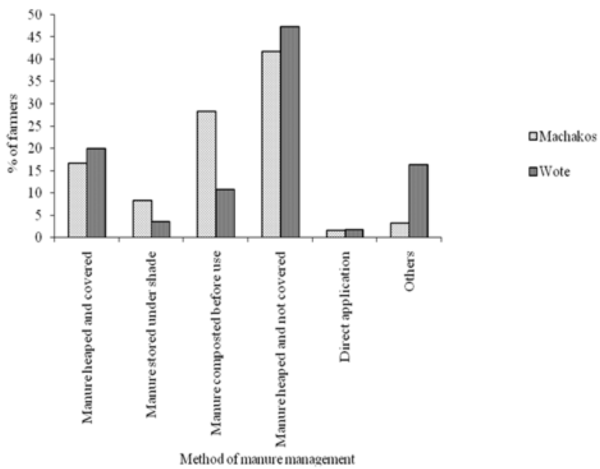

Figure 4: Percentages of farmers using various methods of manure management in the two areas

Methods of applying farmyard manure

Farmers in the two areas apply manure in several ways, with some using exclusively one method and others using combinations of different methods. Figure 5 shows percentages of farmers using the various methods in the two areas.

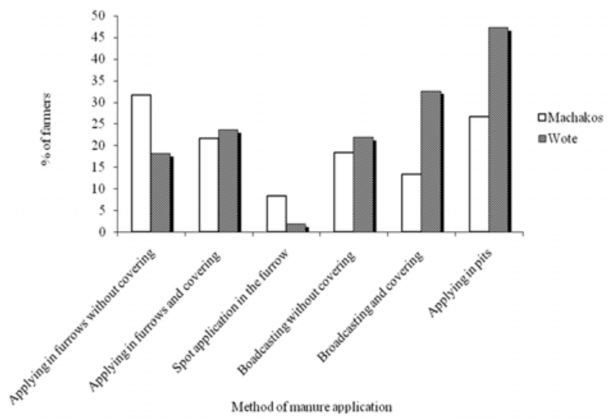

Figure 5: Percentages of farmers using the various methods of applying manure in the two areas

In the peri-urban areas of Machakos town, the main method of applying manure was applying in furrows without covering with soil while applying in pits was the main method of application in the peri-urban areas of Wote town. In both areas, spot application within the furrow was the least common method of application.

Frequency of manure application to vegetables

Figure 6 shows the frequency of application of manure to vegetables in the two areas. A majority of farmers in the two areas applied it every season. In the peri –urban areas of Machakos town, application after every other season was practised by the least number of farmers while in the peri-urban areas of Wote town, application once a year was practised by the least number of farmers.

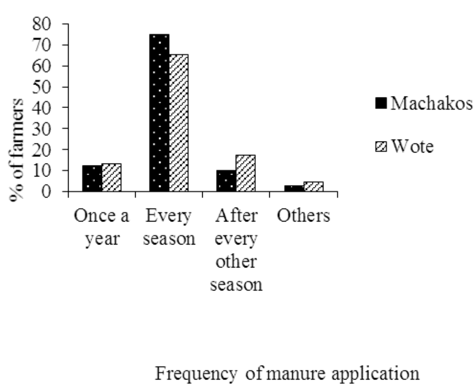

Figure 6: Frequency of manure application in the two areas

Constraints in manure application

Although farmyard manure is the principal source of nutrients for crop production in the semi-arid areas of Eastern Kenya, its utilization is constrained by several factors, most of them related to its bulky nature. Figure 7 shows the percentages of farmers who cited the various factors as constraints to its efficient utilization. In both areas, shortage of labour was the main constraint to manure utilization, with all the interviewed farmers in the peri-urban areas of Wote town citing it as a constraint. Low quality of manure was cited as a constraint by the least number of farmers in the two areas, which was surprising considering the results of analysis of manure samples collected from nearby areas and the high rates of manure application reported from those areas.

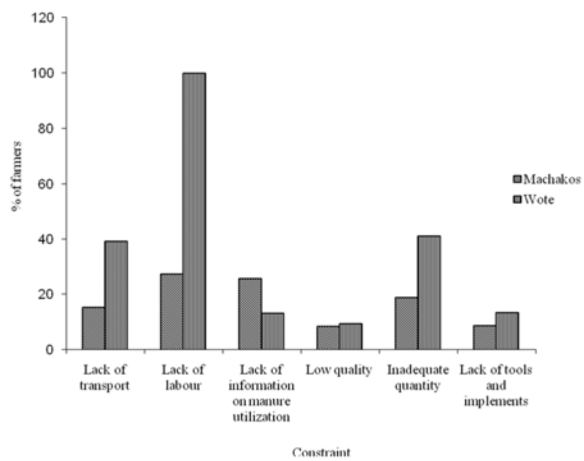

Figure 7: Percentages of farmers citing various constraints in manure utilization in the two areas

Sources of information on vegetable production

Vegetable producers obtained information on production from diverse sources. Table 4 shows the main sources of information on vegetable production. Fellow farmers as information source ranked high (69.0% and 78.3% in Machakos and Wote, respectively). This was followed by government departments at 53.4% and 76.1% in Machakos and Wote, respectively. The third most important source of information was electronic media (radio) at 56.9% in Machakos and 50.0% in Wote.

Pest and disease control was ranked the highest among the types of information provided on vegetable production at 70.3% and 88.9% of farmers in Machakos and Wote, respectively (Table 5). This was followed by types of vegetables at 56.8% in Machakos and 61.1% in Wote. Types of fertilizer was third with 41.7% of farmers in Machakos and 61.1% of farmers in Wote having received this information.

Table 4: Major sources of information on vegetable production

	Machakos	Wote	Mean
Source	Famers (%)	Famers (%)	Famers (%)
Church	5.2	2.2	3.8
Print media	25.9	30.4	27.9
Electronic media	56.9	50.0	53.8
NGOs	10.3	26.1	17.3
Government departments	53.4	76.1	63.5
Fellow farmers	69.0	78.3	73.1
Research institutes	3.4	10.9	6.7
Universities	0	2.2	1.0

Table 5: Type of information provided on vegetable production

Information	Machakos	Wote	Mean
	Famers (%)	Famers (%)	Famers (%)
Type of vegetable	56.8	61.1	58.2
Type of fertilizers	41.7	61.1	48.1
Marketing	35.1	38.9	36.4
Processing	16.2	0	10.9
Storage	2.7	16.7	7.3
Pest & diseases control	70.3	88.9	76.4
Other	10.8	16.7	12.7

Conclusions and recommendations

The main source of nutrients for vegetable production in the two areas was farmyard manure, mainly from cattle. The use of inorganic fertilizer was low due to its high cost. Thus enhancing integration of crop-livestock systems has the potential to increase productivity of the farms in a sustainable manner. To enhance this integration, emphasis should be given to:

- promotion of adapted feed resources, particularly forage legumes that when fed to dairy cattle increase milk production and improve the quality of manure and soil fertility through nitrogen fixation; and
- strategies that mitigate nutrient losses during handling and storage of manure (a majority of farmers in the two areas heap manure in the open without covering it, leading to loss of N through volatilization)

Most farmers in the two areas use a combination of livestock manure and inorganic fertilizer, thereby exploiting the positive synergies that optimize nutrient supply to crops. However, the use of other organic sources of nutrients such as compost is negligible. There is, therefore, a need to sensitize farmers on the use of other sources of organic nutrients in combination with inorganic sources in order to optimize all aspects of nutrient cycling.

Acknowledgement

The authors are grateful to the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) for funding this study and the Director, KARI for permission to publish the results. We are also grateful to all those who contributed to the success of this study.

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Increasing land productivity through optimum cattle stocking rates

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Abstract

Elmba Rhodes (*Chloris gayana*, Kunth) grass is known to have wide climatic and soil adaptation; being persistent in growth under frequent grazing, producing high dry matter yield per hectare that is evenly distributed throughout the year. These characteristics make it a popular grass for improving grazing land in Kenya. General increase in beef output per hectare with increased stocking rate has been reported elsewhere. Hence the objective of the current study was to increase determine optimum cattle stocking rates when cattle were grazed on Elmba Rhodes grass paddocks by evaluating available dry matter, yearling Boran cattle daily weight gain and beef yield per hectare. Three paddocks were fenced in an established Elmba Rhodes grass field to match the experimental requirements. Eighteen yearling Boran cattle were distributed in a randomized complete block design to three treatments: stocking rates of two, four and six yearling Boran cattle per hectare. The yearlings were continuously grazed on their respective paddocks for 240 days. Their initial mean weights were 191.0, 191.9 and 189.3 , respectively. The data was subjected to analysis of variance and the means separated using Duncan's multiple range tests. The stocking rate significantly affected available dry matter, yearling Boran cattle daily weight gain and beef yield per hectare. The available dry matter recorded a decreasing trend of 3.9, 2.8 and 1.3 tonnes per hectare and yearling Boran daily weight gain and beef yield increased to an optimum and thereafter decreased with trends of 453.9, 480.5 and 200.2g; 108.9, 230.6 and 144.2 kg per hectare, respectively. Improved grazing land planted with Elmba Rhodes grass provided to grazing cattle up to 3.9 tonnes dry matter per hectare monthly, increased cattle growth rate to 480.5 g daily under continuous grazing and increased land productivity to the optimum beef yield of 230.6 kg per hectare. The optimum cattle stocking rate was 4 yearlings Boran was under continuous grazing on Elmba Rhodes grass. Further research should be done to determine the optimum cattle stocking rates for cattle grazing Elmba Rhodes grass in the various ecological zones in Kenya.

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Introduction

Rhodes grass (*Chloris gayana*, Kunth) has a wide climatic and soil adaptation (Bogdan, 1969) and is easy and economical to establish as it produces large quantity of viable seeds. It is therefore widely cultivated to improve grazing pasture land. A popular variety of Rhodes grass called Elmba heads early, has high dry matter yield and is persistent to frequent grazing (Boonman, 1978).

Much pasture agronomic work has been carried out in Kenya (Thairu, 1970 a, b) but these, lack measures of pasture grazing land productivity in terms of beef, milk and mutton output per hectare. Most reports refer to relatively short periods of grazing utilization and to mixed improved grassland of Rhodes grass with other types of grasses (Bogdan, 1969, Otim and Mugerwa, 1976).

Boran cattle have been bred in Kenya and are popular for beef production as they are adapted to a wide range of climatic conditions (Boran Cattle Breeders Society, 1990). Boran cattle are common among pastoralists and commercial beef ranchers. Low post-weaning Boran growth in pastoralist cattle leads to low mature body weight and late maturity (Cossins, 1985). These reduce land productivity through delayed first calving in heifers, while in steers; the time taken to reach slaughter weight is longer. Improved post weaning gain, therefore, will result in higher land productivity through increased mature weight which would be sold earlier, fetching higher incomes. Improved grassland through planting productive pasture

provides adequate feed which has been shown to play a vital role in enhancing post-weaning growth (Kayongo-Male, *et al*, 1977 and Abate, 1988).

The objective of the current study was to increase land productivity through the determination of optimum cattle stocking rates when cattle were grazed on Elmba Rhodes grass paddocks by evaluating available dry matter, yearling Boran cattle daily weight gain and beef yield per hectare.

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Materials and methods

Improved grazing land and beef cattle

Elmba Rhodes grass establishment involved breaking new land by ploughing and harrowing until a fine seedbed was achieved. Rhodes grass seeds were planted on the soil surface using a seed drill at 5kg per hectare. Single super phosphate was applied at 100kg per hectare during planting. Weeds were controlled using 2,4-D (2,4-dichlorophenoxy acid amine) post emergence. No nitrogen top-dressing was done and grazing was deferred during the first year to allow complete Rhodes grass establishment. The area was subsequently fenced into three paddocks according to experimental treatments. Water was reticulated into the paddocks and salt troughs were provided.

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Eighteen Boran weaned cattle were selected from a herd of 250 within KARI, Lanet. They were initially herded together for 180 days before the beginning of the experiment and were drenched against internal worms regularly and plunged into a dip weekly to kill ticks.

Experimental design and data collected

The 18 weaned cattle were randomly distributed into three equal and uniform groups according to weight in a randomised complete block design. The effects of stocking rate at three levels on available dry matter, average daily weight gain and beef output per hectare were studied. The stocking rates were 2, 4 and 6 weaned cattle per hectare denoted A, B and C respectively. The initial mean cattle weights were 191.0, 191.9 and 189.3kg in treatments A, B and C.

Grass samples were taken monthly in the continuously grazed paddocks. A quadrant was randomly thrown and all the grass within the quadrant was clipped and weighed. Five samples were taken along the paddock diagonal and were used to calculate available pasture.

The five samples per paddock were bulked and a sub-sample taken for laboratory analyses (Table 1). Cattle were weighed fortnightly to establish patterns of growth and determine beef output per hectare during the experiment lasting 240 days.

Table 1: Composition of Elmba Rhodes grass grazed by Boran cattle at different stocking rates

Components, per cent	Treatments		
	[1]A	B	C
Dry matter	46.7	49.3	44.7
Organic matter	91.1	90.9	89.2
Crude protein	4.9	5.5	6.2
Neutral detergent fibre	79.2	74.9	73.5

[1] A, B, C are cattle stocked at 2, 4 and 6 per hectare continuously grazed

Analyses

Pasture dry matter, organic matter and crude protein were determined according to the procedures of Association of Official Analytical Chemists (1990). Neutral and acid detergent fibre were determined according to procedures of Van Soest *et al.,* (1991). Analysis of variance was done on available pasture, cattle daily weight gain and beef output per hectare for a randomised complete block design. Separation of means was performed using Duncan's multiple range tests (1955).

Results

Available pasture and cattle growth performance

Stocking rate greatly affected (P<0.05) pasture availability (Table: 2). Cattle on A had the most pasture while those on C had the least pasture available. The pasture available to cattle stocked in treatments A, B and C was 3.9, 2.8 and 1.3 tonnes dry matter per hectare respectively.

Average daily gain was affected by stocking rate (P<0.05) (Tale: 2). Cattle stocked at A and B gained at a similar rate (P>0.05) but those on C had a significantly (P<0.05) lower gain. The average daily weight gains (ADG) were 453.9, 480.5 and 200.2g for cattle stocked at A, B and C respectively.

Beef output per hectare

The beef output was affected by the stocking rate (P<0.05) and a general increase in beef output per hectare occurred with increase in stocking rate (Table 2). The cattle stocked at B produced the most beef per hectare and those at A the least (P<0.05). The beef output was 108.9, 230.6 and 144.2 kg per hectare on treatments A, B and C respectively.

Table 2: Available pasture, average daily gain and beef output of cattle stocked at different rates while grazing on Elmba Rhodes grass

Treatments	Available pasture (tonnes, DM)	ADG (g)	Beef out put (kg)
[1]A	3.9[c]	453.9[b]	108.9[a]
B	2.8[b]	480.5[b]	230.6[c]
C	1.3[a]	200.2[a]	144.2[b]
SEM	0.42	106.3	27.9

[1] A, B, C are cattle stocked at 2, 4 and 6 per hectare continuously grazed

[abc] Means on the same column bearing different superscripts are different (P<0.05)

Discussion

Elmba Rhodes grass is known to be very persistent in growth (Boonman, 1977) and furthermore, tropical grasses have a rapid growth and fast maturation (Mwakatundu, 1977) so that the maturation may cause constant dry matter yield per hectare. However, cattle stocked at B and C exerted such a high grazing pressure that a reduction in available dry matter per hectare occurred. Overall, the Rhodes grass dry matter yields in this study were lower than those recorded by Thairu (1970a), Gastel, (1977) and Arkel, (1978). This may be due to nitrogen deficiency as the planted pasture was not top dressed with nitrogenous fertilizer.

The ADG recorded in the study is within the range of 290 to 490 g obtained by Otim (1975) and Otim and Laboke (1975) using beef steers grazed on improved pasture. The gains recorded by Kayongo-Male *et al* (1977) of 300 to 460g daily using heifers grazed on improved grassland without and with concentrate supplementation are not different from those in the current study. However, the ADG were higher than those recorded by Abate *et al*., (1981) for dairy heifers. This may be due to site effect, Rhodes grass variety used and the breed of cattle. Boran cattle are known to efficiently use high fibre diets better than exotic cattle (Creek, *et al*. 1975). The cattle stocked at C had the lowest average daily weight gain due to the relatively low available dry matter. The low available dry matter is attributable to low recovery by Elmba Rhodes grass due to too frequent and heavy grazing.

There was a general increase in beef output per hectare with increase in stocking rate. The increased trend was, however, diminished beyond B. This can be explained by the low quantity and quality of available grazing with resultant lower ADG. The quality of the diet was lower below the stocking rate at B and beyond B shortage of pasture reduced beef output.

Conclusions and recommendations

Increased stocking rate reduced available pasture and ADG but increased beef output per hectare. Based on available pasture, cattle ADG and beef output, the optimum stocking rate was at four weaned Boran cattle per hectare. Elmba Rhodes grass withstood continuous grazing and to obtain adequate pasture, high ADG and beef output per hectare, Boran weaned cattle should be stocked at four cattle per hectare to increase land productivity under continuous grazing on Elmba Rhodes grass. Further research should be done to determine the optimum cattle stocking rates for cattle grazing Elmba Rhodes grass in the various ecological zones in Kenya. The effect of fertilizer application on the grassland herbage yield and land productivity should be determined.

Acknowledgement

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Livestock, banana and livelihoods: A case of sedentary pastoralism in the western shoreline of Lake Victoria, Uganda

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Abstract

Shrinking of grazing land and the expansion of banana plantations are key land use changes that threaten the sustainability of land resources in the Western shoreline of Lake Victoria. An integrated approach to land evaluation that examines the suitability of selected land utilization types and their impact on soil nutrient budget was used to evaluate the suitability of land resources for rainfed bananas and livestock grazing at low, intermediate and high input levels. Arable soils in the western shoreline are suitable for crop production; however, sustainability is threatened by the low levels of nutrient inputs. Consequently most of the low input land utilization types are associated with negative nutrient balances. Livestock is not profitable and the situation is likely to be worsened by the continued shrinkage of grazing area. As such, land degradation is on the increase due to the above optimal stocking rates. At intermediate input level of banana production, about 5 ha are needed to support a household of 6 that fully depends on farm income for survival.

Keywords: land evaluation, soil nutrient balance, grazing, household income, Lake Victoria basin, Uganda.

Introduction

Semi nomadic pastoralism in the western shoreline of L. Victoria is changing fast into agricultural land with consequent increase in sedentary pastoralism. Agricultural land increased by over 100 % at the expense of forest, thicket and savannah. The rangeland decreased by 30%; while the actual livestock population tripled and exceeds by more than 200% the optimal stocking density. While the shrinkage of grazing land may cause land degradation, the profitability of livestock enterprise is debatable.

Apparently, there is need to design land use systems that promote food secure livelihoods within a healthy Lake Victoria ecosystem through promotion of changes in land use that benefit farm households, the terrestrial ecology and the lake itself. Until this balance of sustainable use of natural resources to full economic growth can be coupled with land use decisions that ensure food security in all its dimensions, livelihood conditions can be expected to deteriorate at an accelerated rate with significant negative social and economic impacts.

Evaluating the performance of grazing enterprises is central to the management of the stock and the supporting land resources like pastures and soils to ensure minimal degradation of land resources. This study looked at the availability of grazing land, pastures and the economic performance of grazing in the western shoreline of Lake Victoria basin.

Methodology

Study site

The western part of Lake Victoria consists of a plain on the shoreline and a hilly landscape beyond it. The mean annual rainfall is 916 mm with a bimodal rainfall with the first rainy season from March up to May, and a second between September and December. The natural vegetation consists of aquatic grassland, aquatic tree savannah, savannah grassland, semi-deciduous forest and thicket and swamp forest. Eroded

gravely shallow soils on the hills and the imperfectly and poorly drained soils on the lacustrine plain are extensive with deep clayey soils located on the foot of the slopes.

Intensive mixed agriculture consisting of banana-coffee systems with maize, beans and sweetpotatoes as annual crops coupled with extensive grazing (Parsons, 1970) is practiced. Burning of rangelands is a common practice and seasonal swamps are grazed during the dry season. The Uganda Bureau of Statistics (UBOS) (2001) household survey shows that 57 % of the income comes from farming with an average monthly income of 73.5 $. Monthly household expenditure stands at 66.5$. The same study shows the average human population growth rate is 3.4% with an average household size of 5.7, 53 % of the population is aged less than 15 years, and is composed of 49 % males and 50.4 % females.

Between 1960 and 1999, livestock population in Rakai increased as follows: cattle from 35,000 to 118,726 heads; goats from 8000 to 181,463 heads; sheep from 2,471 to 26,647 heads; Ministry of Agriculture, Animal Industry and Fisheries, 1993. The average banana bunch weights recorded at three input levels was 46.7 kg (high), 30.4 kg (Intermediate) and 13.4 kg (low). The same study showed livestock output at the following three input levels: milk (Litres / ha) = 31 (intermediate), 55.2 (low), and meat (kg / ha) = 37.0 (intermediate), 61.0 = (low), and manure (kg / ha) = 1245 (intermediate), and 1861 (low).

Estimation of available rangeland and optimum livestock population

In this study, the available rangeland was taken to be all that land currently not utilized for crops, gazetted forest and nature reserves. By comparing available rangeland (ARL) with the optimal stocking rate, the sustainable number of grazing livestock was estimated. Optimal stocking rates used were based on results of a four year stocking rate trial conducted in South-western and Eastern Uganda (Stobbs, 1966; Thornton, 1966). The experiment in South-western Uganda, on black alluvial clays and silts, involved Ankole longhorn steers (248 kg) with three stocking rates, 1.2, 2.4, and 3.6 ha per head, under continuous and deferred grazing on *Themeda triandra* and *Hyperrhenia filipendula* pastures. Under deferred grazing, the best stocking rate (1.2 ha per head) was associated with 65.2 kg live weight gain per ha per year; continuous grazing was associated with 48 kg live weight gain per ha per year.

Although 1.2 ha per head under deferred grazing was best in South-western Ugandan, it is rarely practiced by farmers. As such, 1.2 ha per head under continuous grazing was chosen as the optimal stocking rate. These stocking rates are equivalent to optimal stocking rates of 0.83 Tropical Livestock Unit (TLU) per ha for South-western Uganda. One TLU is equivalent to an animal of 250 kg live weight. The calculations were based on the district census done in 1999. Livestock population for 1960 was obtained from the Department of Veterinary Service and Animal Industry (1961). The available rangeland area was assumed constant between 1954 and 1960.

Economic suitability

In ALES, economic suitability for Bananas and grazing land use types was evaluated by the net margin (all crops), net present value (bananas), and the benefit per cost ratio (Bananas and livestock). The *discount rate* was adjusted by subtracting the inflation rate (0.1) from the interest rate (15% for sugarcane farmers and 10% for others). For all levels of production, it was assumed that all labor costs are hired at a rate of 0.35 $ per person day. It is also assumed that all farmers rent land at a cost spread out to cover all the growth cycle.

Economic suitability classes

For compatibility with the FAO framework, the net present value and gross margins were expressed as currency grouped into four discrete suitability classes corresponding to FAO classes 's1', 's2', 's3', and 'n1' within ALES . To allow ALES to perform this grouping, three *economic suitability class limits*, i.e. values of currency per unit area –year (for gross margin analysis) which divide 's1' from 's2', 's2' from 's3', and 's3' from 'n1' were determined.

The *limit between 's3' and 'n1'* was set for a gross margin below which the land user will elect not to implement the land use type. The *limit between 's1' and 's2'* and that between *'s2' and 's3'* was set to differentiate the best land from moderately good land, and moderately good land from marginal land.

Expenditures were used to give an indication of the annual financial needs of a farm household. Annual household expenditures were derived by farm sizes (average of 2.55 ha; to obtain annual financial requirements per ha; the estimated value was 346 $ per ha per year.

Suitability rating was based on the assumption that all the money spent was earned through agricultural enterprises. S2 and S3 net margins reflect a reduction of 20% and 40% of the S1 net margins (Table 1).

Table 1: Net margin and net present value $/ha suitability ratings for the study **area**

Rating	High*	Intermediate	Low
S1	346	277	221
S2	277	221	177
S3	138	111	88

* Level of production

Calculating the nutrient budget

The nutrient budget was calculated using the methodology described by Stoorvogel and Smaling (1990). The nutrient budget of a land use type was calculated as the difference between the sum of inputs (application mineral fertilizers, organic manure, Atmospheric deposition, Biological nitrogen fixation, oedimentation) and the sum of outputs (removal of harvested crop parts, removal of crop residues, leaching, denitrification, and water erosion). The NUTMON toolbox was used to calculate the balances using the determinants of inputs and outputs for bananas, maize and sugarcane.

The costs incurred to replace depleted nutrients were assessed by using the value of the depleted nutrient on the market. This gave the Nutrient Deficit Market Value (NDMV) – van der Pol (1993). The ease with which nutrients could be replaced was assessed using the Farmers Income Sustainability Quotient: FISQ = 1 – value of nutrient deficit/farmer income.

Assumptions. All crop residues are removed from the field and all organic household waste is applied to bananas. All livestock faeces are dropped in the rangeland during the day and in the kraal during the night. Pastures not grazed are returned to the soil as crop residues. Pastures are also used as source of mulching material. Food for home consumption and associated residues e.g. banana peelings are estimated based on the household food requirements. After supplying the household food requirement, the balance of the produce harvested is considered as surplus for sale.

Food requirement estimates

Food requirement estimates were calculated based on the following assumptions: There was no pregnant or lactating mother in the household; same energy and protein requirements for 0-14 (1 boy; 2 girls) year's category, 15-64 (1 boy; 1 girl) and 65+ (1 woman) years category. Energy requirements are based on FAO (1985) and 4 kcal/gram are provided by carbohydrates. As long as the energy requirements are met, protein requirements are met too. A household size of six (Uganda Bureau of Statistics, 2001) and farm located on suitable land for growing bananas as food crop is assumed.

Results

Available rangeland and livestock population in Rakai district

Table 2 shows that between 1960 and 1999, available rangeland decreased by 30% while the actual livestock population tripled. Hence, whereas in 1960 the stocking rate was still below the optimum in 1999 it is exceeded by more than 200%.

Table 2: Evolution of available rangeland compared to actual and optimal livestock population in Rakai district

	1960	1999
Available rangeland ('000 ha)	153.1	107.5
Optimal stocking rate* (TLU/ha)	0.83	0.83
Actual livestock population ('000 TLU)	35.61	133.54
Optimum livestock population ('000 TLU)	127.07	89.23

The breeds are Ankole long horn in Rakai, Optimal stocking rates based on Stobbs (1966) and Thornton (1966); †Estimation based on 1987 data (Source: authors' calculations based on livestock data from Ministry of Agriculture, Animal Industry and Fisheries, 1993)

Economic suitability

In Table 3, the net margins show that bananas are marginally suitable at high and intermediate input levels and not suitable at low input levels. The benefit cost ratios are low and close to zero. The Net Present Value is high and positive. Livestock production is associated with negative Net Margins and Net Present Values with close to zero Benefit / Cost at intermediate input level. Low input livestock production is not suitable as indicated by the low Net Margin, Net Present Value and Benefit / Cost valuees.

Table 3: Economic Benefit/Cost and Net Present Values for banana and livestock land use types in Rakai district

land Use Type	Net Margin	Benefit/Cost	Net Present Value
Bananas (High input)	264	1.2	606
Bananas (Intermediate input)	163	1.3	985
Bananas (Low input)	25	0.9	-79
Livestock (Intermediate input)	-185	0.6	-110
Livestock (Low input)	10	1	8
Livestock* (Intermediate input)	-160	0.7	-99
Livestock* (Low input)	60	1.1	-39

* Lowland grazing;

Nutrient balances

Generally NPK nutrient balances calculated for bananas are more negative at low input level of production and the reverse is true for pastures (Table 4). NPK balances are positive for bananas at high, and intermediate level of production.

Household food requirement

Environmental threat and food security are closely intertwined, since food production is highly sensitive to environmental conditions, and conversion of natural land for agriculture is a major cause of the deterioration of earth's support systems (Ehrlich *et al.,* 1993). Table 5 shows the estimated nutritional supply and demand-based on banana as source of calories. As expected the energy supplied decreases with yield against a constant household demand. Energy supply estimates are well above the demand at all levels of the banana land utilization type. However, with bananas at low input level, energy supply from one hectare of land is marginal. Protein associated with the supplied energy is very high compared to the household demand at both per hectare and household levels. In monetary terms, a household of six people will require 544 $ to purchase 10,872 kg bananas required to last one year. In terms of land resource allocation, 0.78 hectare of land is required to produce at low input level, bananas that can supply enough energy requirements for a household.

Table 4: Comparison of sustainability characteristics for land utilization types

	land Use Type	Nutrient Balance			Fertilizer Value			Economic parameters*			
		N	P	K	Urea	TSP	MOP	NDMV	NM	NDMV/NM	FISQ
		Kg/ha			$/ha			$/ha			
Banana	High Input	67	23	63	77.3	55.4	66.8				
	Inter. Input	35	11	29	40.3	26.5	30.7				
	Low Input	2	-2	-6	2.3	4.8	6.6	11.4	130	0.09	0.91
Pastures	Inter. Input	-44	-25	-4	50.7	60.2	4.2	115.0	34	3.38	-2.38
	Low Input	-28	0.9	0.8	32.0	1.7	0.85	32.0	14	2.29	-1.29

NDMV=Nutrient Deficit Market Value; NM=Net Margin; TSP=Triple Super Phosphate; MOP=Muriate of Potash
FISQ=Farmers Income Sustainability Quotient:= 1 – NDMV/NM (van der Pol, 1993);

Table 5: Annual energy and protein output and requirements per household

land use	Yield	Output†	Starch‡	Energy*	Starch	Energy	$Energy_{req}$**	$Prot._{req}$**
	kg/ha	per HH	kg/HH	Kcal/HH	kg/ha	Kcal/ha	Kcal/HH	kg/HH
Banana								
High	46,700	49,689	10,932	43,726,144	5,753	23,013,760	5,237,750	97
intermediate	30,355	32,298	7,105	28,421,994	3,740	14,958,944	5,237,750	97
Low	14,010	14,907	3,279	13,117,843	1,726	6,904,128	5,237,750	97

†farm area used -1.9ha; * FAO, 1985; ** FAO, 1985 based on UBOS 2001 household size

Discussion

conomic suitability

With good prices and market accessibility, bananas are some of the most paying crop enterprises in Uganda (Karugaba and Kimaru, 1999; Nkuba, 2001; Pender, 2002; Nkonya, *et al.,* 2004). The marginal economic performance of bananas, despite the relatively high yields realized, is due to remoteness that is usually associated with low produce prices (Ssewaya, 2003). It is demonstrated that with high input good yields can be achieved. Overall, livestock is performing poorly better.

Nutrient balances

Uganda has been associated with generally negative NPK balances at national level (Stoorvogel and Smaling, 1990) Balances at farm level vary depending on the level of production. Negative nutrient balances are associated with land use types at high inputs and the reverse is observed for low input farms (Walaga *et al.,* 1999; Esilaba, 2000, de Jagera, In press). de Jagera (In press), calculated negative NPK balances for both conventional and low external input farm practices. Negative or positive NPK balances at field levels have been calculated (Walaga *et al.,* 1999. Esilaba (2000), observed negative balances for total N, P and K for all soil fertility management classes. However, farmers classed as good soil fertility managers had higher negative nutrient balances than farmers classed as poor soil fertility managers. This is because class 1 farms extracted more nutrients from the soil when they produce and sell more.

However, calculations here indicate that low input levels of production are associated with negative balances for NPK. Table 4, shows that intensification of production is generally associated with positive balances with the exception of K whose balances are negative for all land Use Types except for high and intermediate bananas. The negative K balances could not be offset by fertilizer and manure inputs at both high and intermediate input levels. Bananas are more ecologically balanced with negative balances experienced only at low levels. Fortunately most farmers produce bananas at intermediate level with good soil management practices.

Livestock and low input banana farmers operating with negative net margins do not have the financial ability to compensate for the nutrients lost through various pathways. These enterprises are also associated with negative Farmers Income Sustainability Quotient. Farmers Income Sustainability Quotient near or above 0.50 indicates that farmers have the capacity to replace nutrients mined through fertilizer application.

Net margins alone portray the profitability of land Use Types; additional information from nutrient balances has shown how unsustainable some land Use Types can be despite their good net margins. It is more revealing when nutritional aspects are included as discussed below.

Food requirements

Results show that one hectare of suitable land can supply enough starch or carbohydrate to meet the annual energy requirements for a household. Farms below one hectare, at least from the nutritional point of view, cannot support a household of six from land alone. This concurs with similar observations in Nepal where, an average farm size below one hectare is considered too small to support a typical farm family of six people (Ehrlich *et al*., 1993). In such a situation, off farm income is required to supplement the energy requirement through purchase of food items. This explains the observed importance of off farm income in supplementing farm income in sustaining rural households (Zwick and Smith, 2001; Abele, 2003; Nkonya *et al*, 2004). The non-farm income generating activities have increased in number with a majority of households involved in at least one non-farm income generating activity in addition to farming (Zwick and Smith, 2001; Isabirye *et al*., 2001). A study on strategies for sustainable land management and poverty reduction in Uganda shows that off farm income is associated with better soil management and therefore improved crop productivity (Nkonya *et al*., 2004).

The problem of hunger linked to a particular land use type does not exist in Rakai despite the lower net margins for bananas because the dual subsistence and commercial objective of banana crops. However, assuming that all household energy requirements are purchased, a household of six will require 544 $ annually to purchase bananas for food. Net income from bananas is estimated at 264 $, 163 $ and 25 $ for high, intermediate and low input banana crop respectively. Apparently the proceeds from one hectare of bananas at all levels of input cannot support the nutritional requirements of a household. Annual household welfare financial requirement estimates by UBOS (2001) is 798 $. At intermediate input level of banana production about five hectares are needed to support a household that fully depends on farm income for survival.

The above findings indicate that cultivation at low input levels is not sustainable for the average farm sizes. However, with good market accessibility and prices, intensive crop production has been associated with secure food supply, increased household income from 280-500 $ and annual savings of about 70 $ (Nkuba, 2001).

Agriculture is unprofitable in Uganda. Farmers will only really start enhancing soil fertility when they have the money to do so; and that only occurs when most of the population is located in towns which can pay high prices for agricultural produce, which will, in turn, pay for the fertilizers and manure. In his concluding remark, It will take a long time before real and lasting improvement to the land can be expected. Stobbs (1966) observed that it was not possible to establish a profitable livestock enterprise on small farms due to the low returns available from genetically inferior stock.

In the absence of non-farm income to supplement farm income in meeting household requirements, farmers have no option other than acquisition of extra land so as to meet these demands. As a strategy to cope with nutritional demands and general household livelihood, able farmers rent additional land but the majority, constrained by poverty, have been forced to cultivate shallow, steep marginal land or encroach on the forest reserves in the neighborhood. Agricultural expansion, in pursuit of food security and household welfare, is the leading land use change associated with nearly all deforestation with poverty and human population dynamics as underlying driving causes (Ehrlich *et al*., 1993; Place and Otsuka, 1997; Geist and Lambin, 2002; NFP, 2002).

The analysis of nutritional household requirements possibly explains why, even when the net margins and Farmers Income Sustainability Quotient indicate that a farmer has the financial capacity to replace nutrients, will not actually do it. He is hungry and hungry people are in no position to consider the long-term health of the earth's life-support systems – Ehrlich *et al.*, 1993. In most cases scientists and policy makers will see how irrational the farmer is as seen from statements like "unfortunately farmers do not clearly visualize the problems of nutrient mining"

Conclusion

Low input levels of production are associated with negative balances for NPK. The intensification of production is generally associated with positive balances with the exception of K whose balances are negative for all land use types except for high and intermediate bananas.

Livestock and low input banana farmers operating with negative net margins do not have the financial ability to compensate for the nutrients lost through various pathways as indicated by the Farmers Income Sustainability Quotient. Net margins alone portray the profitability of land use types; additional information from nutrient balances has shown how unsustainable some land use types can be despite their good net margins. It is more revealing when nutritional aspects are included as discussed below.

Assuming that all household energy requirements are purchased, a household of 6 will require 544 $ annually to purchase bananas for food. Net income from bananas is estimated at 264 $, 163 $ and 25 $ for high, intermediate and low input banana land use types respectively. Apparently the proceeds from one hectare of bananas at all levels of input cannot support the nutritional requirements of a household. Annual household welfare financial requirement estimates by UBOS (2001) is 798 $. At intermediate input level of banana production, typical for Rakai, about 5 ha are needed to support a household that fully depends on farm income for survival.

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Characterizing access to climate information and services by the vulnerable groups in semi-arid Kenya

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Abstract

Women and the elderly living in semi-arid environments of Kenya are vulnerable to the frequent exposure to impacts of changing climate and need to access climate information and services to build their adaptive capacity. This study characterised the channels through which the vulnerable people in a semi-arid area of Kenya access climate information and services from data collected from randomly selected sample in cross sectional survey using structured questionnaire. Over 70% of both women and the elderly perceived change in rainfall, drought, floods, human and livestock diseases to have been "severe" to "very severe" over the last five years. Majority of women (88.5%) most preferred radio while the elderly (83%) most preferred indigenous knowledge to access climate information and services. Women consistently rated radio higher ($P<0.05$) than the elderly for delivering reliable information, explaining details and use of local language understood to them. However, Principal Component Analysis (PCA) indicated that comprehensive informing on climatic hazards and support services for adaptation to changing climate is from extension service unlike the other channels which delivered information only on climatic hazards. The study concluded that combination of extension agents, radio and local administration would be more effective for disseminating climate information and services to vulnerable people in marginal areas. Capacity building for extension service is needed in interpretation of weather data to enable them effectively disseminate climate information and services to vulnerable people of arid and semi-arid environments.

Key words: dissemination, vulnerable groups, climate information, marginal areas.

Introduction

Climate change is associated with increase in temperature and heat stress, more frequent droughts and intense flooding, windstorms and disease outbreaks (IPCC, 2001). These climatic hazards are projected that will have greatest impact on livelihoods in semi-arid environments of sub Saharan (Thornton *et al*, 2006). The vulnerability of livelihoods to impacts of climate change depends on the extent of exposure, sensitivity and adaptive capacity of the people affected (IPCC 2001). More than 70% of people living in the semi-arid areas are highly dependent on climate sensitive natural resources and agriculture for their livelihoods (Siri *et al*, 2008). The concern is that they may not be adequately empowered to respond and adapt to the magnitude of climate changes projected (Boko *et al.*, 2007).

Climate information and services play a critical role in providing Early Warning Systems (EAS) as well as increasing awareness for building the capacity and disaster preparedness to a changing climate. Choice of the dissemination channels can influence access and use of climate information and service disseminated to enable the vulnerable groups exposed to climatic hazards build adequate response capacities. Climate information and services relevant to adaptation in semi-arid areas include early warning signals, weather forecasts, food aid distributions, emergency guidelines, and financial support, medical and veterinary assistance.

Though the people living in semi-arid environments are in most need of access to climate information and services, they are yet to experience the full benefits of climate research, information and services to enable them effectively cope and build adaptive capacity to the changing climate (O'Brien *et al.,* 2008). Harvey *et al.,* (2009) expressed concern that information sharing among climate change actors in Africa is limited and

may be worse in semi-arid environments due to barriers of poverty, lack of infrastructure, illiteracy and socio-economic factors. Limitations also exist in the information delivery mechanisms in terms of reliability, timing, infrastructural development and even language (Chamboko *et al*., 2008).

In Kenya, the Meteorological Department (KMD) disseminates climate forecasts using different channels such as mass media, print media and the internet. Arid Lands Information Networks (ALIN) on the other hand, disseminates climate related information to people in semi-arid areas through use of Information and Communication Technologies (ICTs) (Nguo *et al*., 2005). Effective access by the vulnerable people especially women and the elderly in semi-arid Kenya to these dissemination channels has however not been evaluated empirically. The objectives of this study were specifically to:

- Determine perception of the vulnerable people about impacts of climate change that have experienced most in the last five years
- characterize the patterns of climate information and services that vulnerable people access,
- Identify the dissemination pathways that the vulnerable people in a semi-arid environment perceive most useful for delivering climate information and services to them,
- Determine the user-friendly attributes of those dissemination pathways for delivering climate information and services to vulnerable people in a semi-arid environment

Materials and methods

Conceptual framework

Access to climate information and services is necessary for coping, adaptation and mitigation strategies necessary in the face of changing climate. Figure 1 presents the conceptual framework adapted for this study, illustrating the hypothesized flow of climate information and services to vulnerable people. Underlying assumption is that vulnerable people can effectively access climate information and services if disseminated through channels which are accessible and effective with user-friendly attributes. The pathways through which climate information and services are disseminated include mass media, print media, electronic media, and contact with informed people. Those employing these pathways include researchers, meteorological departments, development agencies and indigenous knowledge systems. The attributes can influence information that users access such as timeliness, accuracy, reliability, ease of use, depth of content.

Study site

The study was in Marigat Division, a semi-arid environment experiencing frequent exposure to climate variability within areas identified as hotspots of climate change (Thornton *et al*., 2006). Rainfall is highly variable which makes both livestock keeping and crop production very risky, due to water and pasture shortage. Households here are agro-pastoralists who experience prolonged droughts with frequent cases of flooding during rains and outbreaks of human and livestock diseases (GoK, 2001). Frequent exposures to climatic hazards cause famine alerts and poverty and there is competition for scarce natural resources contributing to the area being conflict-prone (Mango *et al*., 2004). Five locations in the area most prone to impacts of climate variability were selected for sampling the vulnerable women and the elderly.

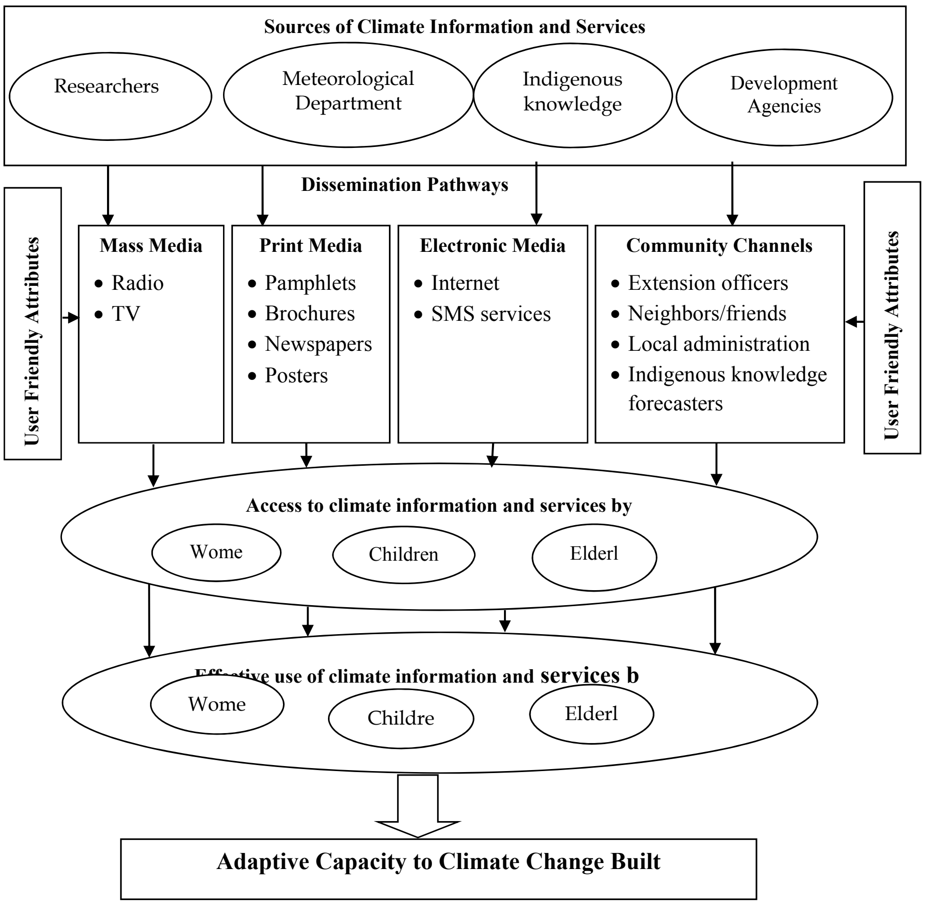

Figure 11: Conceptual framework on dissemination pathways of climate information and services to vulnerable people

Research design and data collection

Data required was obtained in a cross-sectional survey in which simple random sampling technique was applied to obtain a sample of representative vulnerable women and the elderly. Women sampled were those within the age group of 24 to 60 years old considered vulnerable because they are married and shouldering household chores and have to provide food for the family under impacts of climatic hazards. The elderly were both males and females aged at least 65 years old considered vulnerable because of old age yet exposed to climatic hazards. The local administration chiefs and agencies involved in food assistance program within the area facilitated identification of the individual vulnerable women and the elderly people within their administrative areas.

A structured questionnaire was administered to women and the elderly respondents to obtain data on their experiences in the past five years about impacts of climate change, dissemination channels through which they climate change and information and services, their preferences for each of the channels and user-friendly attributes of those channels to them. For each dissemination channel accessed, respondents rated on a Likert scale of 1 to 5 (1 = low to 5 = high) the climate information and services accessed, preferences and user-friendly attributes.

Data analysis

For each dissemination channel, Principal Component Analysis (PCA) was performed on type of climate information and services often accessed. PCA is a statistical approach (Cattell, 1978) for removing redundant information from correlated variables to represent the original variables with a smaller set of derived variables called principal components. The method was relevant for this analysis because the variables of interests were highly correlated. The derived principal components (PCs) are uncorrelated and account for most of the total variation contained in the variables fitted in the model.

Preferences of the vulnerable people were evaluated through cross tabulation in order to obtain chi square statistics for detecting proportional differences. The Likert scale measures of preferences attached to specific attribute of a dissemination channel were subjected to Kruskal Wallis test and where differences were detected, Mann U Whitney test was applied for pairwise comparisons. Instead of median and mean ranks outputs from the non parametric statistics, mean score for each attribute is presented to ease interpretation of the results.

Results and discussion

Characteristics of the sampled vulnerable people

The age, education, livelihood source and income levels of the sample vulnerable people are summarized in Table 1. About two thirds of (66.7%) of the elderly people lived on less than one dollar a day (1 US $ = KES 80) while about a similar proportion of women (63.3 %) lived less than two dollars a day, indicating high poverty incidences. Majority (64.7%) of the women and the elderly had attained only primary level of education, reflecting low literacy levels, which can be a barrier to effective access and use of early warning systems and climate forecasts disseminated through reading materials and in non local language. The major source of livelihood was rain-fed agriculture supplemented with remittances which provides important supplemental income that vulnerable people can spend in emergencies related vulnerability to climatic variability and shocks.

Table 1: Age, education, livelihood source and income levels of the vulnerable groups

Social characteristics	Women	Elderly	Statistics
Age (years)	37.7 ± 9.3	69.5 ± 5.7	t value 828.75***
Education			
Without formal education (%)	42.9	79.2	χ^2 value=1.26***
With primary level (%)	44.8	12.5	
With secondary level (%)	7.8	4.2	
With post-secondary level (%)	4.5	4.2	
Livelihood source			
None (%)	0.6	-	χ^2 value = 3.98***
Farming (%)	98.7	62.5	
Remittances (%)	-	37.5	
Casual labor (%)	0.6	-	
Income Level			χ^2 value = 3.26***
< $ 1/ day (%)	26.6	66.7	
< 2 $ / day (%)	63.0	29.2	
< 2-5 / day (%)	10.4	4.2	

*** Significant at P= 0.000

Perception about climate change

Figure 2 illustrates perception of the vulnerable people about impacts of climate change as having been 'severe' to 'very severe' in the last five years. Over 70% of both women and the elderly perceived change in rainfall, drought, floods, human and livestock diseases to have been "severe" to "very severe" over the last five years. They associated these changes with failure and destruction of crops and property and loss of human lives and livestock and frequent famine.

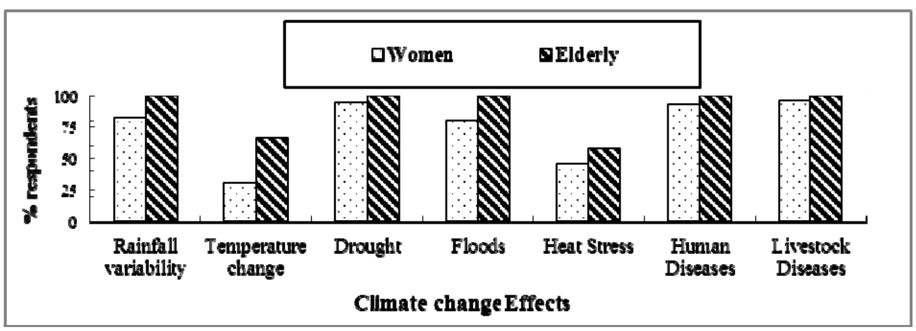

Figure 2: Perception of the vulnerable people about impacts of climate change as having been 'severe' to 'very severe' in the last five years

Patterns of climate information and services that vulnerable people access

Principal component analysis (PCA) was used to characterise climate information and services that the vulnerable people access through radio, extension agents, local administration and indigenous knowledge

(Archer, 2003). . The rotated correlation coefficients associated with the Principal Components (PCs) extracted is explained on the basis of magnitude of the factor loading coefficients (≥ ± 0.30). The positive coefficients indicate positive association while negative coefficients indicate negative association. For each PC, variables with the largest pattern coefficient make the largest contribution in explaining the total variation there is in the data.

Climate information and services accessed through radio

Table 2 shows PCA of the model fitted for radio. The model had goodness of fit from Bartlett's test of sphericity (Chi-square = 962.06; df =120; P value 0.000; KMO = 0.60). Seven principal components (PCs) were extracted which explained 69% of the total variance. The PC1 which explained most of the variance (17.06 %) indicate that through radio, vulnerable people mostly access information about diseases and rainfall variability and is thus labelled climate hazards information specific.

Table 2: Rotated correlation coefficients factor patterns for radio

Climate Information and services	Factor loadings						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Climate related livestock diseases	0.92						
Climate related human diseases	0.90						
Rainfall variability	0.31						
Drought		0.88					
Floods		0.86					
Veterinary services			0.73				
Human health services			0.71				
Adaptation technologies			0.57				
Relocation to safer places			0.54				
Heat stress				0.86			
Wind storm				0.87			
Early warning signals					0.76		
Weather forecasts					0.75		
Food aid						0.81	
Temperature change						0.45	
Financial support							0.83
Variance explained (total 69%)	17.06	11.22	10.50	8.92	7.76	7.06	6.52

Climate information and services accessed through extension services

The PCA results of the model fitted for extension agents presented in Table 3 had goodness of fit from Bartlett's test of sphericity (Chi-square =498.550, df =28; P value = 0.000, KMO =0. 715). Four PCs accounting for 62.35% of the total variance were extracted of which PC1 explained more than half (38.91%) of total variance. The largest contribution was from climate information and services accessed on drought, floods, diseases, early warning signals, veterinary and medical services, food aid and relocation of vulnerable people to safer places. The loadings indicate that through extension service, vulnerable people access comprehensive information on climatic hazards and support services. This can be labelled climate hazards with support adaptation responses. The results suggest that extension agents are very effective in reaching the vulnerable people with climate information and services that are necessary for building adaptation. Extension agents have regular contacts with rural farming community and in this sample, 98.7% women and 62.5% elderly people were engaged in farming activities. Though extension service can be effective in disseminating climate information and services in the semi arid and arid areas with marginalised infrastructural development, Ziervogel and Opere (2010) has warned that the agents are

unable to interpret seasonal climate forecasts presented in probabilities. Capacity building is therefore necessary to enable extension agents understand weather reports.

Table 3: Rotated correlation coefficients factor patterns for extension services

Climate Information and Services Variables	Factor loadings			
	PC1	PC2	PC3	PC4
Climate-related human diseases	0.86			
Climate-related livestock diseases	0.83			
Adaptation technologies	0.81			
Floods	0.71			
Early warning signals	0.68			
Drought	0.67			
Relocation to safer places	0.64			
Veterinary services	0.64			
Human health services	0.58			
Food aid	0.46			
Heat stress		0.85		
Windstorm		0.82		
Rainfall variability		0.57		
Weather forecast			0.69	
Temperature change			0.01	
Financial support				0.81
Variance explained (62.35%)	38.91	9.39	7.42	6.62

Climate information and services accessed through local administration

Local administration is important in information dissemination in semi arid and arid areas where communication infrastructure is underdeveloped. The PCA results for climate information and services that the vulnerable people access through the local administration extracted seven PCs (Table 4) accounting for 62.79% with a model showing goodness of fit for the data fitted (Bartlett's test of sphericity (chi-square =562.700, df =28, P=0.000 and KMO =0. 540**)**.

The rotated correlation coefficients loading on PC1 explained 14.01% of the variation with largest contribution from information about climate-related diseases of both human and livestock. This reflects greater concentration on diss**e**minating disease information, hence labelled climate-induced disease information specific. Local administration includes local chiefs and village elders, often used by the government agencies to communicate with the grass root people through monthly village meetings "Baraza's".

Climate information and services accessed through indigenous knowledge informers

PCA results for climate information and services that vulnerable people access through indigenous knowledge informers are represented in Table 5. Seven PCs were extracted accounting 77.11% of the total variance. The model had a goodness of fit (p=0.000) Bartlett's test of sphericity (chi-square = 3130.244, df =120 and KMO =0. 559**)**. The factors loading on PC1 explain 19.58% of the total variance with most contribution from information on drought and floods. This is therefore labelled climatic hazards specific. Community members indicated that they were able to make predictions using various indicators while some of the elderly were recognized "experts", diviners, seers and even rainmakers. The elderly compared to the women were more sceptical about modern information probably because they do not understand them easily.

Table 4: Rotated correlation coefficients factor patterns for local administration

Climate Information and Services Variables	Factor loadings						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Climate related human diseases	0.84						
Climate related livestock diseases	0.84						
Floods		0.88					
Drought		0.85					
Temperature change			0.82				
Rainfall variability			0.80				
Food aid				0.68			
Veterinary services				0.61			
Human health services				0.60			
Early warning signals					0.66		
Relocation to safer places					0.62		
Weather forecast					0.58		
Windstorm						0.74	
Heat stress						0.72	
Financial support						0.43	
Adaptation technologies							0.84
Variance explained (62.79%)	14.01	9.62	9.41	8.58	7.65	7.14	6.39

Table 5: Rotated correlation coefficients factor patterns for indigenous knowledge informers

Climate Information and Services Variables	Factor loadings						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Drought	0.99						
Floods	0.99						
Veterinary services		0.93					
Human health services		0.92					
Early warning signals			0.98				
Weather forecast			0.98				
Climate related livestock diseases				0.96			
Climate related human diseases				0.95			
Rainfall variability					0.84		
Temperature change					0.83		
Relocation to safer places						0.77	
Adaptation technologies						0.76	
Heat stress						0.43	
Food aid							0.80
Windstorm							0.65
Financial support							0.33
Variance explained (77.12%)	19.58	13.28	12.41	9.64	8.45	7.31	6.46

Preferences of vulnerable people for the dissemination pathways

Results in Table 6 presents respondents' preference for the channels through which vulnerable people access climate information and services measured as never, seldom, sometimes, often or most preferred. Only the last two measures are presented hence the proportions indicated do not add up to hundred percent. Radio was the preference of a large majority of women (88.5%) while indigenous knowledge was

the preference of the elderly (83%). In the study area, radio broadcast are in vernacular language so the news about climate information and services are easily understood by the vulnerable people. Extension service and indigenous knowledge were the next preferred channels for access climate information and services by both women and the elderly. Hansel *et al* (2007) argues that radio and ICT-based communication offer immense potential to support the delivery of climate information services; but cannot replace the trust, visual communication of location-specific information, feedback and mutual learning that face-to-face interaction provides. Therefore extension service and indigenous knowledge can be utilized if key informants at the village level are identified and trained in interpreting weather data.

Table 6: Preferred Dissemination pathways by the vulnerable groups

Dissemination Pathway	Vulnerable Group	Sample (n)	Preference Rating (%)		Chi square Statistics
			Often preferred	Most preferred	
Radio	Women	154	24.0	68.8	χ^2 = 72.81 **
	Elderly	24	41.7	4.2	
Local Administration	Women	154	63.7	24.7	χ^2 = 31.58**
	Elderly	24	58.3	37.5	
Indigenous Knowledge	Women	154	59.1	32.5	χ^2 = 1.83**
	Elderly	24	16.7	83.3	
Extension Agents	Women	154	85.0	5.5	χ^2 = 1.77**
	Elderly	24	58.3	41.7	

** Significant at P = 0.00

User-friendly attributes of the dissemination pathways accessed by the vulnerable groups

Table 7 presents means of preference rating by the vulnerable people on a scale of 1 (very poor) to 5 (excellent) for user-friendly attributes of the channels for delivering climate information and services in a semi-arid environment. User-friendly attributes were rated on the basis of cost, timeliness, details, reliability and language from the perspectives of the respondents. Both women and the elderly expressed equally preferences for the attributes of the channels through which climate information and services are disseminated, except for ($P<0.05$) radio regarding information reliability, detail and language used in which the elderly consistently rated lower than women.

Table 7: Mean ratings for user-friendly attributes (1=very poor 5= excellent) of the dissemination Channels by the vulnerable people

Channels	Group	Cost	Timeliness	Detailed	Reliability	Language
Radio	Women	3.43 ± 0.68^a	2.74 ± 0.61^a	2.88 ± 0.62^a	2.66 ± 0.63^a	4.03 ± 0.51^a
	Elderly	3.17 ± 038^a	2.50 ± 0.51^a	2.33 ± 0.51^b	2.21 ± 0.51^b	3.17 ± 0.38^b
Extension	Women	3.09 ± 0.97^a	2.73 ± 0.61^a	3.07 ± 0.53^a	2.75 ± 0.56^a	3.33 ± 0.53^a
	Elderly	3.46 ± 0.51^a	2.20 ± 0.68^a	3.00 ± 0.58^a	2.00 ± 0.59^a	3.67 ± 0.48^a
Local Administration	Women	3.97 ± 0.47^a	3.81 ± 0.44^a	4.04 ± 0.61^a	3.99 ± 0.67^a	4.62 ± 0.58^a
	Elderly	3.79 ± 0.51^a	3.67 ± 0.48^a	3.83 ± 0.38^a	3.79 ± 0.42^a	4.58 ± 0.50^a
Indigenous knowledge	Women	3.71 ± 0.78^a	3.64 ± 0.51^a	3.96 ± 0.52^a	3.77 ± 0.59^a	4.56 ± 0.58^a
	Elderly	3.75 ± 0.68^a	3.67 ± 0.36^a	4.21 ± 0.51^a	4.25 ± 0.61^a	4.39 ± 0.41^a

^{ab} = means with different letter superscripts in a column differ significantly at α=0.05

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Fertility in a humic nitisol in the Central highlands of Kenya

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Abstract

Soybean (*Glycine max* (L.) Merrill) is one of the most important legume crops being introduced into the smallholder farming systems of the central highlands of Kenya for soil improvement, income and improved household nutrition. However, phosphorus fixation, depletion of soil nutrients and soil acidity are major causes of low yields. The objective of this study was to evaluate effects of manure, liming and phosphorus application on soil properties and soybean performance. The study consisted of 9 treatments: manure (0, 5 and 10 t ha^{-1}), Lime (0 and 2 t ha^{-1}) and P fertilizer (0, 30 and 60 kg P ha^{-1}). The experiment was laid out in a randomized complete block design with 4 replicates in plots of 4 x 4.5 m. Manure and lime significantly reduced exchangeable acidity and increased soil pH. Application of manure alone or combined with lime or P fertilizer also increased Mg and K. Treatments that had sole lime, lime combined with manure and manure combined with P applied gave a significant increase in exchangeable Ca. Soybean yields responded well and significantly to application of manure either alone or combined with lime, P or both. These results showed the potential role of lime, manure and P fertilizer in improving soil fertility and soybean yields.

Key words: manure, lime, P fertilizer, soil pH, exchangeable acidity.

Introduction

Smallholder farmers in the central highlands of Kenya are faced with declining soil fertility due to intensive cultivation, nutrient removal via crop harvest and soil erosion on steep slopes (Sanchez and Jama, 2002). Use of commercial fertilizers to address the declining soil fertility remains minimal due to farmer's low income. High costs of fertilizer, lack of credit, delays in delivery of fertilizer due to poor transport and marketing infrastructure, lack of know-how about their usage, have individually or jointly constrained fertilizer optimal use (Heisey and Mwangi, 1996). Several researchers have therefore recommended Integrated Soil Fertility Management (ISFM) options for increasing soil fertility and agronomic efficiency of applied inputs (Sanginga and Woomer, 2009; Vanlauwe *et al*., 2010). Legume integration into the farming systems is an important component of ISFM because of their (legumes) potential to fix nitrogen and hence reduce farmers' costs for purchase of fertilizers. Legumes have also been reported to improve the soil physical and chemical attributes as well as provide protein supplements for poor families (Latif*et al.,* 1992).

Soybean, is one of the legumes being integrated into the smallholder farming systems of the CHK. Soybean has a high commercial value and high concentration of protein, about 40%, calcium, phosphorus, fiber, and in addition it is cholesterol free (Hassan *et al.,* 2010). It plays an important role in provision of food, cash and animal feeds (Mugendi *et al*. 2010). Soybean, like other leguminous crops has a positive impact on the soil; the canopies of soybean cover the soil and protect it from recurrent erosion (Latif *et al.,* 1992), has potential to fix N from the atmosphere through biological fixation (Nieuwenhuis and Nieuwelink, 2002). This is important in farming systems where soils are continuously been exploited since the increasing population demands increased food production.

In Kenya, this crop is relatively new and expected to increase production due to its importance in supply of food, income and improving household nutrition (Mugendi *et al.,* 2010). However, its yields are still below the potential (3.0-3.6 t ha^{-1}), with average yields in Central Provinces of 560-1100 kgha-^{1} (Mahasi *et al*., 2010). Among the factors that affect productivity are inherent poor soil fertility of the African soils (Bationo *et al.,* 2006), continuous decline of the soil fertility (Kimani *et al.,* 2004), poor management practices and low agricultural input use (Njeru, 2009).

The predominant soils in the central highlands of Kenya are Humic Nitisols that have moderate to high acidity with inherent high Phosphorus fixing (Kanyanjua *et al*., 2002). The prevalence of acidity is associated with Nitrogen (N), Phosphorus (P) deficiency in the soil, Aluminum (Al) toxicity, low exchangeable bases (Ca, Mg, K and Na), and reduced microbial activity therefore low crop yield and land productivity(Crawford *et al*., 2008). All these, among others, affect performance of soybean. This study therefore aimed to evaluate the effect of manure, lime and P mineral fertilizer on soil properties and soybean yields in an acidic soil in the central highlands of Kenya.

Material and methods

Site description

The experiment was carried out at Embu Agricultural Training College (Embu-ATC); located in Embu West district (0°35′ 25.58′′S and 37° 25′ 31.84′′E); in Central Highlands of Kenya at an elevation of 1494 m above sea level. Embu West district is in Upper Midland 2 and 3 (UM 2 -UM 3) agro ecological zones having an altitude of about 1440 m a.s.l with annual temperature of about 20^0 C and annual rainfall of 909 - 1230 mm (Jaetzold *et al*., 2006). The rainfall is bimodal with two seasons; long rains (LR) in March through to June and Short Rains (SR) from October through to January. Over 65% of the rains occur in the LR season (Jaetzold *et al*., 2006).The soils are mainly humic Nitisols (Jaetzold *et al*., 2006),which are deep, well weathered with moderate to high inherent fertility but over time soil fertility has declined due to continuous mining of nutrients without adequate replenishment. Recent studies have reported that they have generally low levels of organic carbon (< 2.0%), nitrogen (<0.2 %), phosphorus (< 10 ppm) and are moderately acidic (pH ranges from 4.8 – 5.4), conditions that result in low crop production (Mugwe, 2007). The district is a predominantly maize growing zone with small land holdings ranging from 0.1 to 2 ha with an average of 1.2 ha per household.

The area is characterized by rapid population growth, low agricultural productivity, increasing demands on agricultural resources and low soil fertility. The farming systems are complex consisting of an integration of crops trees and livestock, and smallholder farms that are intensively managed (Mairura *et al*., 2007). Land sizes are small ranging from 0.1 to 1.5 ha (mean=1 ha), and slope cultivation is widespread. The main cash crops are coffee (*Coffeaarabica L*) and tea (*Camelinasinensis*(L) O. Kuntze) while the main staple food crop is maize (*Zea mays L*.), which is cultivated from season to season mostly intercropped with beans (*Phaseolus vulgaris L*). Other food crops include potatoes (*Ipomeabatatas (L.) Lam*), bananas (*Musa* spp. L.) and vegetables that are mainly grown for subsistence consumption. Livestock production is a major enterprise especially dairy cattle that is of improved breeds. Other livestock in the area include sheep, goats and poultry.

Experiment design and field management

The experiment was a Randomized Complete Block Design (RCBD), in plots measuring 4.0x4.5 m and replicated four times. The experiment had 8 treatments with the following factors; manure (M) (0, 5 and 10 t ha^{-1} as goat manure); Lime (0, 2 t ha^{-1} as CaO) and P fertilizer (0, 30 and 60 kg P ha^{-1}) as Triple Super Phosphate (TSP). The treatments were;

1.	Manure	10 t ha^{-1} M
2.	Lime	2 t ha^{-1}CaO
3.	TSP	60 kg ha^{-1} P_2O_5
4.	Manure+Lime	5 t ha^{-1} M + 2 t ha^{-1} CaO
5.	Manure+TSP	5 t ha^{-1} M + 30 kg ha^{-1} P_2O_5
6.	Manure+Lime+TSP	5 t ha^{-1} M + 2 t ha^{-1}CaO + 30 kg ha^{-1} P_2O_5
7.	Lime+TSP	2 t ha^{-1} CaO + 30 kg ha^{-1} P_2O_5
8.	Control	No inputs

Land was ploughed manually using a hand hoe followed by leveling 2 weeks before planting. Manure and lime, with regard to required rate, were broadcasted and then incorporated in the soil within 15 cm depth, using hand hoe also 2 weeks before planting. TSP was the source of P and was applied per furrow and well mixed with the soil at planting. Soybean var. Gazelle, was sown (13thOctober, 2012) by placing 3 seeds per hole at 50cmx10cm spacing. Two weeks after emergence the seedlings were thinned to 2 plants per hill. All agronomic practices were undertaken during the growing season.

Soil sampling and analysis

Prior to experiment set up soil samples were collected for initial determination of soil fertility parameters. Thereafter, and to evaluate changes in soil as a result of applied treatments soils were sampled at harvest. The soil samples were analyzed for pH, available P, exchangeable cations (Ca, Mg, K), mineral N, and exchangeable acidity. Soil pH was measured in a 1:2.5 ratio soil to water (pH_{H2O}) and to KCl (pH_{KCl}) using a pH meter model AD1000 (Okalebo *et al*., 2002). Soil exchangeable acidity was determined by titration (0.1M NaOH) method using 1M KCl for extraction (Okalebo *et al*., 2002). Soil mineral N was determined by flow injection method after extraction with 2M KCl. Exchangeable cations and available P were determined by Mehlich 1 method as described by Okalebo *et al*. (2002). The soils of the experimental site were moderately acidic (pH=5.07) according to soil classification based on soil pH (Kanyanjua *et al*., 2002); and moderately low in available P (Table 1).

Table 1: Soil chemical properties of the soil prior to planting

Parameters	Soil
pH water (1:2.5)	5.06
pH KCl (1:2.5)	4.21
Exchangeable acidity (cmol/kg soil)	3.72
Exchangeable cations (cmol/kg soil)	
Ca^{2+}	0.63
Mg^{2+}	0.51
K^{+}	0.12
Na^{+}	0.14
Extractable P (mg/kg soil)	7.54
Total N (%)	0.06

Harvest of soybean and yield determination

At physiologic maturity stage four central lines were harvested by leaving 50cm from the both edges of the rows, harvesting therefore a net area of $6m^2$. Plants were cut at ground level and fallen leaves were collected and weighed together in the field. Subsequently the plants were threshed and recorded fresh weight of the grain. Thereafter the grain samples were sun dried and yields determined and adjusted to 12% of moisture content.

Data analysis

Data generated was subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 8. The means were subjected to *t*-test at 95% of confidence to test means difference. Least Significance Difference (LSD) at 95% of significance level was used to separate means.

Results and discussion

Soil chemical properties

Application of soil amendments significantly affected soil pH: water ($p < 0.0001$) and KCl ($p < 0.0001$) (Table 2). The treatment with lime applied recorded the highest increase in soil pH. This was followed by the combination of manure, lime and P fertilizer. There was also significant difference (p = 0.0115) in

exchangeable acidity due to treatments. All treatments significantly reduced exchangeable acidity except the control and 60 kg P ha^{-1}. The combined application of 5 t ha^{-1} of manure with lime and 30 kg P ha^{-1} as well as sole application of lime mostly reduced exchangeable acidity by 2.3 times followed by both application of 5 t ha^{-1} of manure combined with 30 kg ha^{-1} and with lime by 2.0 times; which was not statistically different from the application of lime combined with 30kg P ha^{-1} (1.8 times). The increase in soil pH and reduction of soil exchangeable acidity following application of manure and lime either sole or combined can be attributed to the release of organic acids (during mineralization of manure), which in turn may have suppressed Al content in the soil through chelation. Moreover, lime when applied in the soil reacts with water leading to the production of OH^- ions; and Ca^{2+} ions content,which displaces H^+ and Al^{3+} ions from soil adsorption sites resulting in soil pH increase (Kisinyo *et al.,* 2012). These findings are similar to those of Adeniyan *et al*. (2011) who found improved soil acidity with application of manure in Nigeria.

Table 2: Effects of manure, lime and P fertilizer on soil pH and exchangeable acidity at Embu

Treatments	pH		Exchangeable acidity cmol/kg soil
	H_2O	KCl	
Manure	5.62	4.53	2.25
Lime	5.83	4.76	1.75
TSP	5.26	4.31	3.0
Manure+Lime	5.64	4.58	2.0
Manure+TSP	5.46	4.43	2.0
Manure+Lime+TSP	5.79	4.67	1.75
Lime+TSP	5.59	4.51	2.25
Control	5.05	4.19	4.0
p-value	<0.0001***	<0.0001***	0.0115*
$LSD_{0.05}$	0.27	0.19	1.20

Application of 5 t ha^{-1} of manure combined with lime and 30 kg P ha^{-1} and the application of 10 t ha^{-1} of manure significantly (p = 0.0185) increased exchangeable Mg by 1.2 times. Contrary and consistently application of sole P fertilizer (60 kg P ha^{-1}) recorded the lowest values in soil available Mg. Increased Mg availability in the soil as result of manure application was also observed elsewhere by Adeleye *et al*. (2010) who suggested that this was due to the release of nutrients through manure decomposition. Rahman *et al*. (2002) also found increased available Mg in the soil as result of applied manure either alone or combined with lime and attributed the increased to improved Mg availability as result of improved soil pH, as was observed in this study.

Soil exchangeable Ca differed significantly (p = 0.0477) among the treatments. Application of 5 t ha^{-1} of manure combined with lime and 30 kg P ha^{-1} significantly increased soil exchangeable Ca by 2.97 times followed by application of 10 t ha^{-1} of manure by 2.14 times. Meanwhile, application of 5 t ha^{-1} of manure plus 30 kg P ha^{-1} and sole application of P fertilizer (60 kg P ha^{-1}) recorded the lowest increase by 1.3 and 1.4 times, respectively. The increase can be attributed to the release of Ca^{2+} ions in lime through its dissociation (Chimdi *et al.,* 2012) and to mineralization of manure with release of mineral nutrient element content in it (Shen and Shen, 2001). The application of sole manure (10 t ha^{-1}) recorded the highest significant (p< 0.0001) increase in soil K by 3.75 times which was followed by the application of 5 t ha^{-1} of manure plus 30 kg P ha^{-1} by 2.25 times. On the other hand, application of combined lime with P fertilizer and application of sole lime recorded the lowest soil K of 0.07 and 0.08 cmol kg^{-1} soil, respectively. It was observed that application of manure either sole or combined with P fertilizer and both P fertilizer and lime had a positive effect on soil exchangeable K, and may be attributed to release of K from the manure. Similar findings were reported by Chimdi *et al*. (2012).

Application of treatments did not significantly (p = 0.8575) affect soil extractable P (Table 3). However, relative to the control the application of 10 t ha^{-1} of manure increased numerically soil extractable P by 1.08 times followed by application of 5 t ha^{-1} of manure plus lime which increased by 1.05 times. The application of 5 t ha^{-1} of manure combined with 30 kg P ha^{-1} recorded the lowest value (6.87 mg kg^{-1} soil) followed by lime plus 30 kg P ha^{-1} (7.24 mg kg^{-1} soil), 5 t ha^{-1} of manure plus lime and 30 kg Pha^{-1} (7.32 mg kg^{-1} soil) and 60 kg P ha^{-1} (7.35 mg kg^{-1} soil). Manure alone or combined with lime increased most the soil available P, depict that the increase was not significant. Abera *et al*. (2005) also found higher soil extractable P with higher application of manure. The soils tested low P (7.54 $mg.kg^{-1}$) before experiment set. It was observed that the levels of P before planting were higher than after harvest under all treatments except sole manure. The same trend was also observed by Abera *et al*. (2005) in Ethiopia and attributed it to the higher phosphorus fixation capacity of acid soils and to the uptake of the plants. This was also supported by Jibrin *et al*. (2002) who also reported extremely low concentration of P even with application of 60 kg P ha^{-1}. The soils where this study was undertaken was moderately acidic (pH_{H2O} = 5.06; pH_{KCl} = 4.21) therefore high P fixation expected. Also the little changes in soil available P even with application of P fertilizer may be due to the method of application of the fertilizer (Kamara *et al*., 2008), which was placed rather than broadcasted while the soil samples are taken between the rows. The results also shows that application of manure either alone or combined with lime, P fertilizer or both had significant effect on soil mineral N. These results are in agreement with Kihanda *et al*. (2004). The increase may be due to supply of N content in manure through mineralization associated to the improvement of soil conditions for microorganism's development and activity as result of lime application.

There was statistical difference in soil mineral N (p = 0.0238) among the treatments (Table 3). Soil mineral N increased by 1.6 times compared to the control with application of 10 t ha^{-1} of manure, followed by the combination of 5 t ha^{-1} of manure with lime and with both lime and 30 kg P ha^{-1} (1.3 times). However there was no significant difference between lime alone or combined with P fertilizer. On the other hand, application of lime alone or combined with 30 kg P ha^{-1} recorded the lowest soil mineral N increase.

Table 3: Effects of manure, lime and P fertilizer on soil exchangeable cations and available P

Treatments	Mg^{+2} cmol/kg	Ca^{+2} cmol/kg	K^{+} cmol/kg	Available P mg/kg	Mineral N mg/kg
Manure	0.61	0.73	0.30	8.02	22.35
Lime	0.57	0.61	0.08	7.51	14.95
TSP	0.51	0.48	0.09	7.35	17.08
Manure+Lime	0.57	0.68	0.13	7.79	17.30
Manure+TSP	0.56	0.43	0.18	6.87	17.25
Manure+Lime+TSP	0.62	1.01	0.15	7.32	16.13
Lime+TSP	0.56	0.7	0.07	7.24	15.78
Control	0.51	0.34	0.08	7.45	13.76
p-value	0.0229	0.0477	< 0.0001	0.8575	0.0238
$LSD_{0.05}$	0.07	0.39	0.08	1.53	3.79

Soybean growth and yields

Plant height was significantly (p = 0.0044) affected by the treatments (Table 4). The highest plant height was obtained in the plots receiving the combination of manure and P fertilizer (50.43 cm), while application of sole P fertilizer recorded the lowest plant height (40.15cm) over the control. The number of pods per plant was affected statistically (p = 0.0006) by application of soil amendments. Manure alone recorded the highest number of pods per plant (34.95) while lowest was by sole P (22.63). Treatments also significantly affected (p = 0.0238) weight of 100 seed. Manure combined with P increased by 1.08 times 100 seed weight compared to the control followed by manure plus lime and P, 1.06 times. Stover yield did not show significant differences (p= 0.0937) due to treatments.

Grain yield and harvest index were significantly affected by treatment application (Table 4). Manure (10 t ha^{-1}) significantly (p = 0.0011) increased grain yield 2.5 times more than the control and manure plus P by 2.3 times. The lowest grain yield was recorded in the plots with P alone (1.2 t ha^{-1}) followed by combination of lime and P (1.7 t ha^{-1}). Harvest Index (HI) which relates the grain yield to the total dry matter yield showed significant (p = 0.0037) differences. The highest HI was in treatment with manure combined with P; and both lime plus P (0.35); while the lowest was in plots with sole P (0.24). The application of manure whether alone or combined with lime and P fertilizer influenced crop growth, yield components and yield of soybean. These results are similar with the results reported by Chiezey and Odunze (2009), Umoetok *et al*. (2007). Manure is a reservoir of nutrients, which are released through mineralization, thus supplying the necessary elements for plant growth Chiezey and Odunze (2009), and when combined with P fertilizers increase nutrient supply which enhanced vegetative growth, affecting therefore and indirectly plant height and yields (Umoetok *et al.,* 2007). Moreover the high yields observed under manure application may be a result of its ability for improving soil biological and physical properties such as structure which increase soil water retention and enhances nutrient uptake (Nwachukwu and Ikeadigh, 2012). During the growing season was observed symptoms of K deficiency mostly in unmanured plots, and it was evidenced with low soil available K in the same plots. Potassium is a macronutrient very important to plants and it is involved in cell division, water and nutrient uptake (Tisdale *et al.,* 1993) therefore its deficiency negatively affect shoot and root growth as well as water and nutrients uptake. In addition, K is the second nutrient mostly taken up by the crop after N and its deficiency greatly affects crop development and yields (Imas and Magen, 2007). Thus, the low yields observed under the treatments lacking manure may be, apart from other factor, caused by the low soil K and N, as well as poor N fixation observed (data not shown). Therefore, it suggests that the use of manure combined with lime, P fertilizer or both enhanced good soil conditions which in turn contributed to relatively high yields.

Table 4. Effects of manure, lime and P on soybean growth, yield components (t ha^{-1}) and harvest index

Treatments	Plant ht (cm)	No. pods/plant	100 seed (g)	Stover yield	Grain yield	HI
Manure	49.90	34.95	18.43	5.52	2.80	0.34
Lime	42.35	23.03	18.35	4.42	1.66	0.27
TSP	40.15	22.63	18.10	3.78	1.20	0.24
Manure+Lime	45.00	26.18	18.13	4.70	2.45	0.34
Manure+TSP	50.43	25.55	19.13	4.81	2.66	0.35
Manure+Lime+TSP	48.60	23.80	18.63	4.84	2.62	0.35
Lime+TSP	41.98	22.70	18.05	4.86	1.70	0.26
Control	39.85	22.30	17.65	3.76	1.14	0.23
p-value	0.0044*	0.0006**	0.0238*	0.0937ns	0.0011**	0.0037*
$LSD_{(0.05)}$	6.17	5.02	0.75	1.21	0.86	0.07

Conclusion and recommendations

In conclusion, results showed that manure applied at the rate of 10 t ha^{-1}or 5 t ha^{-1} combined with lime or mineral P fertilizer mostly improved soil conditions and soybean grain yields. These treatments improved soil Ca, Mg, K, mineral N and pH. They also increased soybean yields by 114.9% to 145.6% beyond the control treatment. The good performance of combined application of manure and lime and P fertilizer, is in line with Integrated Soil Fertility Management (ISFM) principles that include the use of organic and inorganic resources, improved germplasm with agronomic practices adapted to local conditions. These preliminary results recommend use of manure alongside with lime and mineral fertilizers for increased soybean yields. More research needs to be carried out for more seasons to assess the consistence of these

findings, and the response of soybean to K fertilizer since there was observed K deficiency symptoms during the study.

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Effect of Mavuno and farmyard manure and fertilizer application on soil properties in western Kenya

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Abstract

The study was undertaken to evaluate the effect of organic and inorganic fertilizer application on soil chemical and biological properties in Siaya and Vihiga districts of Kenya. The experiment was set up in a completely randomized block design with a split plot arrangement with the fertility gradients (high and low) as the main plots and the treatments (IR maize control, manure only and mavuno + manure) as the sub plots. IR maize was the test crop. Soil pH, organic C, P and total N were analyzed at initial, flowering and at maturity maize growth stages. Organic carbon respiration was recorded at 3, 7 and 14 days of incubation. There were significant differences in P levels between treatment means with mavuno + manure treatment recording the highest mean P levels (11.78) at crop maturity. Soil organic C and total N showed significant differences across sites and treatments prior to planting and at harvest ($P<.001$). There were significant differences in soil pH across sites prior to planting. Soil respiration showed significant differences across fertility gradients after 7 and 14 days of incubation. A combination of both organic and inorganic fertilizers potentially enhanced both soil biological and chemical properties. Further studies are recommended on dynamics of soil microbial biomass across fertility gradients in smallholder farms.

Key words: fertility gradients, inorganic fertilizer, organic fertilizer, soil respiration.

Introduction

Soil fertility management practices by small holder farmers mainly depend on application of farmyard manure (FYM) since it is cheap and readily available in their fields (Sanginga and Woomer, 2009). Sufficient mineral fertilizers are not available at the right times during the year due to high transaction costs and inefficiencies throughout the production-consumption chain (Nyamangara *et al*., 2009). Mavuno (10-26-00) is a mineral fertilizer being advanced in western Kenya and the use of local minerals in its production makes mavuno blends less expensive than other mineral fertilizers and hence an alternative option for small holder farmers. However continual use of mineral fertilizers has led to the development of fertility gradients in a single farm. On the other hand Western Kenya is heavily infested with *striga* weed that strives greatly in low fertile soils. The existence of the fertility gradients therefore enhances the occurrence of this weed. Farmers in Siaya and Vihiga use IR maize in their fields to minimize the effects of *striga* on their crops. IRmaize is a herbicide coated maize that makes it resistant to attacks by *striga*. Fertilizer manufacturing and blending is shifting to ensure that fertilizers not only have the major macronutrients but also the secondary and micro-nutrients (Sanginga and Woomer, 2009). It is therefore important to carry out research not focusing only on NPK but other elements and their effects of soil properties since soil properties act as possible early-warning indicators of changes in plant and microbial community and changes in nutrient cycling and energy flow processes (Chiurazzi, 2008). This allows us to come up with better management strategies aimed at maximizing the available resources whilst maintaining or improving the soil health and quality. The study was therefore conducted to assess the effects of application of mavuno and manure fertilizers on soil biological and chemical properties in small holder farmer fields in Siaya and Vihiga.

Materials and methods

Fertility trials were conducted on- farm in Siaya (Nyalgunga and Nyabeda) and Vihiga (Emusutswi) in Western Kenya. Mean annual rainfall and temperatures in Vihiga and Siaya are 2000 mm, 24 $^{\circ}$C and 1450 mm, 21.75 $^{\circ}$C respectively (Cheserem, 2012). Humic nitosolsNitisols and ferralsols (Emusutswi) and ferralsols and acrisols (Nyabeda, Nyalgunga) are the main soil types (Gachene and Kimaru, 2003). From the three sites, 12 farmers how many per site?were selected, using Y frame sampling procedure and farms were demarcated into fertility gradients as perceived by farm owners (Tittonell *et al.*, 2010). A randomized complete block design with a split plot arrangement replicated 4 times was used and the main plots were the fertility gradients (high and low) and the subplots were the fertilizer treatments; control, manure and manure+ mavuno. IR maize was used as the test crop and mavuno was applied at a rate of 20 kg P per ha whilst FYM was applied as a projection of 2 tons per ha. IR maize was planted at a spacing of 30 x 75 cm in a plot of size 6 x 4.2 m.

Commented [J6]: Was the experiment replicated within the farms?
Did all the farms have low and high soil fertility?

Soil samples were collected at a depth of 0-20 cm using W-sampling (Peters *et al.*, 2008). Soil pH was measured using a soil to water ratio of 1:2.5. Organic carbon and total N were determined using wet digestion method and the Kjedahl method. The Mehlich 1 method was used to determine soil P (Okalebo *et al.*, 2002). Organic carbon respiration was measured using passive CO_2 absorption in an alkali trap incubated for 3, 7 and 14 days (Jensen *et al.*,1996). Analysis of variance was conducted using GENSTAT 14th Edition and the Least Significant Difference (LSD) was used to separate means of significant differences.

Results

There were significant (P<0.001) differences in soil pH across sites at the initial soil sampling (Figure 1). The pH ranged from 5.1-6.0 in all the fields before the maize crop was planted. During the flowering stage there was a slight increase in pH ranging from 5.6 -6.1 and at maturity pH ranged from 5.2 to 5.7 (Figure 1). The results showed higher decreases in soil pH in the mavuno+ manure treatment when compared to the manure alone treatment. Does it mean significant?

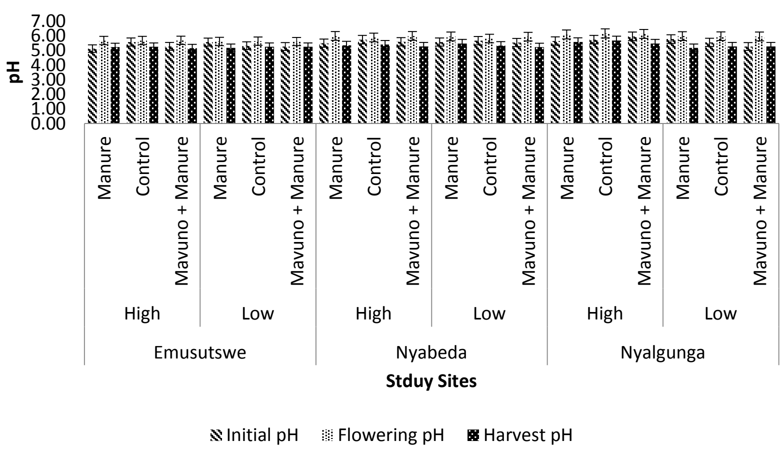

Figure 12: pH in different treatments

There were significant differences in P levels between treatment means (p<0.01) at all stages of crop growth. The P levels across sites and treatments were highest at the flowering stage and reduced at maturity (Figure 2).

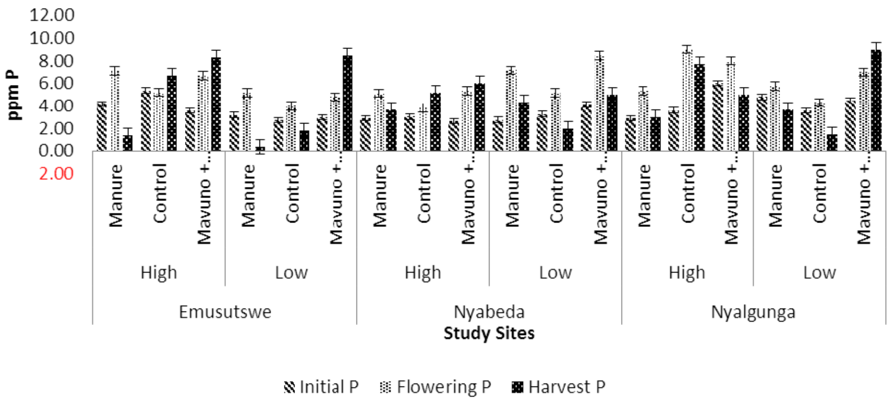

Figure 2: Soil P at different growing

Soil organic C showed significant differences across sites at the initial soil sampling (P<.001). The highest mean (2.19%) in Nyabeda which was significantly different from the other sites (Figure 3).

There were no significant differences across sites, treatments or fertility gradients in %OC at the flowering stage. %C was higher at the flowering stage across several treatments than at initial and final sampling stages of maize. The mavuno+ manure treatment had the largest P (11.78 ppm) at maturity stage (Figure 2). The sites and fertility gradients were not significantly different in P content.

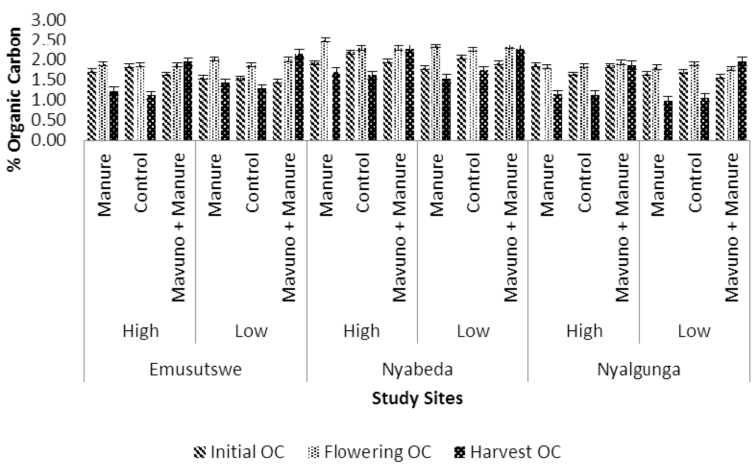

Figure 3: % OC in across sites, fertility gradients and treatments

Percent C showed significant (P <0.001) differences at crop maturity across sites and treatments (Figure 3). % N showed significant (P<0.001) differences in the sites at the initial stages of the season (Figure 4).

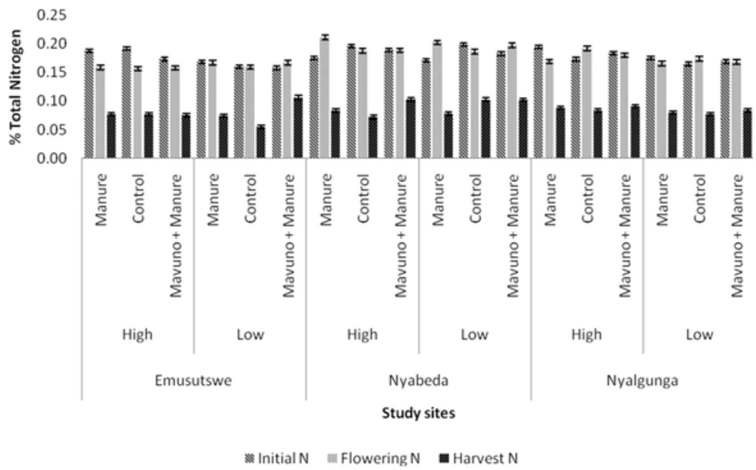

Figure 4 : %Nitrogen at different levels of maize crop maturity

There were no significant differences in %N across treatments, sites and fertility gradients at flowering and maturity stages as hypothesized. There was however a decrease in %N in most of treatments across the three sampling stages in the order initial < flowering < maturity stages (Figure7). Soil Respiration showed no significant differences (P<0.001) in treatments means after 3 days of incubation but higher respiration rates were noted from the mavuno+ manure treatment (Figure 8). After 7 days and 14 days of incubation, fertility gradients were significantly different (p<0.001) with higher C_{org} respiration occurring in fields of lower fertility. The soil respiration rates across treatments and sites were generally below 9.5 mgCO2/kg/day (Figure 9) indicating that there was very low soil activity.

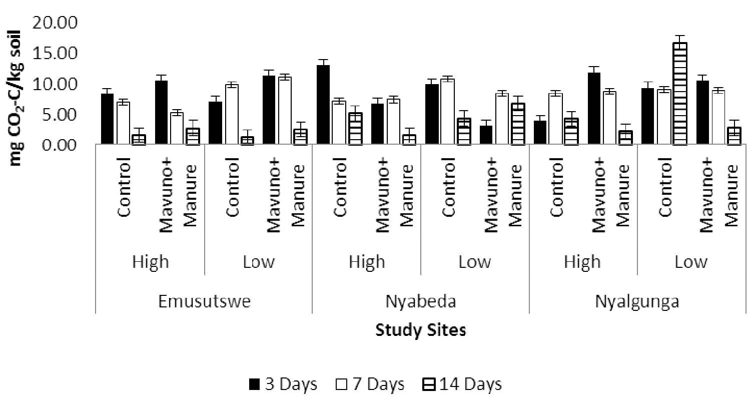

Figure 5: OC respiration rates at 3, 7 and 14 days incubation

Discussion

The differences in pH across sites at initial sampling are attributed to the variations in soil types and rainfall distribution across sites. Emusutswi receives higher rainfall than Nyabeda and Nyalgunga resulting in leaching of cations and accumulation of Al^+ and H^+ ions hence making the soils more acidic. Basu *et al.* (2011) also found that soil types influenced the pH across different sites. When microbes decompose FYM they produce acids in the process and if these acids are in large amounts, a significant decrease in pH is observed as observed from initial to maturity sampling. These results are similar to those of Nalatwadmath *et al.* (2003) who recorded that there was a production of acids on decomposition of organic manure (FYM) that resulted to decreases in soil pH.

The decrease in P at the flowering stage is due to crop nutrient uptake as P is a critical element in crop development. The mavuno + manure treatment had the highest P and this is because Mavuno is a P fertilizer and contains 26% P_2O_5 that improved the soil's mineral components and on the other hand FYM may have improved the soil's structure and hence its ability to hold nutrients. Thus the mavuno+ manure treatment created an ideal environment for nutrient uptake by the plant and retention in the soil matrix. These results indicate that a combination of both organic and inorganic fertilizers is better at improving soil P compared to their sole applications. These results are in agreement with those reported by Kathuku *et al.* (2011) that there was an increase in yield and soil nutrient availability in soil that was added mineral N fertilizer combined with manure when compared to their sole applications. The manure only treatment showed a decrease in P and this could have resulted from the reaction of P with organics in manure to form more stable compounds making it unavailable for plant uptake. Waldrip *et al.* (2012) supports these findings and observed that manure C content influenced P cycling and reduced P availability in soils amended with manure. Stabilization of P due to low pH may have also resulted in its unavailability for plant uptake (Abaye *et al.*, 2006).

The OC increased during the flowering stage and this may be due to high precipitation during the growing season. The moist environment and moderate temperatures created when it rains, allow soil microbes to become active and hence breakdown organic residues thus increase the soil carbon. This is also suggested by Alvarez and Lavado (1998) that OC in the top 0–50 cm soil layer is positively correlated with the precipitation/temperature ratio. The differences across sites may be attributed to the clay content in the soils of the different sites. The higher the clay content a soil has the higher the %OC it contains due to the stability of clay colloids (Feller and Beare1997). The treatments had an influence on the %OC as hypothesized when a combination of organic and inorganic amendments were added and not sole application.

Total N showed significant differences at initial sampling and this can be attributed to growing of legumes by farmers in Siaya prior to the experiment which may have fixed nitrogen and hence resulted in a significant differences being observed across sites. Oriola and Bamidele (2012) supported the findings in that cropping systems have effects on soil elements, fertility status and have implications for agricultural productivity. No significant differences were observed in total N across treatments and this is due to the low N content of the FYM (P<10ppm and %OC <5%) added and Mavuno which contains 10% N and also to manure's slow release of nutrients. Johnson, *et al.*(1987) further elaborates these findings in that a substrate with low N and high C:N ratio results in a disappearance of nitrates from the soil due to great demand from microbes for reproduction. Nutrient leaching is also evident as the treatments showed no significant differences. N losses can be attributed to leaching down the soil profile due to heavy rains, microbial immobilization and or denitrification. Hoeft *et al.* (2000) supports the findings and reports that excessive rainfall is an effective agent for removing basic cations resulting in losses in agricultural nutrients.

Commented [J7]: Not clear how?

Commented [J8]: ANOVA not shown

The higher respiration rates observed in the mavuno+manure treatments could be attributed to higher organic matter present in fertilizer amended plots hence a higher microbial activity as compared to the control plots. These findings are in line with Yuste *et al.* (2007) who reports that the higher the carbon inputs added to the soil the higher the soil respiration. Soils in this treatment have a medium soil activity indicating that the soil could be approaching or declining from an ideal state of biological activity (United

States Department of Agriculture, 2001).This could be due to exposure of organic matter to organisms and oxygen following tillage as suggested by Stoyan *et al.*(2000).

Conclusions

The pH levels highly affected availability of nutrients to plants causing a general decrease in soil chemical and biological properties in all fields not shown in the results. Soil fertility gradients were not significant across most of the properties but sites and treatments were significant with the mavuno + manure treatment superior over the control and manure only treatments. A combined application of mavuno and FYM therefore has the potential to improve soil properties over their sole application.

Recommendations

- pH levels highly affected the availability of nutrients to plants hence liming should be done in the study area. Not valid – did not evaluate liming
- Farmers can benefit from the integrated use of both FYM and mavuno as this will enable them to save money in procurement of inorganic fertilizers. Not valid.. did not evaluate economics
- Improvement of the management of the FYM is encouraged in order to improve its quality. Does not emanate from the study

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THEME 4: LAND USE

Andosolisation of soils on a strombolian cone at Mount Bambouto, Cameroon

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Abstract

Morphology, mineralogy and geochemical investigations were carried out on two selected soil pedons (ZA and TO) developed on a late Quaternary-aged strombolian cone to better understand andosolisation processes in Mount Bambouto, Cameroon. Both pedons have A-BC-C sequence of horizons. They have thick surface (A) horizon with bulk density less than 0.7g cm^{-3}, aluminum oxalate and iron oxalate (Alo + 0.5Feo) about 2% and phosphorus retention of more than 90%. Mineral association consists predominantly of kaolinite, gibbsite, goethite, organo-metal complexes and trace amount of ferrihydrite and allophane. The SiO_2/Al_2O_3 (Ki) values are 1.1-1.6, the low total reserve in bases (TRB: 45-67 mg kg^{-1}), the important mobility index (IMob: 20-24%), the chemical index of alteration of 60-70% and the enrichment factors above 1.16 for Al and Fe, and below 0.6 for Si indicate sparingly hydrolysis process in subsoil during which released Al, Fe and Si form allophanic or ferrihydrite minerals undergo crystallisation into kaolinite, gibbsite and goethite, respectively. In the topsoil, part of the released Al (and Fe) is organically bounded with organic acids to form organo-metal complexes. In the late quaternary strombolian deposits from Mount Bambouto, andic soils refer to aluandic Andosols (dystric) according to the World Reference Bases for Soil Resources. They are derived from the andosolisation process which corresponds to fast and intense release of Si, Al and Fe during rapid hydrolysis of volcanic products under humid conditions. Transient allophanic and ferrihydrite minerals are formed and crystallised into kaolinite, gibbsite and goethite. Part of released Al (and Fe) is bounded at topsoil by organic acids to form stable and less mobile organo-metal complexes. Thus in Mount Bambouto, andosols are non-allophanic which seem to have developed at the same period despite the wide range of rock ages and types.

Key words: soil morphology, mineralogy, geochemistry, andosolisation, strombolian cone, Cameroon volcanic line

Introduction

The Cameroon volcanic line extends 1600 km from the Gulf of Guinea (island of Pagalu) into western Cameroon. Volcanic activity principally ranged from Tertiary to Quaternary age, but the volcano is still (Nono *et al*., 2004; Marzoli *et al*., 2000). Mount Bambouto is a strato-volcano with a well-preserved collapse caldera that has developed from multiple volcanic events initiating with thick basalt lava flow sequences, followed by an eruption with trachytic (fine-grained alkali intermediate igneous rocks) lava flows, with other subsequent volcanic eruptions (Marzoli *et al*., 2000; Marzoli *et al*., 1999). These volcanic deposits cover about 500 km^2 which is intensely used for annual crops and vegetable production. Soil survey of Mount Bambouto, documented soils with andic properties above 1700 m that are formed under a wet, humid climate. Several studies related to pedogenesis have been conducted on soils developed from both trachytes (Tematio *et al*., 2009; Tematio *et al*., 2004) and basaltic rocks (Doube, 1989) dated between 16 and 4.5 Ma (Youmen *et al*., 2005; Marzoli *et al*., 1999). These studies showed that Andosols occur on both parent materials.

The andosolisation process involves the rapid weathering of fine-grained parent rocks containing glass and microlites under humid conditions. In old trachytes and basaltic rocks from Mount Bambouto, this weathering commonly results in the formation of stable organo-metal complexes at the soil surface

(Tematio *et al.,* 2009). They are thus non-allophanic Andosols and are classifyied as Aluandic Andosols (leptic) based on the World Reference Bases (WRB) system of soil classification. Shoji *et al.* (1993) reported that non-allophanic Andosols show very strong acidity (pH <5.0), high Al saturation and subsequent toxicity of Al to plants. They have horizons with Sio less than 0.6%, Alp/Alo ratio above 0.5 in the top horizon and phosphorus retention more than 70%. The major occurrences of Andosols in Africa are in the Rift Valley in Kenya, Rwanda and Ethiopia and in Madagascar (FAO, 2001). In Cameroon, they occur around Mount Cameroon stretching through the Bakossi area (Mount Manengouba) to Loum and Nkongsamba areas, in Foumbot and in Mount Bambouto (West region), in Wum (North West region), and in the Adamawa plateau (Tematio, 2005; Yerima and Van Ranst, 2005).

However, a recent geological review of Mount Bambouto reported the presence of a strombolian cone made of late Quaternary (Middle Pleistocene) basaltic clasts on the NE slope of the mountain that dated around 0.480 ± 0.014 Ma (Dongmo *et al.,* 2010). This finding brought up a question about the andosolisation process in Mount Bambouto, and the source of Al (and Fe) involved in the formation of organo-metal complexes in topsoil is also questioned. Although it is well-known that the physico-chemical composition of the parent rock is one of the main factor controlling andosolisation, Tematio *et al*. (2009) mentioned that Al and Fe involved in organo-metal complexes in Mount Bambouto may originate from partial hydrolysis of secondary minerals (halloysite and iron oxides) due to high microbial activities (Lucas *et al.,* 1993) with liberation of metals which bond to organic acids (Aran *et al.,* 2001). This explanation is proved to be acceptable for soils derived from old trachyte (Aran *et al.,* 2001). This is what motivated the current research on morpho-chemical characterisation of soils derived from the recent strombolian cone.

The objectives of the study were thus to:

- Evaluate and quantify the andosolisation mechanism prevailing on recent strombolian cone in Mount Bambouto by identifying the source of Fe and Al involved in the process
- Assess the weathering process and intensity operating in this environment as compared to andosolisation process on ancient trachytic lava flows

Materials and methods

Study site

Mount Bambouto is one of the major volcanic mountains in the Cameroon volcanic line that crosses the western part of the area. It is made up of various volcanic products grouped into basic (alkali basalt, basanite, mugearite, hawaïte) and highly differentiated (trachyte, phonolite, rhyolite, ignimbrite) rocks (Marzoli *et al.,* 2000). A recent geological review (Dongmo *et al.,* 2010) reports a late quaternary (Middle Pleistocene) strombolian cone in the NE slope of Mount Bambouto (Figure 1). This strombolian cone consists of basaltic clasts with hyalo-microlitic and porphyritic texture. Mineral paragenesis is spinel, olivine, Ti-magnetite, clinopyroxene, pla-gioclase, leucite and interstitial glass with nepheline to sodic plagioclase composition.

According to their silica (SiO_2: 41.9-43.3%) and alkaline (MgO: 12.4%-12.7%; CaO: 10.5%-11.4%; Na_2O: 2.1%-3.0% and K_2O: 0.9%-1.2%) contents, and their normative composition (6.3 < nepheline % weight <10.7; 24.2 < olivine % weight <24.8), they belong to basanite from sodic series (Dongmo *et al.,* 2010).

The NE slope of Mount Bambouto is characterised by wet, humid and cool climate with perudic moisture regime (1700 to 1800 mm annual rainfall) and isothermic conditions (15- 18° C mean annual temperature). The rainy season stretches from March to October and the drying season from November to February. The land use in this area inludes annual row cropping with rotational farming of maize, bean, potatoes, etc.

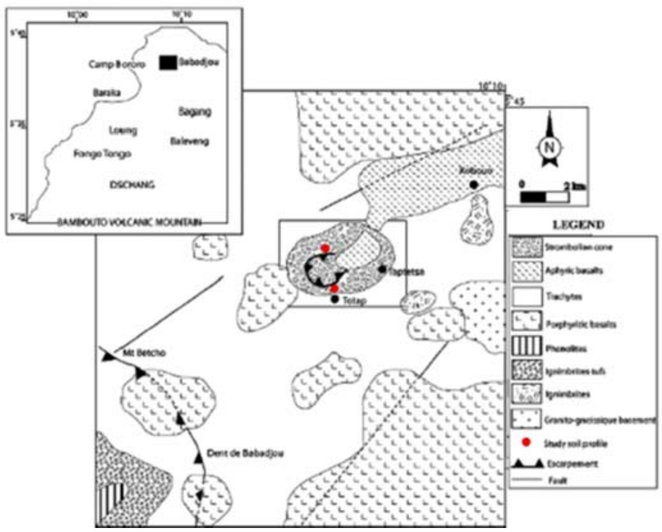

Figure 1: Geological map of the study site

Methods

Two soil profiles were selected for the study on the late quaternary-aged deposits: the ZA pedon at 1925 m in the northern slope of the cone, and the TO pedon at 2005 m in the southern slope of the cone. Soil profiles were dug up to the unweathered parent material. Profiles were differentiated by horizon and a morphological description was made (Maignien, 1980), consisting of soil colour, texture, structure, consistence, and horizon boundary. In each profile, soil samples were collected in triplicate along the thickness of each horizon and mixed to obtain a mean sample. Samples were air-dried, crushed (for saprolite samples), and sieved through <2 mm fraction before physical, mineralogical and chemical analyses.

The bulk density (BD) was obtained by the cylinder method using BD = w/v formula where w is the weight of soil contained in the cylinder and v its volume. Particle size was analysed using Robinson pipette method with Na hexametaphosphate as dispersing agent. Organic matter was previously oxidised using di-ionised water (H_2O_2). Organic carbon (OC) was obtained by oxidation using potassium dichromate as oxidising agent. The available P was extracted by the combination of HCl and NaF, and quantified using ammonium molybdate with ascorbic acid as reducing agent. CEC and exchangeable cations were extracted by ammonium acetate ($CHOONH_4$) at pH 7 and quantified using atomic adsorption spectrometer (AA spectrometer). The retention of P was performed by colorimetry with nitric acid reagent, and quantified by spectrophotometer.

An X-ray diffraction (XRD) was performed in finely ground samples using a Rigaku Geigerflex X-ray diffractometer operating at 40 kV and 45 mA with a Dmax-B controller and Cu Kα radiation. Samples were analysed from 3-75° 2θ, at 1° 2θ/min. Relative amounts of minerals were assessed using peak height above background assuming that intensity (counts/s) of the highest peak of a mineral corresponds to 100% of this mineral in the sample. Selective dissolutions (Dahlgren, 1994) were performed using acid ammonium oxalate, dithionite-citrate (DC) and Na pyrophosphate, identified here by the subscripts "o", "d" and "p", respectively. Extractable Si, Al and Fe were quantified by plasma emission spectroscopy using a JY24 ICP-

OES spectrometer. Allophane was estimated by 7.1 × Sio (Poulenard and Herbillon, 2000). Ferrihydrite was estimated by 1.7 × Feo (Childs *et al*., 1991) and goethite by [1.6 × (Fed – Feo)] (John and Asho, 1998).

Elemental analysis of the soil was performed after dissolution of the material in concentrated HNO_3, HCl and HF acids. Selected elements (Si, Al, Fe, Ti, Ca, Mg, K, Na, Mn, P) were quantified by inductively-coupled plasma spectrometry (ICP-AES). Mass content of each analysed element is reported on a percent oxide basis. Enrichment factor (EF) was estimated by the ratio between content of an element in soil material and that of the fresh rock according to the relation EF(X) = (Xi/Ri)/(Xs/Rs) (Rahn and Mc Cafrey, 1979), in which Xi and Ri are the concentrations of the element of interest and a reference element (Ri) in a given horizon and Xs and Rs are the concentrations of the same elements in the rock. The total reserve in bases (TRB) represents the sum of base cations (Ca + Mg + K + Na) from the total analysis, expressed as mg kg^{-1} of soil (Herbillon, 1986). The chemical index of alteration (*CIA*) corresponds to $[Al_2O_3/ (Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100$, where CaO* is the amount of CaO incorporated in the silicate fraction of fresh rock while Na_2O, K_2O and Al_2O_3 are their concentrations in the analysed soil samples (Nesbitt and Young, 1982). The mobility index of element (*IMob*) is $[(Mob_{rock} - Mob_{soil})/(Mob_{soil})] \times 100$ with *Mob* equal to (K_2O + CaO + Na_2O) (Irfan, 1996).

Results

Soil morphology

The two soil pedons (ZA and TO) (Figure 2) have relatively shallow, weathered (A-BC-C) profiles with thick surface horizons (Table 1). In ZA pedon, the A horizon is 52 cm thick and consists of very dark grey (5YR3/1) silty clay, with fine to very fine crumb structure, and friable to very friable consistence. Its lower boundary is diffuse and irregular. It grades to the underlying brighter colored BC horizon. This BC horizon consists of light yellow brown (2.5Y6/4) weathered saprolite fragments with micrometric and polychromatic punctuations embedded in a dark brown (7.5YR4/4) silty clay soil matrix. It has fine granular soil structure with firm consistence. There are also a few unweathered pyroclastic fragments. With depth, weathered saprolite fragments become bigger and form a continuous C horizon below 2.0 m.

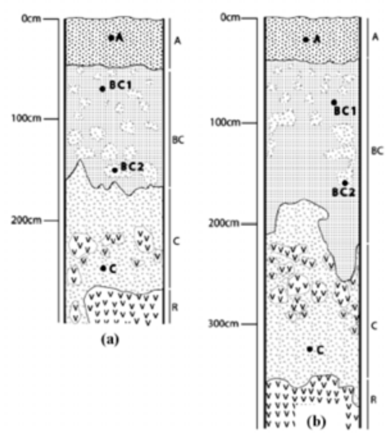

Figure 2: Morphological represntation of (a) ZA and (b) TO soil pedons

Table 1. Morphological characteristics of the selected pedons.

Pedon	Horizon	Samples	Depth (cm)	Color	Textural classes	Structure	Consistence	Lower boundary	Rock fragments (size and volumetric percentage)
ZA pedon	A	A	0 - 52	5YR3/1	sc	very fine crumble	friable to very friable	diffuse and irregular	-
	BC	BC1	52 - 160	7.5YR4/4	sc	granular	firm	distinct and abrupt	-
		BC2		2.5Y6/4	sc	massive	-		5 cm - 20cm 2% - 20%
	C	C	160 - 260	7.5YR7/4 to 2.5Y6/2	ss	massive	-	-	-
TO pedon	A	A	0 - 44	5YR3/4	sc	fine to coarse crumble	very friable	diffuse and irregular	-
	BC	BC1	44 - 206	7.5YR4/4	ss	fine granular	firm	distinct and abrupt	-
		BC2		10YR5/3 2.5Y6/2	ss*	massive	-		5 cm - 25cm 5% - 20%
	C	C	206 - 360	10YR5/3	ss*	massive	-	-	-

Textural classes: sc, silty clay; ss, silty sand; ss*, sandy silt.

The boundary of the BC horizon with the underlying C-horizon is distinct, with an abrupt, wavy boundary. This C horizon consists of pink (7.5YR7/4) to light brown grey (2.5Y6/2) silty sand weathered materials with micro- metric and polychromatic punctuations.

Pedon TO is 3.6 m deep. The A horizon is 44 cm thick, dark brown (5YR3/4) coloured, silty clay texture with fine to coarse crumb structure and very friable consistence. Its transition to the underlying brighter coloured BC horizon is gradual, with a diffuse and irregular boundary.

The fine earth of BC horizon is dark brown (7.5YR4/4), silty sand texture with fine granular structure and firm consistence. It has weathered saprolite fragments that are light brown (10YR5/3) and break down into a sandy silt texture, and few light brownish grey (2.5Y6/2) unweathered pyroclastic fragments. With depth, the weathered saprolite and unweathered pyroclastic fragments increase in number and size and demarcate an almost continuous C horizon at about 1.5 m depth. The transition to the underlying C horizon is distinct, with an abrupt and irregular boundary.

Physico-chemical soil properties

The bulk density (Table 2) is very low (<0.82 g cm^{-3}) throughout the profiles of both soils, with values of 0.65 g cm^{-3} and 0.67 g cm^{-3} in surface horizons of pedons ZA and TO, respectively, and increasing slightly with depth. Particle size indicates moderate proportion of sand at the soil surface (≈35%) which increases up to about 75% with depth. Inversely, the amount of clay is high at soil surface (39% and 29%, for pedons ZA and TO, respectively) and decreases significantly in the C horizons (<8%). The amount of silt also decreases slightly with depth.

Table 2. Physical and chemical soil properties of the selected pedons.

Studied pedon	Soil horizon	samples	BD ($g.cm^{-3}$)	Particle size (%)				Organic matter		Exchangeable cations ($cmol·kg^{-1}$)						CEC ($cmol·kg^{-1}$)	P retention (%)	Alo + 0.5Feo (%)
				clay	silt	sand	pHw	OC (%)	available P ($mg·kg^{-1}$)	Ca^{2+}	Mg^{2+}	K^+	Na^+	S	Al^{3+}			
ZA pedon	A (0 - 52 cm)	A	0.65	31	31	38	4.3	7.0	11	2.2	0.8	0.1	0.0	3.1	1.5	27.1	94	1.9
	BC (52 - 160 cm)	BC1	0.75	39	27	34	4.5	0.48	1	0.3	1.2	1.0	0.0	2.5	1.5	22.2	92	1.7
		BC2	0.77	38	26	36	5.3	0.15	0	1.1	1.8	0.4	0.0	3.3	0.5	19.6	93	1.6
	C (160 - 260 cm)	C	0.81	7	18	75	4.9	0.0	7	1.7	7.6	0.1	0.0	9.4	0.5	28.9	83	1.2
TO pedon	A (0 - 44 cm)	A	0.67	29	38	33	4.7	5.9	7	2.3	1.0	0.1	0.0	3.4	4.5	25.4	95	2.2
	BC (44 - 206 cm)	BC1	0.66	20	24	56	3.9	1.1	0	1.0	1.7	0.1	0.0	3.4	7.0	23.1	92	1.3
		BC2	0.75	6	20	74	3.9	0.0	7	1.1	3.0	0.1	0.0	4.2	11.3	20.1	75	0.8
	C (206 - 360 cm)	C	0.72	4	18	78	4.4	0.0	5	3.2	7.7	0.2	0.0	11.1	1.3	22.3	78	1.1

OC, organic carbon; S, sum of exchangeable cations; BD, bulk density.

Table 3. Selective extraction data for selected pedons.

Selected pedon	Soil horizon	samples	Total concentration		Selective extraction						
			concentrations in %								
			Al_T	Fe_T	Al_d	Fe_d	Al_o	Fe_o	Si_o	Al_p	Fe_p
ZA pedon	A (0 - 52 cm)	A	11.01	13.64	1.30	8.90	1.18	1.39	1.88	0.80	1.20
	BC (52 - 160 cm)	BC1	12.07	13.64	1.40	9.10	0.93	1.57	1.72	0.90	0.60
		BC2	12.01	13.78	1.00	9.0	0.72	1.71	1.58	0.30	0.40
	C (160 - 260 cm)	C	10.43	15.32	0.50	7.50	0.50	1.37	0.69	0.10	-
TO pedon	A (0 - 44 cm)	A	10.58	13.50	1.30	8.40	1.31	1.68	2.15	0.80	0.60
	BC (44 - 206 cm)	BC1	11.85	13.15	0.90	7.90	0.69	1.26	1.32	0.30	0.30
		BC2	11.59	9.72	0.50	4.10	0.48	0.62	0.79	0.20	-
	C (206 - 360 cm)	C	10.74	13.57	0.40	7.70	0.42	1.25	1.07	0.10	-

Table 4. Minerals in the selected pedons.

Pedon	Soil horizon	samples	Minerals detected by XRD				Minerals estimated by selective extraction			
			abundance in %							
			kaolinite	gibbsite	plagioclase	pyroxene	goethite	ferrihydrite	allophane	Organo-metal complexes
ZA pedon	A (0 - 52 cm)	A	71	12	0	-	12	2.4	1.1	2.1
	BC (52 - 160 cm)	BC1	57	26	0	-	12	2.7	0.6	0.9
		BC2	54	29	0	-	12	2.9	0.9	0.7
	C (160 - 260 cm)	C	60	13	14	-	10	2.3	1.1	0.1
TO pedon	A (0 - 44 cm)	A	75	9	0	0	11	2.9	1.1	1.4
	BC (44 - 206 cm)	BC1	29	19	23	0	11	2.1	0.7	0.6
		BC2	3	3	64	23	6	1.1	0.6	0.2
	C (206 - 360 cm)	C	29	0	57	0	10	2.1	0.9	0.1

The soils ranges from highly-acid to acid, with pH of 4.3-5.3 in pedon ZA and 3.9-4.7 in pedon TO. The organic carbon is very high in the surface horizon (7.0 and 5.9% in pedons ZA and TO, respectively). The available P is also relatively high at soil surface (11 $mg·kg^{-1}$ and 7 $mg·kg^{-1}$ in pedons ZA and TO, respectively). The sum of exchangeable cations is low (less than 12 $cmol.·kg^{-1}$), with its highest values

deeper in the profile. The most abundant exchangeable cations are Mg^{2+} (≤7.7 cmol. $\cdot kg^{-1}$) and Ca^{2+} (≤3.2 cmol. $\cdot kg^{-1}$). Inversely, the CEC is relatively high (19.6 to 28.9 cmol. $\cdot kg^{-1}$ in pedon ZA and 20.1 to 25.4cmol $\cdot kg^{-1}$ in pedon TO). The exchangeable Al^{3+} is relatively low in pedon ZA, but ranges up to 11.3 cmol. $\cdot kg^{-1}$ in pedon TO. The P retention is very high, >90% in the upper part of both soils. The acid ammonium oxalate extractable Alo + 0.5Feo is about 2% at soil surface, but decreases with depth.

Soil mineralogy

In general, mineral associations in the studied soils correspond to kaolinite, gibbsite, goethite, ferrihydrite, allophane and organometal complexes. However, primary minerals like plagioclase and pyroxene are still present in specific materials. Both soils contain a large amount of organometal complexes (Tables 3 and 4) as well as short-range and long-range ordered minerals. There are also not completely weathered primary minerals remaining in these soils.

The primary minerals: Primary minerals include plagioclase and pyroxene (Figure 3). In pedon ZA, plagioclase is the remaining primary mineral in weathered saprolite (C horizon) and represents 14% of the minerals (Table 4). Plagioclase and pyroxene are present in pedon TO. Plagioclase displays a sharp and intense peak at 0.323 nm in the weathered rock fragments (Figure 3). In the weathered rock fragments, it represents 57-64% of the minerals. Peak representing pyroxene is at 0.283 nm and the weathered saprolite has 23% of this mineral.

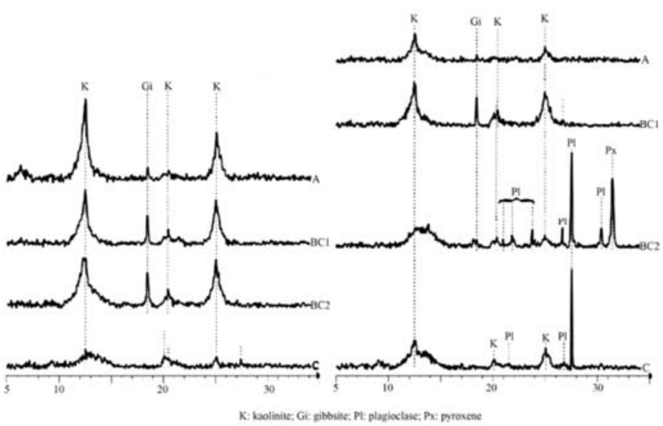

Figure 3: X-ray patterns of thte studied soil pedons

The short-range ordered minerals and the organometal complexes. The organometal complexes correspond to the Al (and/or Fe)-humus complexes extracted by sodium pyrophosphate (Table 3). These complexes are found in small quantities at soil surface (Table 4). The short-range ordered minerals identified correspond to allophane and ferrihydrite. Allophane contents are relatively low in both soils (less than 1.2%) and varied little with depth. Ferrihydrite contents are slightly higher throughout these soils (2.3-2.9% in pedon ZA and 1.1 to 2.9% in pedon TO) (Table 4).

The long-range ordered minerals. The long-range ordered minerals identified by XRD (Figure 3) are kaolinite and gibbsite, and goethite was quantified by selective extraction (Table 4). Kaolinite has peaks at about 0.715 nm and 0.357 nm. It is the most abundant secondary mineral in these soils representing 54-71% and 3-75% of the minerals in pedons ZA and TO, respectively (Table 4). The largest amount of kaolinite is in the topsoil. Gibbsite is also prominent in these soils, with major peak around 0.485 nm. It is the second

most abundant secondary mineral in these soils and is 12-29% in in pedons ZA and 3-19% in TO. This mineral is present in largest amounts in the BC horizons, and decreases in concentration in the A and C horizons (Table 4). Goethite is the only iron bearing mineral in these pedons and has a relatively uniform concentration with depth in both pedons. It is 10-12% in pedons ZA and 6-11% in TO (Table 4).

Soil geochemistry

Silica contents (Table 5) decrease from about 43% in the parent material to 28% in the soil surface. Alkalis (K_2O and Na_2O) and alkaline earth (CaO and MgO) elements also decrease in soil relative to the fresh rock (Table 5), and remain very low throughout the profiles. Inversely, Al_2O_3 and Fe_2O_3 contents increase in soil (23% Al_2O_3; 21%% of) relative to the fresh rock (about 12% Al_2O_3 and 13% Fe_2O_3). The Al_2O_3 contents decrease very slightly at soil surface (about 20%) while Fe_2O_3 did not vary much throughout the profiles.

The molar ratio Ki (SiO_2/Al_2O_3), an indicator of the relative mobility of Si to Al (Table 5), decreases in relation to the parent material (3.5-1.1). The total reserve in base (TRB), a measure gives of the weathered primary minerals in soils, also drops from the fresh rock (252.9 and 170.7mg·kg^{-1} in pedons ZA and TO, respectively) to the weathered level (46.1 and 66.7mg.kg^{-1}, respectively), suggesting the depletion of weatherable minerals in the topsoil.

Table 5. Major elements abundances and weathering indexes in the selected pedons.

Studied pedons	Soil horizon	samples	Major elements abundance (%)										Ki	TRB (mg·kg^{-1})	CIA (%)	IMob (%)
			SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	MnO	P_2O_5				
ZA pedon	A (0 - 52 cm)	A	28.1	20.8	19.5	4.0	0.2	0.7	0.4	0.2	0.3	0.4	1.4	57.6	65.4	17.2
	BC (52 - 160 cm)	BC1	25.4	22.8	19.5	3.9	0.1	0.6	0.3	0.2	0.2	0.4	1.1	52.4	67.6	21.4
		BC2	26.2	22.7	19.7	3.9	0.1	0.7	0.3	0.2	0.2	0.4	1.2	46.1	67.6	24.5
	C (160 - 260 cm)	C	29.0	19.7	21.9	4.5	0.2	3.8	0.3	0.2	0.3	0.6	1.5	48.9	64.3	20.7
	R (260 cm -)	R	43.3	12.6	13.3	2.8	10.5	12.5	0.9	3.0	0.2	0.7	3.4	252.9	46.6	-
TO pedon	A (0 - 44 cm)	A	27.6	20.0	19.3	3.6	0.2	0.9	0.4	0.2	0.3	0.4	1.4	62.6	63.8	19.4
	BC (44 - 206 cm)	BC1	30.9	22.4	18.8	3.6	0.1	0.7	0.4	0.2	0.3	0.4	1.4	57.1	66.3	20.0
		BC2	39.6	21.9	13.9	2.6	0.2	0.7	1.1	0.6	0.3	0.3	1.8	66.7	63.6	6.9
	C (206 - 360 cm)	C	32.9	20.3	19.4	4.0	0.2	14.0	0.6	0.2	0.3	0.4	1.6	101.0	63.7	14.5
	R (360 cm -)	R	42.2	12.1	13.9	2.9	10.9	12.7	1.2	2.7	0.2	0.8	3.5	170.7	45.0	-

Ki, SiO_2/Al_2O_3; TRB, total reserve in bases; CIA, chemical index of alteration; IMob, mobility index.

Inversely, the chemical index of alteration (*CIA*), representing the weathering intensity, and the mobility index (*IMob*) used to evaluate the intensity of CaO, Na_2O and K_2O exportation during weathering [24], increase drastically from the fresh rock (46.6 and 45.0% of *CIA*, in pedons ZA and TO, respectively) to the topsoil, with their highest values in horizon BC (67% CIA, 24.5% *IMob*). This is consistent with a moderately weathering intensity in a highly leaching milieu.

Enrichment-depletion of chemical elements in the studied soils was assessed using enrichment factors (EF) define EF. The chemical elements analysed are grouped into enriched (EF >1.00) and depleted (EF <1.00) elements according to their enrichment factors (Figure 4). Enriched elements are Al_2O_3 and Fe_2O_3. Al_2O_3 is enriched in both studied pedons, with EF at 1.16-1.30 in pedon ZA and 1.22-2.02 in pedon TO. The highest EFs for Al_2O_3 are in the subsurface horizon BC. Fe_2O_3 is slightly enriched in the studied profiles, with EF not exceeding 1.03 in pedon ZA and 1.12 in pedon TO. Depleted elements are SiO_2, CaO, MgO, K_2O and Na_2O. SiO_2 is moderately depleted, with EF at 0.42-0.45 in pedon ZA, and 0.53-1.05 in pedon TO. Also moderately is K_2O in the studied profiles (EF from 0.21-0.31 in pedons ZA and 0.27-1.02 in pedon TO). But, CaO, MgO and Na_2O are strongly depleted in the studied profiles, with EF <0.2.

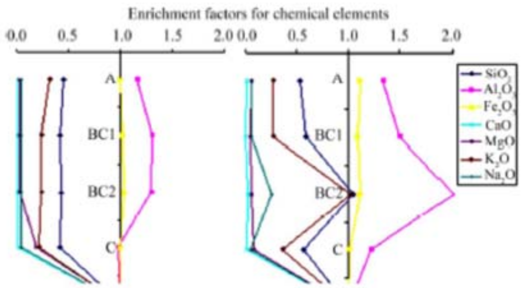

Figure 4: Chemical elemeny mobility in the studies pedons

Discussion

The studied soils belong to the reference group of Andosol in the WRB system as indicated by the low bulk density (<0.7 g cm^{-3}), Alo + 0.5Feo about 2% and the P retention >90% in their surface horizon A. The high organic carbon in the surface horizon A (OC: 5.9 and 7.0%) confirms that the pedogenetic conditions in andic soils favour accumulation of organic matter (Yonebayashi and Hattori, 1988). They are depleted of bases with the base saturation <15% (not shown) which results in the use of the dystric qualifier as suffix for this WRB reference group. The low content of Si extracted by ammonium oxalate (Sio: 0.15%) (Table 3) and the Alp/Alo ratio >0.5 (0.7 in pedon ZA and 0.6 in pedon TO) (not shown) which indicate that Al is predominantly organically bound (Prevosto *et al.,* 2004) suggest that these soils owe their andic properties to Al-humus complexes and therefore belong to the non-allophanic category of andosols. These remarks justify the use of the *aluandic* qualifier as prefix for this reference group. Therefore, these soils key out as aluandic Andosols (dystric) according to the WRB soil classification system.

Referring to the weathering process, kaolinite and goethite are the dominant weathering products in both soil pedons. Their presence in the weathered saprolite is accompanied by the decrease of *TRB*, the increase of *IMob* and the EFs far below 0.6 for Si, Ca, Mg, K and Na. These observations point out an important depletion of silica and total leaching of base cations, highlighting a sparingly hydrolyses (Childs *et al.,* 1991) in subsoil. Thus, in these soils, weathering leads to faster release of Al, Fe and Si which are initially incorporated into allophanic and ferrihydrite minerals. These short-range ordered minerals are transient and undergo crystallisation into poorly crystallised kaolinite and goethite under humid conditions (Dahlgren, 1994; Mizota and Van Reenwijk, 1983). In the topsoil, kaolinite, goethite, gibbsite and organometal complexes are present. Occurrence of gibbsite isolated in the topsoil has been reported in various andosols worldwide (Tematio *et al.,* 2009; Ndayiragije and Delvaux, 2003; Wada and Harward, 1974). It was largely attributed to localised desilication of kaolinitic minerals during intense leaching in highly acid milieu under perudic conditions. Also, the topsoil is strong acidic (pH <4.7), enhancing the formation of organometal complexes (Aran *et al.,* 1998) and accumulation of organic matter which limit precipitation of Al and Si (Parfitt and Kimble, 1989), and result in anti-allophanic effect (Shoji *et al.,* 1993). Below pH 4.9, Al is in a monomeric or organically complexed form and is not available for incorporation into mineral structure. About the weathering intensity, the CIA between 60 and 70% and the abundance of secondary minerals indicate that the weathering gradient of these soils is moderately high (Fedo *et al.,* 1995). This is emphasised by the absence of weatherable primary minerals at soil surface (low TRB), which attests that the fresh rock has been completely weathered.

From findings, a major difference in the andosolisation process operating on old trachytic formations from those operating on recent strombolian deposits is the formation of kaolinite instead of halloysite in the late quaternary strombolian cone soils. This may be consistent with the less humid conditions prevailing in the NE slope of Mount Bambouto, highly influenced by relatively dry wind from Sahara desert named

Harmattan (Tsalefac, 1999). Except the above difference, both Andosols in Mount Bambouto show similar morphology (shallow weathered A-BC-C soil pedons) and about the same mineral composition (organometal complexes, Al bearing 1:1 clay minerals, gibbsite and goethite). Consequently, the similar weathering processes are likely operating in both sites at Mount Bambouto, and therefore, the discontinuities of the volcanic activities (rocks age) of these sites have little influence.

Conclusion

In the late quaternary strombolian deposits from Mount Bambouto, andic soils refer to aluandic Andosols (dystric). They derive from the andosolisation process which corresponds to fast and intense release of Si, Al and Fe during rapid hydrolysis of volcanic products under humid conditions. Transient allophanic and ferrihydrite minerals are formed that crystallised into kaolinite, gibbsite and goethite. Part of released Al (and Fe) is bounded at topsoil by organic acids to form stable and less mobile organometal complexes. Thus in Mount Bambouto, andosols are non-allophanic which seem to have developed at the same period despite the wide range of rock ages and type.

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Effects of tillage, fallow and burning on selected properties and fertility status of Andosols in the Mounts Bambouto, West Cameroon

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Abstract

To assess the impact of land use on soil fertility, changes in chemical and physical properties affecting soil quality were monitored on Andosols from Mount Bambouto, West Cameroon. In fact, these soils were subjected to four land uses and management systems: natural cover, tillage, burning and fallow. In comparison with the natural cover, results indicated that tillage reduced Andosol organic carbon (OC: 6.5% to 4.8%), total nitrogen (N: 4.51‰ to 2.95‰) and cationic exchange capacity (CEC: 22.0 to 20.9 cmol $\cdot kg^{-1}$). The abundance of soil macro-aggregates expressed by the water stable aggregates (*WSA*) varied from 53.8% to 12.0%. Tillage also increased the bulk density (*da*: 0.69 to 1.09 g $\cdot cm^{-3}$) and the sum of exchangeable cations (S: 3.58 to 4.84 cmol $\cdot kg^{-1}$). Burning reduced Andosol OC (6.5% to 0.8%), total N (4.51‰ to 0.95‰) and CEC (22.0 to 10.2 cmol $\cdot kg^{-1}$), but increased soil pH (4.62 to 6.54), the sum of exchangeable cations (3.58 to 5.74 cmol $\cdot kg^{-1}$) and the abundance of soil macro-aggregates (*WSA*: 38.2% to 57.0%). In comparison with tillage, fallow increased Andosol OC (4.8% to 6.5%), total N (2.95‰ to 5.04‰), CEC (18.0 to 21.6 cmol $\cdot kg^{-1}$), the sum of exchangeable cations (3.58 to 5.05 cmol $\cdot kg^{-1}$) and the abundance of soil macro-aggregates (*WSA*: 12.0% to 48.8%). Globally, the tillage management deteriorated Andosol chemical and physical properties affecting fertility, whereas the fallow management restored them. The burning management also improved some Andosol chemical and physical properties affecting quality, though it did not last long.

Key words: Andosols; land use management systems; soil physic-chemical properties; soil fertility.

Introduction

Soil quality is fundamental for sustainable agriculture development (Dumanski and Pieri, 2000). The land use and management systems strongly influence soil quality expressed by changes in soil chemical and physical properties (organic matter content, CEC, sum of exchangeable cations, acidity, bulk density, aggregates stability, etc.). Thus, improper land use and management systems reduce soil fertility and the subsequent food security (Oldeman *et al*., 1990). Many studies on soil fertility have focused mainly on nutrients budget and balances (Smaling *et al*., 1996; Harris, 1998) without emphasis on changes in soil chemical and physical properties affecting soil quality over time.

In Mount Bambouto, a volcanic mountain in West Cameroon Highlands where Andosols are widespread (Tematio *et al*., 2004), strong human pressure on land expressed by the tillage and burning management systems have affected the agroecosystems in the past 30 years (Tematio and Olson, 1997). One of the consequences is the overexploitation of soil resources with subsequent crop yields decrease. Considering the precarious conditions of Andosols characterized by a rapid degradation of the majority of their chemical and physical properties when farming, new strategies for sustainable management of Andosols in this area have to be found urgently. Therefore, it might be useful to identify the land use and management systems impacts on Andosol fertility in Mount Bambouto. The main objective of this study was quantified changes in chemical and physical properties of the Andosols from Mount Bambouto subjected to tillage, burning or fallow management systems in order to compare the effects of these land uses and management systems on Andosol quality changes. This would contribute proposed standard systems that safeguard Andosol quality.

Materials and methods

This study was carried out in Mount Bambouto, one of the major volcanoes in the Cameroon Volcanic Line that crosses the western part of the Cameroon territory. In this mountain, a recent soils survey (Tematio *et al.,* 2004) points out that Andosols are widespread above the altitude 2000 m.

They are shallow weathered pedons, either with A and BC horizons when developed on crests and steep slopes, or A, B and BC horizons when developed on foot-slopes. The surface horizon A is the main agricultural soil horizon supporting crop farming. It corresponds to a thick (up to 60 cm) and dark grey to dark brown (10YR3/2 - 10YR3/3) loamy soil with fine to coarse crumbly structure. These Andosols in Mount Bambouto are mainly devoted to Irish potato and cabbage farming.

In this area, 17 plots were selected with respect to the farming crops (Irish potatoes), the slopes gradient (slightly undulated landscape), the landscape position (foot-slopes), the type of land use and management system applied and its duration. They were distributed as follows: 3 plots under the natural cover named NT, 2 plots under the short-term (5 years) tillage (T1), 4 plots under the long-term (10 years) tillage (T2), 2 plots under the short-term (5 years) burning (B1), 2 plots under the long-term (10 years) burning (B2), 2 plots under the short-term (5 years) fallow (F1) and 2 plots under the long-term (10 years) fallow (F2). In this area, the most significant variations in chemical and physical properties induced by the different land use and management systems occurred within the first 40 cm of the surface horizon A. Hence, in each selected plot, soil samples for chemical analyses were collected at 20 cm depth, mixed, air dried, crushed and 2 mm sieved. Undisturbed soil samples were also collected at the same depth for bulk density and aggregates stability measurements.

Chemical analyses included soil organic carbon (OC), total nitrogen (N), available phosphorus (P), exchangeable cations; cations exchange capacity (CEC) and the soil pH. Soil organic carbon was extracted by oxidation with potassium dichromate in strongly acid solution and determined using a TOC-5000A analyzer. The total N was determined by Kjeldahl method, the available P by Bray II method and the exchangeable cations extracted by NH_4OAc buffered at pH 7 and determined by atomic absorption spectrophotometer. The CEC at pH 7 was determined using ammonium acetate method. The soil pH was determined in a 1:2.5 soil suspension with de-ionised water.

Physical analyses refer to the bulk density (da), the particle size distribution and the soil aggregate stability. Bulk density was obtained using the cylinder of Koppeki method (Blake, 1982). With regard to the particle size distribution, sand fraction was separated by wet-sieving with 63 µm sieve, oven dried at 105°C and weighed. Silts and clay fractions were determined by laser diffraction after destruction of organic matter with hydrogen peroxide, followed by the particle dispersal in sodium hexametaphosphate solution. The soil aggregate stability was determined according to Le Bissonnais method (Le Bissonnais, 1996) which combines 3 disruptive tests: slow wetting, fast wetting and mechanical breakdown by shaking after pre-wetting tests. After each test, residual aggregates were collected and sieved using a column of six sieves: 2000, 1000, 500, 200, 100, and 50 µm. The proportion of each fraction size of stable aggregates was calculated.

Data analyses refer to the sum of exchangeable cations (S), the cations equilibrium (Ca/Mg/K), Al^{3+} toxicity (m) and the soil aggregate stability calculation. Exchangeable cations (S), was obtained by summing up the exchangeable cations. The cations equilibrium noted (Ca/Mg/K) is the relative abundance of Ca^{2+}, Mg^{2+} and K^+ in soil qualifying the competition between the above cations during plant nutrition. Al^{3+} toxicity (m) (Equation 1) refers to the ratio between the concentration of free Al^{3+} in the soil solution and exchangeable cations (S).

The soil aggregate stability is expressed by the water stable aggregates (*WSA*) as shown in Equation 2, the geometric mean diameter (*GMD*) as given in Equation 3 and the mean weight diameter (*MWD*) in Equation 4.

In these equations, *n* is the number of aggregates size ranges above 0.5 mm, *wi* is the weight of aggregates in a size of average diameter *xi*, and *wo* is the total weight of aggregates placed on 5 mm sieve for analysis.

The mean values of the soil chemical and physical properties in each series of plots under the same land use and management system were obtained using MS EXCEL software.

Results

Soil chemical properties

Organic Carbon (OC), Total Nitrogen (N) and Available Phosphorous (P). The soil OC content was high in the study plots and varied from 4.8% to 6.5%, except in B1 (0.8%) and B2 (1.5%) (Table 1). It decreased slightly from NT (6.5%) to T1 (5.7%) and T2 (4.8%), and abruptly in B1 (0.8%) and B2 (1.5%). Inversely, it increased in F1 (6.5%) and F2 (5.5%) compared to T1 and T2. The total N content followed the same trend like the soil OC content and varied from 0.95‰ to 5.04‰. It thus decreased slightly from NT (4.51‰) to T1 (4.15‰) and T2 (2.96‰), and abruptly in B1 (0.95‰) and B2 (1.96‰), and increased significantly in F1 (5.04‰), but remained low in F2 (1.87‰). The available P content varied from 7.0 to 43.6 mg $\cdot kg^{-1}$ in the study plots. Its lowest value was in NT (7.0mg.kg^{-1}). It increased in T1 (22.2 mg $\cdot kg^{-1}$), T2 (11.7 mg $\cdot kg^{-1}$), B1 (18.7 mg $\cdot kg^{-1}$) and B2 (43.6 mg $\cdot kg^{-1}$), but decreased in F1 (10.8 mg $\cdot kg^{-1}$) and F2 (15.9 mg $\cdot kg^{-1}$) relative to T1 and T2.

Cation Echange Capacity (CEC), Exchangeable Cations and Acidity. The CEC content was relatively high in the study plots and varied from 10.2 to 22.0 cmol $\cdot kg^{-1}$ (Table 1). The highest value was in NT (22.0 cmol $\cdot kg^{-1}$). It decreased slightly in T1 (18.0 cmol.kg^{-1}) and T2 (20.7 cmol.kg^{-1}) and severely in B1 (10.2 cmol $\cdot kg^{-1}$) and B2 (11.4cmol.kg^{-1}), but increased slightly in F1 (20.6 cmol $\cdot kg^{-1}$) and F2 (21.6 cmol $\cdot kg^{-1}$) with respect to T1 and T2. The sum of exchangeable cations (S) was very low in the study soils (3.6 to 5.7 cmol $\cdot kg^{-1}$).

It increased slightly from NT (3.6 cmol $\cdot kg^{-1}$) to T2 (4.9 cmol $\cdot kg^{-1}$), B1 (5.7 cmol $\cdot kg^{-1}$), B2 (3.9 cmol $\cdot kg^{-1}$), F1 (5.1 cmol $\cdot kg^{-1}$) and F2 (4.3 cmol $\cdot kg^{-1}$), and remain unchanged in T1 (3.6 cmol $\cdot kg^{-1}$). It highest content was in B1. The most abundant exchangeable cation was Ca^{2+} (1.60 to 3.92 cmol $\cdot kg^{-1}$), followed by Mg^{2+} (0.61 to 2.00 cmol $\cdot kg^{-1}$), K^{+} (0.15 to 0.99 cmol $\cdot kg^{-1}$) and Na^{+} (0.03 to 0.09 cmol $\cdot kg^{-1}$). The cations equilibrium was close to the optimal equilibrium (76/18/6) in NT (78/17/5), T2 (73/20/7) and F1 (78/17/5), and highly unbalanced in T1 (54/ 39/7), B1 (58/25/17), B2 (41/51/8) and F2 (63/33/4) with respect to Ca deficiency. The exchangeable Al^{3+} content varied from 0.00 to 0.28 cmol $\cdot kg^{-1}$. Consequently, the aluminum toxicity was relatively low (m: 0.0% to 7.0%). Nevertheless, the study soils were strongly acids (pH 4.42 to 4.64), except for B1 and B2 with weak acid soils (pH 6.54 and 6.18 respectively). This acidity increased slightly from NT (pH 4.62) to T1 (pH 4.42) and T2 (pH 4.53), but decreased abruptly in B1 (pH 6.54) and B2 (pH 6.18) and slightly in F1 (pH 4.64) and F2 (pH 4.47) relative to T1 and T2.

Soil physical properties

Bulk density (da) and particle size distribution. The bulk density (da) varied from 0.69 to 1.14 g.cm^{-3}. The lowest value was in NT (0.69 g.cm^{-3}). It increased significantly in T1 (0.93 g $\cdot cm^{-3}$), T2 (1.09 g $\cdot$cm-3), F1 (1.14 g $\cdot cm^{-3}$) and F2 (1.09 g.cm^{-3}) and lesser in B1 (0.77 g $\cdot cm^{-3}$) and B2 (0.79 g $\cdot cm^{-3}$). The silt (60 to 78%) and clay (14 to 36%) fractions were dominant. The clay fraction increased in T1 (36%) and T2 (31%), and decreased in B1 (20%) and B2 (14%) relative to NT (29%). It also decreased in F1 (25%) and F2 (31%) compared to T1 and T2. The highest fine silt content was in NT (53%). It decreased in T1 (47%), B1 (34%), B2 (49%), F1 (45%) and F2 (50%) and remain unchanged in T2 (53%). The coarse silt abundance also decreased from NT (17%) to T1 (13%) and T2 (13%), but increased in B1 (34%) and B2 (29%). It also increased in F1 (28%) and F2 (16%) compared to T1 and T2. The sand fraction was the less abundant (2% to 12%) with the highest value in B1 (12%).

Table 1: Mean values of the physical and chemical soil characteristics in the studied plots

		Soil organic matter			Exchangeable cations					CEC	Exchangeable acidity		Soil acidity	da (g.cm^{-3})	Particle size (%)				Cation equilibrium
Studied plot		OC (%)	N (‰)	P (mg.kg^{-1})	Ca^{2+} (cmol.kg^{-1} of soil)	Mg^{2+}	K^{+}	Na^{+}	S		Al^{3+}	m (%)	pH		clay	Fine silt	Coarse silt	Sand	
Not tilled	NT	6.5	4.5	7.0	1.7	0.9	0.8	0.0	3.4	22.0	0.3	5.9	4.6	0.7	29	52	17	2	(78/17/5)
Tilled	T1	5.7	4.2	22.2	1.8	1.1	0.8	0.0	3.7	18.0	0.2	7.0	4.4	0.9	36	47	13	4	(54/39/7)
	T2	4.8	3.0	11.7	3.1	1.5	1.0	0.0	5.6	20.9	0.2	5.5	4.5	1.1	31	53	13	3	(73/20/7)
Burn	B1	0.8	1.0	18.7	5.1	3.0	2.0	0.0	10.1	10.2	0.0	0.0	6.5	0.8	20	34	34	12	(58/25/17)
	B2	1.5	2.0	43.6	4.9	3.1	2.6	0.1	10.7	11.4	0.0	0.0	6.2	0.8	14	49	29	2	(41/51/8)
Fallow	F1	6.5	5.0	10.8	2.7	1.2	1.0	0.0	4.9	20.6	0.3	5.1	4.6	1.1	25	45	28	2	(78/17/5)
	F2	5.5	1.9	15.9	1.7	1.1	1.0	0.0	3.8	21.6	0.3	5.7	4.5	1.1	31	50	16	3	(63/33/4)

Aggregate stability. The soil aggregate stability parameters were displayed in Table 2 (29.4%, 12.0% and 15.8%) and the highest in B2 (57.0%, 51.4% and 52.2%), respectively after the slow wetting and the stirring after pre-wetting tests.

Table 2: Soil aggregates stability in the studied plots

Studied plot	Test	Slow wetting			Fast wetting			Stirring after wetting		
		WSA (%)	GMD (mm)	MWD (mm)	WSA (%)	GMD (mm)	MWD (mm)	WSA (%)	GMD (mm)	MWD (mm)
Not tilled	NT	58.3	1.76	2.69	38.9	1.55	1.95	38.2	1.47	1.91
Tilled	T1	48.4	1.62	242	37.9	1.44	1.90	34.5	1.26	1.72
	T2	29.4	1.30	1.47	12.0	1.18	0.06	15.8	0.94	0.79
Burn	B1	53.3	1.70	2.66	53.3	1.69	2.67	46.7	1.55	2.34
	B2	57.0	1.72	2.85	51.4	1.70	2.57	52.2	1.64	2.61
Fallow	F1	40.1	1.55	2.00	27.5	1.28	1.38	48.2	1.67	2.41
	F2	48.8	1.63	2.44	42.5	1.53	2.13	29.6	1.28	1.48

The geometric mean diameter (*GMD*) of the soil macro-aggregates decreased progressively after the slow wetting (1.30 - 1.76 mm), the fast wetting (1.48 - 1.70 mm) and the stirring after pre-wetting (0.94 – 1.67 mm) tests. It decreased from NT (1.47 - 1.76 mm) to T1 (1.26 - 1.62 mm), T2 (0.94 - 1.30 mm), B1 (1.55 - 1.70 mm), B2 (1.64 - 1.72 mm), F1 (1.28 - 1.67 mm) and F2 (1.28 - 1.63 mm) whatever the test. The lowest *GMD* values were in T2 (1.30 mm, 1.18 mm and 0.94 mm, respectively after the slow wetting, the fast wetting and the stirring after pre-wetting tests). The mean weight diameter (*MWD*) of the soil macro- aggregates also decreased severely after the slow wetting (1.47 - 2.69 mm), the fast wetting (0.60 - 2.67 mm) and the stirring after pre-wetting (0.79 – 2.61 mm) tests. It always decreased from NT (1.91 – 2.69 mm) to T1 (1.72 – 2.42 mm), T2 (0.60 – 1.47 mm), F1 (1.38 – 2.41 mm) and F2 (1.48 – 2.44mm), but increases in B1 (2.34 – 2.67 mm) and B2 (2.57 – 2.85 mm). The lowest values of the MWD of these soil macro-aggregates remained in T2 (1.47 mm, 0.60 mm and 0.79 mm after the slow wetting, the fast wetting and the stirring after pre-wetting tests respectively). The water stable aggregates (*WSA*) abundance in the study soils remained relatively high after the slow wetting test, and varied from 29.4% to 57.0%. It decreased significantly after the fast wetting (12.0% to 53.3%) and the stirring after pre-wetting (15.8% to 52.2%) tests regardless of the land use and management systems. It decreased in T1 (34.5% - 48.4%), T2 (12.0% - 29.4%), F1 (27.5% - 48.2%) and F2 (29.6% – 48.8%); but increased slightly in B1 (46.7% - 53.3%) and B2 (51.4% - 57.0%) compared to NT (38.2% - 53.8%). The lowest *WSA* abundance was in T2.

Discussion

Variations in most of the soil chemical and physical properties are the key for understanding the impact of land use and management systems on soil quality.

Changes in soil chemical properties

In the Andosols from Mount Bambouto, the tillage management system resulted in a significant reduction of soil organic matter expressed by the soil OC (6.5% to 4.8%) and the total N (4.51% to 2.96‰) contents, giving a reduction ratio of 26.1% and 34.4% respectively. Similar reduction has been reported (Mbagwu and Piccolo, 1998; Spaccini *et al.,* 2000) with the soil OC losses ranging from 15% to 40% within 2 - 12 years of tillage (Davidson and Ackerman, 1993; Evrendilek *et al*., 2004). Such reduction is commonly attributed to the microbial oxidation of the organic compounds previously protected in the soil aggregates which were destroyed by cultivation (Cambardella and Elliot, 1993; Piccolo, 1996). The burning management system also severely reduced the soil organic matter content by calcinations (OC: 6.5% to 0.8%, N: 4.51‰ to 0.95‰) giving a reduction ratio of 87.7% and 78.9% respectively. Generally, reduction in the soil organic matter content influences negatively the fertility of Andosols, since it is known to play a central role in the exchangeable cations retention (Shoji *et al.,* 1993). This reduction could also lead to increased soil erodibility, causing an offsite transport of the soil nutrients and the

subsequent soil fertility decline. Conversely, the fallow management system improves the soil organic matter content relative to the tillage management system (OC: 4.8% to 6.5%, N: 2.96‰ to 5.04‰) with an increasing ratio of 26.1% and 41.3% respectively. This increase in the soil organic matter content with fallow may be consistent with additional supply of the organic residues which act as compost with time (Feller *et al.,* 1987). These particulate organic matters are protected physically in soil aggregates (Six *et al.,* 1999). In Andosols from Mount Bambouto, the tillage and burning management systems also led to net loss of the CEC content (22.0 to 18.0 and 10.2 cmol kg^{-1}) with a reduction ratio of 18.2% and 53.6% respectively, giving rise to the soil fertility decline (Nobel, 1989), whereas the fallow management system restored it relative to the tillage management system (18.0 to 21.6 cmol kg^{-1}) with an increasing ratio of 16.7%. Inversely, the above three land use and management systems are marked by a slight increase of the sum of the exchangeable cations relative to the natural cover (3.6 to 4.9 cmol kg^{-1}, 5.7 and 5.1 cmol kg^{-1}) with an increasing ratio of 26.5%, 36.8% and 29.4%, respectively. In the tillage management system, this may be due to an input of fertilizers during land preparation. In the fallow management system, it suggests that this unmanaged period can restore the soil nutrients exported by the harvest of the plant biomass. In the burning management system, it may be consistent with release of base cations during soil calcination (Vlek *et al.,* 2004) as indicated by the net increase in the soil pH values in B1 (6.54) and B2 (6.18). Thus, the burning management system improves the soil fertility through accumulation of the exchangeable cations. But it is well known that this improvement lasts only for a short period and that the water erosion and the subsequent soil nutrients leaching leads to soil impoverishment (Vlek *et al.,* 2004). The soil acidity also increases in the tillage management system compared to the natural cover (pH 4.62 to 4.42), inducing decrease in agricultural productivity (Aitken, 1997). Even 10 years of the fallow management system practice (F2 plots) is not enough to improve the strong acidity induced by the tillage management system. As noted in the Andosols from Mount Bambouto, the long-term tillage (T2 plots) and the fallow management systems raised the cations equilibrium close to the optimal equilibrium (T2: 73/20/7, F1: 78/17/5 and F2: 63/33/4) and consequently improved Andosol fertility. Inversely, the short-term tillage (T1 plots) and the burning management systems led to cations imbalance (T1: 54/39/7, B1: 58/25/17 and B2: 41/51/8) with a significant Ca^{2+} deficiency. This Ca^{2+} deficiency may induce a severe antagonism between the cations during the plant's nutrition.

Changes in soil physical properties

The soil compaction (36.7%) induced by the tillage management system and expressed by the soil bulk density increase (0.69 to 1.09 g cm^{-3}) had significant effect on soil physical properties. It reduced infiltration and percolation of water, and thus led to surface runoff and land degradation by soil erosion. Even after 10 years of the fallow management system practice, these soils may not recover from the tillage management system induced compaction. The water stable aggregates (*WSA*: 12.0% - 53.3% and 15.8% - 52.2%) abundance, the geometric mean diameter (*GMD*: 1.18 - 1.70 mm and 0.94 - 1.67 mm) and the mean weight diameter (*MWD*: 0.60 - 2.57 mm and 0.79 - 2.61 mm) values revealed that the fast wetting and the stirring after pre-wetting tests representing moderate to violent storms highly disrupt Andosol macro-aggregates. The slow wetting test corresponding to moderate rainfalls is least disruptive (*WSA*: 29.4% - 57.0%; *GMD*: 1.30 - 1.76 mm; *MWD*: 1.47 - 2.85 mm). Generally, Andosols from Mount Bambouto have low to moderate resistance to water erosion. As far as the land use and management system is concerned, the tillage management system led to a significant destruction of Andosol macro-aggregates (*WSA*: 12.0% - 48.4%; *GMD*: 0.94 - 1.62 mm and *MWD*: 0.60 - 2.42 mm), whereas the burning management system regenerated them ((*WSA*: 46.7% - 57.0%; *GMD*: 1.55 - 1.72 mm and *MWD*: 2.34 - 2.85 mm). The fallow management system also regenerated Andosol macro-aggregates after the tillage management system practice (*WSA*: 27.5% - 48.8%; *GMD*: 1.28 - 1.67 mm and *MWD*: 1.38 - 2.44 mm). The destruction of Andosol macro-aggregates by the tillage management system with its subsequent increasing clay fraction (36%) may be consistent with the mechanical breakdown of soil aggregates by ploughing. The regeneration of Andosol macro-aggregates with the burning management system practice may be related to Al^{3+} activity in the soil solution. In fact, above pH 5.5, Al^{3+} precipitates in soil as hydroxides and can act as links between mineral particles, generating soil aggregates. Under the fallow management system, regeneration of Andosol macro-aggregates may be associated to formation of organo-metal and oxides-humus complexes with organic acids acting as binding agents (Tate and Theng, 1980). The increase in Andosol macro-aggregates abundance in both cases and the relatively low bulk density indicate well-structured soils with good pore connectivity.

Conclusion

Tillage management system is a significant driver of Andosol fertility decline. It reduces significantly soil organic matter and CEC content, increases soil acidity and compaction, and destroys Andosol macro-aggregates; the chemical and physical properties that affect negatively the Andosol quality. The relative increase of the sum of exchangeable cations and the cations equilibrium close to optimal equilibrium after 10 years of tillage practice are not enough to restore effectively the Andosol fertility.

Burning management system has mitigated influences on Andosols quality. The severe reduction of soil organic matter and CEC content, and the cations equilibrium imbalance in the burning management system affect negatively the Andosol quality. Inversely, the net increase of the sum of exchangeable cations and the soil pH above 6, and the fairly high soil macro-aggregates abundance contribute to improve significantly the Andosol quality. But this improvement lasts only for a short period because water erosion and it subsequent nutrients leaching leads to the soil impoverishment.

Fallow management system globally improves significantly the Andosol quality. It is sustainable in term of soil organic matter, CEC and sum of the exchangeable cations increase, and soil macro-aggregates regeneration after the tillage management system practice. But, even 10 years of the fallow management system is not enough to regenerate efficiently the soil macro-aggregates and improve the soil acidity.

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Predicting occurrence of small mammals and fleas from landform and soil properties in the plague risk area of Lushoto District, Tanzania

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Abstract

A study was carried out in West Usambara Mountains, Tanzania, to investigate influence of landform and soil properties on the occurrence of small mammals and fleas. A conventional landform and soil data collection was done. Small mammals were trapped along randomly selected transects. Results showed that small mammals' abundance increased with elevation. In the plateau, small mammals abundance was at lower and mid slopes of ridges near valley bottoms where water and food were accessible. A landform-soil characteristics' model showed that available phosphorus (p=0.001), aspect (p=0.01) and elevation (p=0.01) are statistically significant predictors explaining abundance of small mammals. Fleas' abundance and spatial distribution were influenced by hill-shade (p=0.001), available phosphorus (p=0.01) and base saturation (p=0.01). This study improved understanding of relationships between landforms, soils and abundance of small mammals and their fleas in a plague risk area.

Key words: landforms, soil properties, small mammals, fleas, plague hosts, Lushoto District, Tanzania.

Introduction

Small mammals (particularly rodents) are considered the primary natural hosts and reservoirs of *Yersinia pestis* that infects about 203 rodent species (Gage and Kosoy, 2005). Several studies carried out in West Usambara Mountains have shown diversity of small mammals implicated to be plague hosts (Laudisoit *et al*., 2007). Neerinckx *et al.* (2010) reported that plague cases were strongly correlated with landforms particularly elevation above 1500 m a.s.l. in Lushoto. Similar results were reported by Eisen *et al.* (2012) that plague cases were common above 1300 m a.s.l in the Uganda plague focus. The above studies agree with Meade and Earickson (2000) who associated occurrence of plague with landform factors, which are envisaged to influence presence, reproduction of hosts and vectors and their interactions with humans.

Soil may be an important reservoir, with burrowing animals acting as the first link in transmission to other animals and humans through flea bite (Drancourt *et al*., 2006). The survival of *Y. pestis* in natural soil conditions from 24 days (Eisen *et al*., 2008) to 40 weeks (Ayyadurai *et al*., 2008) has been reported.

Studies relating landforms and soils to abundance of plague hosts and vectors are limited. It is envisaged that understanding of landforms and soil properties may provide a clue of plague foci risk, with respect to rodents as plague hosts. The aim of this study was therefore to carry out analysis of landform and associated soil properties in relation to potential hosts and vectors in order to contribute information that will help explain the presence and persistence of plague focus risk in West Usambara Mountains, Lushoto District, Tanzania.

Materials and methods

Study location

The study area is located between UTM 9474965.2 and 9502528.6 N and 389060.2 and 472276.1 E at 418-2273 m.

Methodology

Determination of landform characteristics

A digital elevation model obtained from Advanced Spaceborne Thermal Emission and Reflection Radiometer, Global Digital Elevation Model (ASTER-DEM) with 30 m ground resolution was used to derive landform features i.e. elevation, slope gradient, slope aspect, slope curvature: plan, profile, tangential, cross-section and general curvatures, hill-shade, flow accumulation and flow direction in ArcGIS 9.3. These characteristics were used together with soil properties to establish relationships between landforms and occurrence of small mammals and fleas.

Determination of soil properties

A map derived from digital elevation model and GPS was used to select sites for soil sampling. From each representative landform feature, soil samples were taken from the topsoil at depth of 0-45 cm. The soil samples were analysed in the laboratory for texture, pH_{water}, EC, total N%, Organic C%, CEC, bases and micronutrients following the methods of Moberg (2000). A total of 57 soil samples were collected from corresponding 57 geo-referenced sites.

Determination of small mammals and fleas

Trapping of small mammals was conducted on sites where soil samples were collected twice between December 2009 and March 2010. Traps of different types and sizes were employed to capture diverse small mammal species in the field (Mengak and Guynn, 1987). The traps used were medium-size Sherman live traps (23 x 9.5 x 8 cm), locally made wire cages (for small mammals like squirrel, genetta) and the pitfall traps which were 10-litre plastic buckets. The total number of traps used were 300 including 270 Sherman, 15 wire cages and 15 pitfalls. The traps were arranged in lines each with 10 trapping stations placed 10 m apart and left open during the day and night for two consecutive nights following methods of Mulungu (2008).

The traps were inspected every morning whereby those with catches were replaced by other traps and bait. Peanut butter mixed with maize bran, roasted maize grains and sardines were used as the bait. The trapped small mammals were counted and recorded, treated with ethanol for further analysis. The fleas were removed from animals by brushing the fur using ethanol, counted, recorded and stored.

Data analysis

The data was statistically analysed using generalized linear Model (GLM) in Deducer the R GUI (Fellows, 2012). The small mammals and fleas (dependent variables) and landform features and soil properties (independent variables) were subjected under regression analysis to establish occurrence of small mammals and fleas in different landforms in the study area. The occurrence of small mammals and fleas in different landforms was validated using model goodness of fit given by pseudo R-squared (R^2 or D^2).

Results and discussion

Landform characteristic in the study area

Results showed that landforms were highly variable with strong dissection and steep slopes of different curvatures. The dissection constitutes complex system of elongated terraced ridges separated by narrow drainage V-shaped valleys (converging and diverging hydrological flows). The steep slopes and strongly dissected ridges are characterized by localized rock outcrops, scarps and in places landslide scars with shallow soils. The observed landforms have modified the landscape into complex surface features with varying moisture conditions, vegetation, microclimate and human activities (Blanco and Rattan 2010). These conditions are reported to influence the occurrence of small mammals and fleas (Monjeau *et al.,* 1997).

Both profile and tangential curvatures show scale with high to low values. The positive values indicate upwardly convex surface, whereas negative values indicate upwardly concave surface. The observed values show the degree of concavity and convexity of the surface in the direction perpendicular to the direction of steepest descent. The curvatures influence convergence and divergence of water flows, soil water contents and soil water characteristics (Lindsay, 2005) and therefore influence water and food access and vegetation habitat for small mammals (Monjeau *et al.,* 1997). Slopes aspect in the area is multi-directional ranging clockwise from, 0^0 (N), 90^0 (E), 180^0 (South), 270^0 (West). The aspect

modulated by slope gradient influences slope local climate especially solar radiation and exposure to wind (Goudie, 2013). Aspect therefore affects vegetation habitat and differential soil developments. The aspect is among strong predictors of small mammal abundance in the study (p=0.01) (Table 2). This conforms to report by Urban and Swihart (2010) that species richness was influenced by slope aspect in Indiana.

Soil properties

Soil properties in the study area are strongly correlated with landforms. Table 1 presents results on dominant soil properties in the study area. Soils are sandier in the plains but decline with elevation to clayey in the plateau. The per cent OC content shows variations with landforms, with values ranging from 0.6 to 2.9% for the plain and plateau respectively. Micronutrient contents increases from low in the plain to toxic levels in the plateau. These results agree with findings which reported that landforms greatly influence variability and distribution of soil macro- and micronutrients (Jiang *et al.,* 2006).

The observed results conform to findings by Moore *et al*. (1993) who reported that catenary soil properties development occurs as landscape response to the way water moves through and over the landscape being governed by surface characteristics (convergence and divergence). Other studies by Gessler *et al*. (2000)indicated that the soil-landscape pattern results from integration of short and long term pedogeographic processes.

Table 1: Characteristics of selected physical-chemical properties in the study area

	Means of soil properties and DTPA extractable micronutrients											
	Clay (%)	Sand (%)	Silt (%)	pH (water)	OC (%)	CEC cmol(+)/kg	Ca	Mg	K	Fe	Mn	Cu	Zn
Landforms							cmol(+)/kg soil			Mg/kg soil			
Plain	18.31	69.74	11.85	7.94	0.61	12.1	8.9	2.9	0.34	10.6	47.41	2.271	0.293
Escarpment	26.48	61.15	12.26	7.63	2.77	18.1	13.9	1.9	0.29	29.53	139.6	2.163	1.731
Plateau	52.48	38.7	8.82	5.67	2.91	18.3	7.1	2.2	0.15	107.3	63.1	2.067	1.617

Abundance of small mammals and fleas

Table 2 shows the abundance of small mammals and fleas in different landforms and habitats in the study area. Small mammals and fleas are highly variable. This could be attributed to landform complexity.

The high diversity of small mammals and fleas indices has been reported in the plain, ridges of dissected plateau and escarpments. These geomorphic units are characterized by natural forest, shrubs, cultivation and plantation forests as shown in Table 2. The results indicated that landforms, slope and slope aspect and soil properties impacted on small mammals and fleas abundance.

Table 2: Landforms, habitat, small mammal abundance and fleas

Landforms	Elevation (masl)	Slope gradient (%)	Habitat Veg	Small mammal species	Small mammal abundance	Fleas abundance
PLAIN (Undulating to rolling colluvial footslopes with deep soils) in places tallus slopes	510 - 531	4 - 7	Shrub	Acomys	7	14
			Shrub	Dwarf Mongoose	1	0
			Shrub	Squirrel	1	0
	696	12 - 15	Shrub	Acomys	1	0
			Shrub	Geneta	1	5
			Shrub	Squirrel	2	1
	704	15	Forest	Praomys	1	0
				Squirrel	1	0
ESCARPMENT (Rolling to very steep slopes, with rocky scarps, rock outcrops, boulder and shallow to deep soils)	839 - 1123	23 - 55	Forest	Aethomys	2	9
			Forest	Praomys	1	0
	1182 - 1592	60-80	Herbaceous	Aethomys	2	2
	878 - 1604	15 - 80	Shrub	Acomys	1	0
			Shrub	Mastomys	1	0
			Shrub	Aethomys	7	9
			Shrub	Grammomys	1	1
			Shrub	Lophuromys	10	4
PLATEAU (Strongly dissected plateau into system of ridges with rolling to very steep slopes characterised by shallow to very deep highly weathered soils	1937	70	Cultivation	Grammomys	4	3
	1937	70	Cultivation	Lophuromys	2	0
	1937	70	Cultivation	Mouse Legada	1	0
	1742 - 1883	7 - 30	Cultivation	Mastomys	37	30
		7	Cultivation	Mouse	1	0
	1753 - 1926	55 - 70	Forest	Lophuromys	3	4
	1753 - 1926	15 - 70	Forest	Praomys	11	13
	1753	70	Forest	Shrew	1	0
	1904	15	Forest	Grammomys	2	0
	1903	20	Forest Plant	Lophuromys	4	2
	1903	20	Forest Plant	Mastomys	2	2
	1903	20	Forest Plant	Shrew	1	0
	1899	65	Forest Plant	Grammomys	2	0
	1887 - 1899	16 - 65	Forest Plant	Praomys	5	0
	1887	16	Forest Plant	Crocidura	1	0
	1885	23	Shrub	Aethomys	1	2
	1922	46	Shrub	Crocidura	2	0
	1771 - 1922	11 - 90	Shrub	Grammomys	14	35
	1771 - 1918	16 - 90	Shrub	Lophuromys	19	13
	1136 - 2007	16 - 90	Shrub	Praomys	34	25
	1900	90	Shrub	Mastomys	1	10
	1922	46	Shrub	Mouse	1	0
	1900	90	Shrub	Rattus	1	0

Quantification of small mammals and fleas from landforms and soil properties

The landform-soil properties model for quantification of small mammals and fleas is presented in Table 3. The model demonstrates significant relationship between small mammals' and fleas' occurrence and landform features viz: elevation and aspect. Among the soil properties studied the available P had significant influence on occurrence of small mammals and fleas.

Table 3: Parameters of Generalized Linear Model indicating predictors for small mammals

No	AIC	Pseudo R-squared	Statistically significant predictors
1	257.5	42.4	Elevation*
			AvailBray P.
2	256.6	50.2	Elevation**
			AvailBray P***
3	255	49.4	Elevation**
			ApSand.
			AvailBray P***
4	250.3	61.2	Aspect*
			ApBase saturation.
			Elevation**
			AvailBray P***
5	247.1	55.2	Aspect**
			ApBase saturation*
			Elevation**
			AvailBray P***

Elevation is the most influential landform factor with strong positive correlation with number of small mammals. However, there is negative correlation between small mammal numbers and slope aspect (Figure 6). There is positive correlation between available phosphorus and base saturation, and the number of small mammals. Similar results were reported by Eisen *et al*. (2012) in Uganda showing that plague cases were found in altitudes above 1300 m. Also, Neerinckx *et al.* (2010) reported high correlation between plague brought by plague hosts' outbreaks and elevation and vegetation cover.

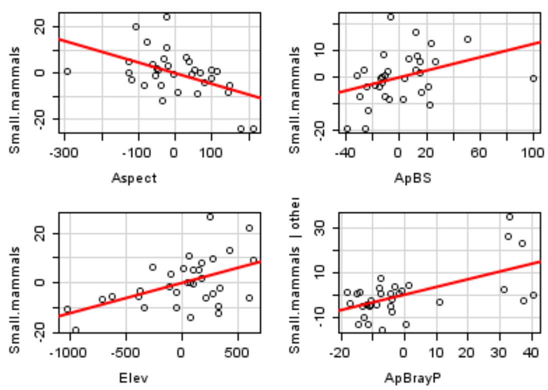

Figure 6: Influence of individual landform-soil properties on the occurrence of small mammals

The best two models explained between 55 and 61% (Table 3) of the variations observed in the prediction of small mammals' abundance. Phosphorus has strong influence on small mammals probably because it's adequate levels favour vegetation growth which provides not only cover and habitat to rodents (Mulungu *et al.,* 2008) but also food and herbage (Krebs, 2001).

Figure 7 and Table 4 present results on landforms and soil predictors for flea abundance. The fleas are negatively influenced by hill-shade, exchangeable calcium and magnesium while they are positively influenced by elevation, available phosphorus and base saturation.

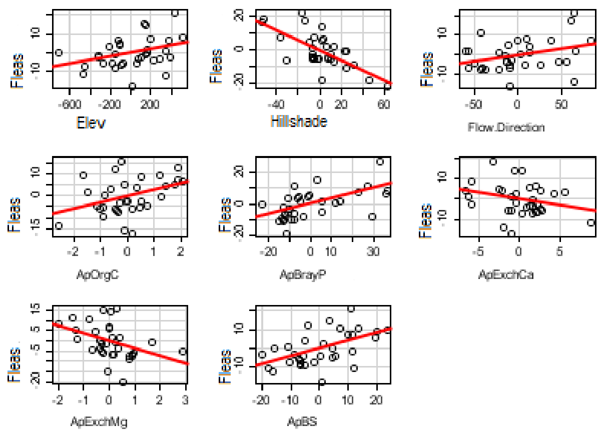

Figure 7: Influence of individual landform and soil properties on abundance of fleas

Table 4: Landforms and top-soil predictors of fleas' abundance

Variables	Coefficient estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	20.88866	12.49297	1.672	0.107507
Elevation (M)	0.009709	0.005351	1.815	0.082095.
Hill-shade	-0.30392	0.065685	-4.627	0.000107 ***
Flow direction	0.066498	0.03826	1.738	0.095016.
Org C (%)	2.939898	1.408512	2.087	0.04766 *
Avail BrayP	0.33196	0.093459	3.552	0.00162 **
Exch-Ca	-0.63307	0.464493	-1.363	0.185555
Exch-Mg	-3.69392	1.670205	-2.212	0.036761 *
BS	0.429641	0.138059	3.112	0.004749 **

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; (Dispersion parameter for Gaussian family; Null deviance: 5524.2 on 32 degrees of freedom, Residual deviance: 1850.7 on 24 degrees of freedom. AIC: 246.53

Although many studies on fleas prediction use mean abundance and variances (Zuo and Guo, 2011), our results show that fleas abundance which show similarity with small mammals can be predicted using landforms and soil properties. Caro *et al*. (1997) and Krasnov *et al*. (1997) reported that the parasites encountered in a given area are related to their specific location and the host. In this study the observed fleas abundance reflected trapped small mammals.

Conclusion

It is concluded that landform and soils have strong influence on the abundance of small mammals and fleas that infest them. Occurrence and abundance of fleas is mainly influenced by hill-shade and available phosphorus, organic carbon and exchangeable magnesium. Elevation and aspect are strong landscape predictors whereas available phosphorus and base saturation are strong soil influencing the occurrence and abundance of both small mammals and fleas.

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Effects of agricultural land uses on Phosphorus fractions and aggregation of wetland soils in East Africa

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Abstract

Conversion of natural wetlands to cropped land can have significant impacts on the transformation of soil aggregates and associated nutrients, including soil phosphorus (P). However, little is known about the changes in P fractions in wetland systems, or the fate of aggregate fractions due to conversion of unused wetland areas to cropped systems.

We hypothesized that conversion of natural wetland systems will result to changes in the size of P pools and aggregate fractions associated with SOM and that these changes will be determined by the soil type and land use. Our objectives were to evaluate the effects of land use changes on: - (1) the proportions of soil P fractions; (2) the size and proportion of water stable aggregates in two different wetlands in East Africa. The wetlands comprise an inland valley in the highlands-Karatina (1700 masl) and a floodplain in the lowlands-Korogwe (320 masl). Land use treatments included the natural unused sites which were dominated by *Cyperus* spp; the cropped fields under anaerobic and aerobic soil conditions and abandoned sites under fallow vegetation. Results indicated that conversion from natural systems to aerobic, anaerobic or abandoned fallow affected soil P fractions and the stability of soil aggregates. The floodplain soils responded sensitively to intensified land use with pronounced decreases in soil aggregate stability, the availability of labile P-fractions, and the supplying capacity of stable P-fractions. The inland valley showed higher contents of available P and stable P, while the stable P stocks in the floodplain were apparently depleted quickly. This may imply that the conversion of wetland systems to cropped systems could have significant alterations of soil P fractions and the aggregate fractions associated with organic matter unless strategies to increase the organic matter level and hence improved aggregation and mineralizable nutrients are put into consideration.

Key words: labile P, organic matter, stable P, wetlands soil.

Introduction

Aggregate fractions associated with soil organic matter (SOM) and phosphorus (P) pools are likely to change with changes in land use or with the intensification of cropping in wetland areas. A reduction in SOM content, which reflects a high rate of aggregate turnover, can be due to a faster SOM mineralization and oxidation of soil organic carbon, smaller quantities of organic inputs, and / or more easily decomposed organic inputs in managed systems as compared to natural systems (Brady and Weil, 2002). In wetland systems, drying and wetting of wetland soils induces oxidation and leads to irreversible changes in its SOM fractional composition. The soil aggregate sizes associated with organic matter include the macro-aggregates (>0.25mm diameter) and the micro-aggregates (<0.25mm diameter). Changes in these fractions sizes are likely to result to changes in the SOM content and hence the mineralizable soil nutrients. Rewetting of the drained soils is accompanied by enhanced release of P due to changes in redox potential of P adherent chemical elements such as Fe (Kirk, 1984). Sequential P analysis can reveal changes in P forms which depend on soil type, climatic conditions and crop management practices. The sequential chemical extraction procedures have been and still are widely used to divide extractable soil P into different inorganic and organic fractions (Tiessen and Moir, 1993). Several studies have also related these different P fractions to plant growth and nutrient uptake (Guo *et al*., 2000).

Though much research has been done on plant available P and total P fractions in cultivated soils in the study regions (Ndakidemi and Semoka, 2006) little information exist on how soil P fractions change under wetland conditions when land uses are changed. Thus, this study demonstrate how land use

changes affect the size of aggregate fractions and thus the organic matter and nutrient (P) release and cycling. We used a sequential P extraction method to determine potential differences in the form and quantity of different inorganic and organic soil P fractions in two wetland soils (inland valley clay soil and floodplain sandy clay) as affected by land use changes from uncultivated wetland areas to cropped fields and fallow plots). In addition by carrying out aggregate stability determination, the aggregate fractions most affected by conversion of natural wetland systems to areas of cultivation are explored.

Materials and methods

Study areas

The study area comprised two wetlands in East Africa differentiated by climatic conditions. Thus, a floodplain in the hot and humid lowlands of Korogwe in Tanzania and an inland valley in the cool highlands of Karatina, Central Kenya were selected. Detailed descriptions of the studied wetland environments are presented in Table 1. The floodplain in the lowland lies at an altitude of 320 m. The soils are mainly the sandy clays (Fluvisols) and some pockets of Vertisols. Annual rainfall averages less than 700 mm with average daily temperature of 35° C. The site is classified as dry Savannah (FAO, 1978-82) and dominated by palm gardens, rainfed and irrigated rice. The inland valley in the highlands of central Kenya is located at an altitude of 1700m with an annual average rainfall of 1450 mm and average daily temperature of 23 °C. The region falls under the Forest zone and dominated by subsistence farming of maize, beans, vegetables and taro (*Colocasia esculenta*). Soil types are mainly clay and some clay loams (Jaetzold *et al.,* 2006).

Land use selection and soil sampling

The selected land uses comprised (i) the 'Natural' or unused wetland fields dominated by natural wetland vegetation of *Cyperus papyrus* in the lowland floodplain and *Cyperus exaltatus* in the highland inland valley; (ii) the 'Anaerobic' cropped fields under permanent to seasonal soil wetness grown to crops such as taro in the inland valley and rice in the lowland floodplain; (iii) 'Aerobic' fields under seasonally wet soil moisture and grown to field crops such as vegetable, maize and beans; and (iv) 'Fallow' plots which comprised land previously under cultivation but now abandoned or under grazing.

Table 1: Description of the selected study wetlands in East Africa -a floodplain in Korogwe Tanzania and an inland valley in Central Kenya

Characteristic	Floodplain-Korogwe	Inland valley- Karatina
Location	Pangani plains-Tanzania	Central Kenya
Longitude (^{0})	38^{0}21'28"E	37^{0}05'57"E
Latitude (^{0})	05^{0}04'29"S	00^{0}27'58"S
Altitude masl	320	1700
Annual rainfall (mm)	<700	1450
Temperature (˚C)	35	23
AEZ[1]	Dry savannah	Forest
Length of growing period (days)[1]	150	270
Soil order[2]	Fluvisols, Vertisols	Gleysols-Fluvisols
Parent material	Alluvial sediments	Volcanic
Textural class	Sandy clay, clay	clay, clay loam

[1]: FAO, (1978-82); [2]: FAO-UNESCO, (1997)

The cultivated fields were managed for rice or vegetable production for the last 5-10 years. Use of inorganic fertilizers was linked to cropped fields in aerobic and anaerobic land uses. Fertilizer application was generally irregular with rates ranging from 20 to 42 kg N and 10 to 25 kg P ha^{-1} year^{-1} (Jaetzold *et al.,* 2006; MOA-URT, 2006). The commonly used fertilizers were urea, triple super phosphate (TSP) and di-ammonium phosphate. Fallow periods at the study sites ranged from 2 months to several years. These fallow sites were dominated by grass and weeds such as *Galinsoga spp*,

Chenopodium spp and *Echinocloa spp*. The fallow sites had been previously cultivated for more than 10 years and later abandoned due to poor productivity.

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Three replicates of the same land use were selected within a minimum distance of 100 m from each other. In each land use type and replication, a sub plot of 10m * 20 m was demarcated and top soil was sampled from ± 0-15 cm depth. In total, 9 auger holes were sampled in a 'W' shape in each sub plot using a hand-held auger, 5-cm in diameter. The composite samples were air-dried, ground and sieved to pass through a 2mm sieve for subsequent soil analysis. General characteristics of the soils from the wetland land uses are presented in Table 2.

Table 2: General chemical properties of the whole soil under different land uses in the floodplains and inland valleys (sampled during land use selection period)

Soil characteristics					
Land use	pH	Total C (g kg^{-1})	Total N (g kg^{-1})	Available P (mg kg^{-1})[a]	Exchangeable K (cmol kg^{-1})
	Floodplain				
Natural	5.5	38.0	6.2	9.4	0.2
Anaerobic	5.8	27.8	1.9	3.2	0.1
Aerobic	6.7	33.3	3.2	7.0	0.2
Fallow	6.2	14.9	1.1	7.1	0.2
	Inland valley				
Natural	5.0	37.2	3.7	16.8	0.2
Anaerobic	5.0	31.6	3.5	18.7	0.3
Aerobic	4.8	37.2	2.8	18.0	0.4
Fallow	5.7	25.8	2.5	7.0	0.2

[a]: Olsen P

Soil analysis

Phiosphorus fractionation. Sequential P fractionation was carried out using the modified Hedley procedure (Tiessen and Moir, 1993). Sequential P procedure uses a series of increasingly aggressive extractants to remove labile inorganic and organic P (P_i and P_o) pools followed by more stable organic and inorganic P forms. At each stage, bound P was assumed to be removed selectively from specific types of compounds contained in the soil. In order to verify the P content of the fractions, it was necessary also to determine total P for each sample. The following P fractions were determined sequentially: Resin-P, 0.5*M* $NaHCO_3$ extractable P, *0.1M* NaOH extractable P, *dil*. HCl and *conc.* HCL. The fractions recovered by this procedure correspond to the following soil P pools (Hedley *et al.*, 1982): (i) Resin Pi: form of soil inorganic P from which plants normally draw their supply; (ii) Bicarbonate-Pi:

extracts additional inorganic P that is available to plants which is adsorbed on surfaces of crystalline compounds; (iii) NaOH-Pi: partially dissolves Fe and Al phosphates and desorbs Pi from the surfaces of sesquioxides and (iv) HCL-Pi: stable P or occluded P held at the internal surfaces of soil aggregates and is thought to be available only on a long-term basis. The P fractions were then grouped to (i) stable pool comprising the NaOH extractable P, the *dil*. HCl and the *conc*. HCL and (ii) labile P fractions of the resin and $NaHCO_3$ -P.

Aggregate fraction determination by wet sieving. Soil aggregate size classes were assessed by a wet sieving technique and the amount of the macro and micro aggregate fractions determined as a percentage of the initial soil weight (Tisdall and Oades, 1982). Air dried soil (<2 mm diameter) was separated into four size fractions thus, the large macro-aggregates (>0.5mm diameter), small macro-aggregates (0.25mm-0.5 mm diameter), micro-aggregates (0.053-0.25mm diameter), and silt + clay associated particles (<0.053 mm diameter).

Statistica analysis. A randomized experimental design was utilized with four land uses, two wetland types and three field replications. A one way ANOVA model was used to determine differences between individual fractions in land uses. Significant treatment comparisons were based on Tukey test at P=0.05 (Bryman and Cramer, 2001).

Results

The results of this study portrayed that wetland conversion from natural system to cropped fields highly altered the soil aggregate fractions and the amounts and proportion of labile and stable soil P pools compared to the initial natural wetland system.

Effect of land use changes on soil P fractions

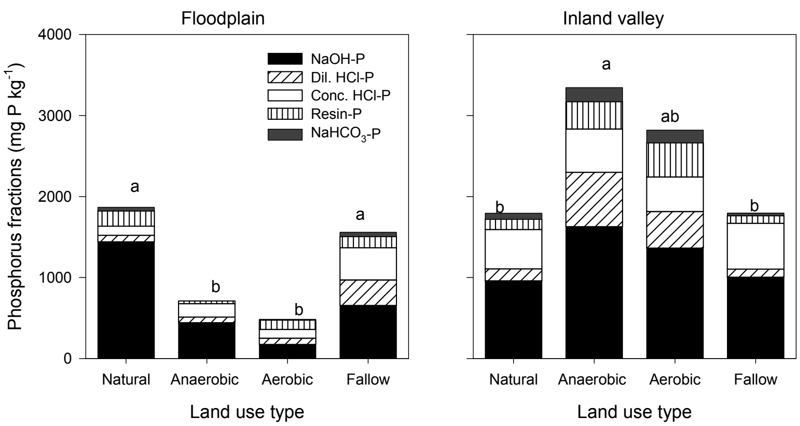
Both floodplain and inland valley soils showed low contents of easily available P (resin- and $NaHCO_3$– extractable) and high contents of stable P (NaOH-P and HCl-P).

Labile P pools. In the floodplain soils, the labile fractions responded sensitively to intensive cultivation and the stable supply of P of the NaOH fraction was also reduced. The amount of ion-exchange resin-extractable P ranged between 33 mg P kg^{-1} and 189 mg P kg^{-1}, while the amount of $NaHCO_3$ extractable P was lower between 2 mg P kg^{-1} and 66 mg P kg^{-1} (Figure 1a). In the inland valley soils the changes were less distinct, but soils from intensive cultivation showed higher P amounts than the uncultivated soil in the natural system. The amounts of resin-extractable P ranged from 92-550 mg P kg^{-1} while $NaHCO_3$-extractable P ranged between 35 mg P kg^{-1} and 202 mg P kg^{-1}.

Stable P pools. The stable pool comprised the NaOH and the HCl extracted P. The NaOH pool contained more P than any other fraction in the two wetland soils (Figure 1a) and was highest in the inland valley and lowest in the floodplain. This pool was differentiated between the land uses whereby it was highest in the natural and the cultivated plots. The greatest impact on the stable fractions was observed under aerobic cultivation in the drained vegetable soils. The NaOH-P ranged between 143 to 1442 mg P kg^{-1} in the floodplain and 959 mg P kg^{-1} in the natural to 1629 mg P kg^{-1} in the anaerobic cultivation plots in the inland valley. The very stable or highly occluded P (HCl extracted P) was high in all the land uses and ranged between 428 to 567 mg P kg^{-1} in the inland valley and from 108 to 399 mg P kg^{-1} in the floodplain soil.

Total P and P stocks. The total amounts of P showed differences between floodplain and inland valley, with higher amounts in the uncultivated soils in the floodplain and a reverse trend in the inland valley, indicating effects of soil amendments under intensive cultivation. Soil P stock varied between the wetlands and the land use types. The P stock was almost twice as much in the inland valley (ranged between 900 to 1700 g P m^{-2}) than in the floodplains (Figure 1b). The unused and abandoned areas had higher and significantly different P stocks ($P < 0.05$) compared to cropped fields in the floodplains while in the inland valleys, the cropped sites had on average higher P stocks.

(a) Labile and stable P fractions



(b) P stocks

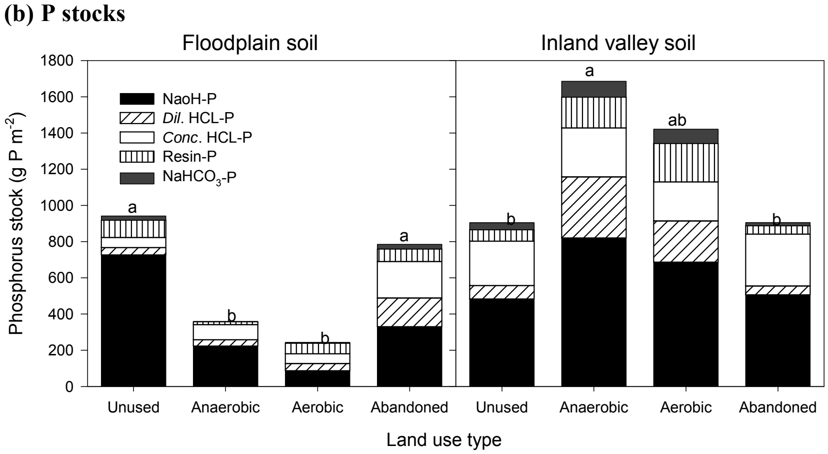


Figure 1: Effects of land use types on soil P fractions (labile and stable) and P stocks in wetland soil from a floodplain and inland valley wetland in East Africa. Label points followed by same letter (s) shows that the total P is not significantly different between the land use types by Tukey test (p=0.05)

Phosphrus fractions as percentage of total P. As a percentage of total phosphorus, the labile phosphorus in resin and bicarbonate extracts constituted less 30% of the total phosphorus pool in all the land uses (Figure 2). The aerobic cultivated plots had the highest share of the labile pool (26% and 21% in the floodplain and inland valley respectively) in relation to the total P pool. The natural system and the fallow sites had the highest share of the stable pools comprising the NaOH and the HCL inorganic fractions and were highest in the inland valley and lowest in the floodplain (range from 87% to 93%).

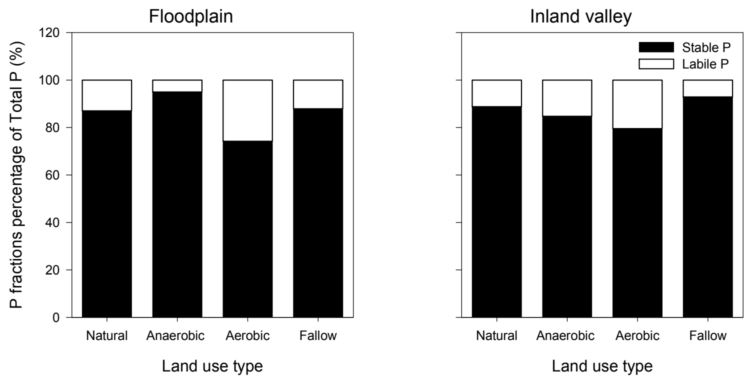


Figure 2: Distribution of labile and stable phosphorus pools as a fraction of the total P as affected by land use changes in wetland soils of East Africa

Effect of land use changes on the proportion of aggregate fractions

Changes in land use significantly affected the proportion of aggregates across the wetland soils and within the land uses (Figure 3). The aggregate fractionation showed the largest share of aggregates occurring in the biggest size fraction of >0.5mm diameter, while only a small share of aggregates was found in the smallest size fraction of <0.053mm diameter, irrespective of the wetland type or the land use. In the floodplain soils the content of soil aggregates >0.5mm diameter ranged from 42-60% with the largest share occurring in natural system and fallow land and the lowest shares occurring in the cultivated soils. The percentage of medium-size aggregates (0.25 - 0.5mm diameter) ranged from 18-32% and followed the trend of the large aggregates with largest shares in uncultivated and lowest shares in cultivated soils. The small aggregates followed a reverse trend and were most abundant in the cultivated soils. The microaggregates (<0.053mm diameter) made up only a minor share (4-5%). In the inland valley soils the content of the aggregate fraction >0.5mm was higher than in the floodplain, ranging from 53-66% and having larger shares in the cultivated than the uncultivated soils. The medium size aggregate fraction (0.25 - 0.5mm diameter) responded most sensitively to land use with a share of 25% in natural system and declining to 12% with intense aerobic cultivation. As in the floodplain, microaggregates made up only a small share with 5-8%.

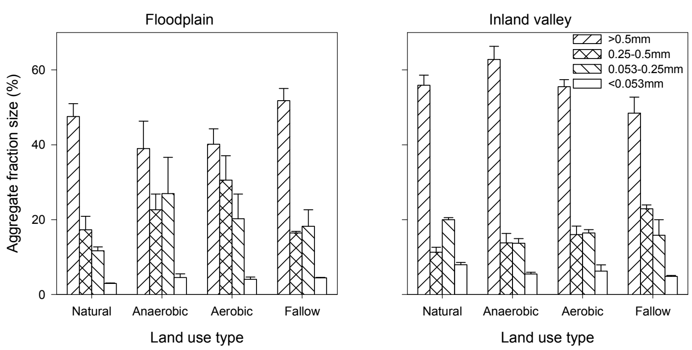


Figure 3: Effect of land use changes on the percentage distribution of aggregate size classes in floodplain and inland valley soils

Water stable aggregates. While the aggregate size did not provide a conclusive picture, the share of the water stable aggregates (WSA) showed distinct differences between the wetland systems. While cultivation of soils in the floodplain strongly affected the amounts of WSA, the share of WSA appeared

unaffected by land use in the inland valley soils (Figure 4). The content of WSA within the respective soil aggregate fractions was higher in all fractions in the inland valley soils (25-30%), with exception of the soil from the floodplain under natural system, which was significantly different from all other soils ($P < 0.05$) and showed the overall highest amounts with about 36% of WSA in all three fractions and a strong decline under cultivation. This decline after conversion from natural systems to cropped land in the lowland floodplains dominated by sandy clay soils was on average 65% in the 0.5mm diameter, 69% in the 0.25mm diameter and 51% in the 0.053 mm diameter aggregates. The soils from the inland valley were more homogenous and showed all the same trend with the lowest contents of WSA in the biggest fraction (0.5 mm diameter) and the highest in the smallest fraction (0.053 mm diameter). The differences between the land uses were minimal, and between the 0.053 and 0.25 mm diameter aggregates. Unlike the floodplain soils, the decline in WSA in inland valley soils after conversion from natural system to cultivated system was less than 6% between the cultivated and the natural systems. This could be associated with stabilization and protection of the aggregates by the clay particles.

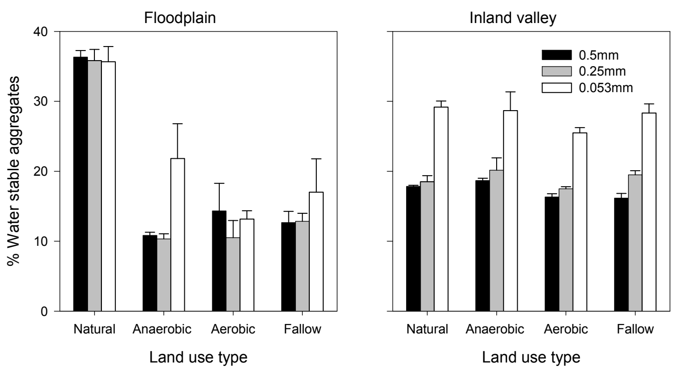


Figure 4: Effect of land use changes on the percentage distribution of water stable aggregates in soils from a floodplain and inland valley wetland in East Africa

Discussion

Results from this study have demonstrated that conversion of natural systems to either aerobic or anaerobic cultivation substantially affected the soil P fractions and the proportions of the aggregates associated with organic matter.

Soil P fractions in wetland soils

The results of the P-fractionation demonstrated that the pools of plant available P (labile fractions) in both floodplain and inland valley are very small. The largest fraction turned out to be the NaOH-extractable P, which mainly contains moderately stable Al- and Fe-bound inorganic P. Labile P represent the most available form of P hence these pools are likely to represent the recent inputs from P fertilizer, rainfall, or P mineralized from organic matter (Negassa and Leinweber, 2009). This arguement probably explains the relatively higher P in soils from the the aerobic cultivated fields. The $NaHCO_3$ extractable fraction contains Fe and Al bound P which is associated with amorphous compounds. The P contained in this fraction is usually unstable in wetland soils and is likely to change with fluctuating redox conditions (Kirk, 2004; Wright, 2009). From the present study, this pool had the lowest P content of all the fractions. The organic matter content of the natural undisturbed plots are likely to have enhanced microbial activity which in turn converted P to inorganic forms which could explain the high proportion of P pools in the natural undisturbed areas. On the other hand, land use conversion from natural systems in reduced conditions to aerobic cultivation may also enhance the mineralization of organic matter and therefore organic P release (Negassa and Leinweber, 2009).

The stable pools (NaOH and HCl extracted P) contains the Ca-bound and the highly occluded P pools. In the present study these fractions had the highest P values. This was probably due to accumulation

of residual P (Smeck, 1995; Wright, 2009). Similar findings have been reported by Nwoke *et al.*, (2003) in inland valley soils of West Africa and by Solomon *et al.*, (2002) in the sub humid highlands of Ethiopia. This fraction has been found to be an important source of available P in the tropical soils not managed with inorganic P fertilizer (Beck and Sanchez, 1994).

Organic matter is known to contribute significantly to P availability in weathered soils by enhancing the CEC and reducing P fixation (Barber, 1984; Okalebo *et al.*, 1991). Thus, P held in the stable pool is a long term source of labile P therefore mineralization of the stable pools may contribute substantially to the supply of available P to these soils (Barber, 1984; Wright, 2009). Intensive fertilization and management probably increased P content in the labile fractions in the cultivated plots. Similar findings have been reported by (Negassa and Leinweber, 2009) on increased P retention in the mineral associated P pools in cultivated plots while land uses with minimal management and no fertilization such as the natural systems and fallow retained more P in the stable fractions. Particularly the cultivated floodplain soils are very low in labile P while the P stock is also much reduced. This means that floodplain soils under cultivation show a low P availability and a shrinking P supplying potential from the stable pools.

Previous studies have shown that the natural systems have a greater proportion of the total P in organic forms while disturbed or cultivated fields usually have more P in the inorganic pools (Graham *et al.*, 2005; Saleque *et al.*, 2004). However under the current land uses and environmental conditions such as wetting and drying in the wetlands soils, organic P may not be considered a stable pool and may eventually be lost from the fields. If the resin and bicarbonate fractions represent soil phosphorus that is both exchangeable and easily mineralizable, then the fraction of the total soil phosphorus pool that is available to plants is a minute fraction of the total phosphorus pool, either as an absolute value or as a percentage of total phosphorus (Cross and Schlesinger, 1995; Nwoke *et al.*, 2003).

The proportion of phosphorus in labile and stable fractions is likely to vary between the soil types, and soil weathering intensity and use intensity. In the lowland floodplains, P deficiency is widespread in rainfed rice fields (Maitima *et al.*, 2009). Thus, these soils when put under cultivation are likely to show a low P availability and a shrinking P supplying potential from the stable pools. However, in the inland valley, the plant available labile P and stable P fractions are larger, which indicates a lesser vulnerability concerning the P supply. Therefore, the inland valley soils prove less susceptible to agricultural use, although the increasing amounts of labile and stable P under intensive cultivation are very likely to be caused by high fertilizer application, especially under drainage for the input-intensive production of upland crops.

Aggregate sizes and stability

The stability of the soil aggregates is affected strongly by anthropogenic interventions and the absence of soil management practices. Wetland soils are often mineral in seasonally wet wetland areas and peaty in permanently flooded wetlands therefore resulting to differentiation in the decomposition and aggregate proportions between the land uses with varying soil moisture (Wright, 2009). In the present study the high proportion of large macro-aggregates >0.25mm diameter observed in the natural systems could probably be due to the high accumulation of vegetation materials on the soil surface. The accumulation of the SOM in the soil has often been related to an increase in aggregation (Bronick and Lal, 2005, Krull, 2004). In anaerobic systems, flooding conditions inhibit aggregate breakdown because microbes slowly decompose the small amounts of carbon-rich binding agents that are produced (Olk *et al.*, 1996). On the other hand in the aerobic cultivation, drainage and tillage leads to increased microbial activity and therefore a higher breakdown of the aggregate fractions resulting to reduced proportions of aggregate fractions >0.25mm diameter. These findings are in accordance with many other studies which confirm the adverse influence of cultivation on SOM content and aggregate stability. For example Bronick and Lal (2005) realized that the macro-aggregates pools (>0.25mm diameter) was the major pool depleted as a result of cultivation. Increased management intensity has also been found to increase the humification process and the proportion of highly decomposable and easily lost organic matter (Leinweber *et al.*, 1995). Thus, in the present study, the decline in the aggregate fractions was observed when the natural system was brought under cultivation in the sandy clay soils of the floodplain. Aggregates 0.053-0.25mm diameter are more stable to rapid wetting and are not destroyed by agricultural practices, partly because they are small, but also because they contain several types of binding agents (Six *et al.*, 1998).

This could probably explain the minimal differences between the 0.053mm diameter water stable fractions in the inland valley soils. Where soil is cultivated frequently like in the aerobic cultivated plots in the present study, aggregates are exposed to physical disruption. This may expose the previously inaccessible organic matter to microorganisms and stimulate oxidation and loss of organic matter. This decline in organic matter is usually accompanied by a decrease in the number of water-stable aggregates (Tisdall and Oades, 1982). The fallow soils indicate that the aggregation seems to improve again after cultivation, but not water stability. In contrast to the floodplain soil stability in the inland valley proved less sensitive. The Inland valley soils appear more resilient to land use change and may present in the long-term a larger potential to absorb the growing pressure on land for food crop production in East Africa than the floodplains

Conclusion

- Land use changes, particularly those involving soil drainage and cultivation led to changes in chemical and physical soil properties which affected the availability and the pool size of different labile and stable P-fractions and aggregate stability. Labile P fractions comprised a relatively small percentage of the total soil P while cultivated plots showed appreciably increased P retention in the stable pools
- The stabilization of macro-aggregates is controlled by management and is decreased when natural systems are converted to cropped fields
- The floodplain soils proved to be more vulnerable to intensive agricultural use than the inland valley soils. Phosphorus fractions and aggregate size proportions and stability declined with a higher margin in the floodplain when compared to the inland valley soils

Acknowledgement

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Soil organic carbon stocks at different elevations in the Miombo woodlands of Kitonga Forest Reserve, Tanzania

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Abstract

This study was conducted to assess Soil Organic Carbon (SOC) at different soil depths and elevations in selected sites of the miombo woodlands of Kitonga Forest Reserve (KFR). Ten sampling points located at different elevations were selected, georeferenced and at each point three randomly selected mini-soil pits were excavated for soil sample collection. Samples from different horizons up to 60 cm depth were collected and composited from three replicates. SOC was analyzed using the wet oxidation method. The mean SOC stock increased from 15.2 to 26.7 t ha^{-1} respectively at 928 and 1548 m in the case of Fluvisols, and from 11.3 to 44.9 t ha^{-1} respectively at 1258 and 1598 masl in Cambisols. Conversely, SOC stocks decreased with elevation in Leptosols and the trend was 28.9 to 12.5 t ha^{-1} at 831 and 1083 masl, respectively. The mean topsoil SOC stock was 26.3±5 t ha^{-1} in Fluvisols, 19.4±7 t ha^{-1} in Cambisols and 26.1±7 t ha^{-1} in Leptosols. SOC stocks at 30 cm depth decreased by 56%, 41%, and 31% when compared to those of top soils in Fluvisols, Leptosols and Cambisols, respectively. The higher amounts of SOC stocks at the surface horizons justify the need for conservation of intact miombo woodlands vegetation.

Key words: SOC stocks, soil types, altitude levels, soil depth, Miombo woodlands, Kitonga Forest Reserve, Tanzania.

Introduction

Soils are the largest carbon reservoirs in the terrestrial carbon cycle and they play a role in the regulation of global warming and greenhouse gas effects (Abebayehu, 2013). According to Yuan *et al*. (2013) 40% of soil organic carbon (SOC) resides in forest ecosystems, with 11% stored in forest soils (Pan *et al*., 2012). The soils of the miombo woodland ecosystems are globally important in C storage (Munishi *et al*., 2011). In Tanzania, the miombo woodlands are found, among other places, in the Kitonga Forest Reserve (KFR). However, few studies on SOC stocks in soils of these woodlands have been undertaken. In view of the growing threats of global warming due to greenhouse gases (GHGs) emissions, an understanding of C storage in soils of the miombo woodlands in Tanzania is necessary. The miombo woodlands, which cover 31.6 million ha, or 93% of the total forested land area in Tanzania, are important as they provide diverse ecosystem services including, among others carbon sequestration (FAO, 2009).

The SOC stock across the landscape may vary among soil types, topographical features, vegetation types, elevation and soil depth. The SOC stocks in different soil types and at different soil depths determine the potential of carbon loss as a result of deforestation and forest degradation, with carbon stored in the upper horizons of soils being more susceptible to loss when vegetation cover is disturbed. Tanzanian forest soils show alarming deterioration rates due to disturbances and land degradation (FAO, 2009), and it would be important to predict the loss of SOC stock as a result of such disturbances.

The objectives of the study reported here were to determine the SOC stocks in major soil types, determine the variation of SOC stocks along elevation gradients and determine changes of SOC stocks with soil depth. The working hypothesis of the study was that SOC stocks of a given soil type are a function of elevation gradient and soil depth.

The data obtained would provide vital information on soil carbon stocks which would be of help to stakeholders in designing interventions to reduce deforestation and land degradation. These interventions would assist in mitigation and adaptation to climate change in Tanzanian forest soils as well as to the Inter-governmental Panel on Climate Change (IPCC) and to the United Nations Framework Convention on Climate Change (UNFCCC), for purposes of coordinating international efforts to mitigate the effects of climate change.

Materials and methods

Study site

The KFR is located in Kilolo District, Iringa Region, at 07°35' - 07°43'S; and 37°07' - 37°10'E. The altitude varies from 660-1880 m with rainfall of 540-900 mm, with a mean of 720 mm. The temperatures range from 13.5 to 24.7 ^{0}C, with maximum temperatures in July to October.

Methodology

Field methods

At each predetermined elevation a 20 m by 20 m square plot was demarcated and partitioned into four 10 m by 10 m quadrants. Within each quadrant, four points were randomly selected for collecting soil samples. Composite samples from these points were collected from natural horizons of excavated mini-pits by mixingsoils

from similar horizons to obtain composite samples for the different horizons. To avoid contamination, soil samples were taken starting from the bottom layer to the upper layer in each mini-pit. These were put into separate labelled plastic bags for laboratory analysis. Such 20 x 20 m square plots were replicated three times. The replications were laid out across the slope. Disturbed and undisturbed soil samples were taken from each horizon for physical and chemical analysis in the laboratory.

Laboratory methods

In the laboratory, soil samples were air dried to constant weight after which they were ground and sieved through a 2 mm sieve to get the fine earth fraction ready for laboratory analysis. The bulk density was determined using the core method (Black & Hartge, 1986), and texture was determined by the hydrometer method (Day, 1965). The pH was measured in water and in 1 M $CaCl_2$ at a ratio of 1:2.5 soil: water or soil: $CaCl_2$, respectively (McLean, 1986). Organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1982). Total N was determined using the micro-Kjeldahl digestion- distillation method as described by Bremner and Mulvaney (1982). Extractable phosphorus was determined using filtrates extracted by the Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined by spectrophotometer (Watanabe and Olsen, 1965). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were determined by atomic absorption spectrophotometer (Thomas, 1982). The SOC in milligrams per hectare was calculated using the equation hereunder:

SOC in Mg/ha = SOC concentration in (%) × Soil bulk density in g/cm^3 × Sampling depth (cm) x 100.

Statistical analysis

Data analysis was carried out using statistical analysis system (SAS version 9.2) following the Completely Randomized Design (CRD) experimental design.

Results and discussion

Physical and chemical properties of the major soil types in the study area

The physical and chemical properties of the surface horizons of the major soil types are presented in Table 1. The soils are coarse textured (loamy sandy, sandy loam, sandy clay loam) with medium pH of 5.9, which is favourable for woodland production. The mean OC is low (1%) as is the CEC (NH_4OA) of (8.4 cmol(+)/kg). The mean total nitrogen was 0.1% (low) while the meanPotassium (0.2 cmol (+)/kg) was also low as was sodium (0.2 cmol (+)/kg). The soils are medium in extractable P (5.8 cmol(+)/kg), calcium (2.2 cmol(+)/kg and magnesium (1.5 cmol(+)/kg). They have adequate levels of copper. (0.7 cmol (+)/kg), iron (67.9 cmol (+)/kg) and manganese (13.7 cmol (+)/kg) but showed deficiency levels of Zn (0.5).

Table 1: Selected physicochemical properties of the surface soils of Kitonga Forest Reserve

Variable	No of observations	Minimum	Maximum	Mean	Standard deviation	Interpretation
% Slope	85	3	42	16.6	9.6	Gently sloping to Steep
pH H_2O	85	4.8	7	5.9	0.5	Medium acidic to neutral
% Clay	85	6.3	42.7	17.2	9.1	Coarse textured soils
% Silt	85	0.6	13	6	2.9	Coarse textured soils
% sand	85	49.1	93.1	77	10.7	Coarse textured soils
OC%	85	0.1	4.4	1.0	0.9	Very low to very high
CEC-NH4OAc	85	2.4	24	8.4	4.1	Very low to medium
Total N	85	0	0.3	0.1	0.1	Low to medium
ExtracTable P	85	0.2	54.4	5.8	9.9	Low to high
Ca (cmol (+)/kg	85	0.3	10.7	2.2	2.1	Very low to very high
Mg (cmol (+)/kg	85	0.2	24	1.5	2.6	Very low to very high
K (cmol (+)/kg	85	0.1	0.6	0.2	0.1	Very low to medium
Na (cmol (+)/kg	85	0.2	0.8	0.2	0.1	Low to high
Cu (cmol (+)/kg	85	0.3	5.8	0.7	1.3	Deficient to adequate
Fe (cmol (+)/kg	85	0.2	339.9	67.9	75.3	Adequate
Zn (cmol (+)/kg	85	0	2.4	0.5	0.5	Deficient to adequate
Mn (cmol (+)/kg	85	0	55.6	13.7	15	Deficient to adequate

In parentheses are ratings according to Baize (1993), EUROCONSULT (1989) and Landon (1991).

cmol(+)/kg The low levels of most of the nutients may have been contributed by deforestation, wild fires, grazing and charcoal burning of the miombo woodlands, leading to rapid decomposition of organic matter and losses of mineral nutrients. Frost (1996) observed a similar trend in the soils of miombo woodlands in Tabora (Tanzania), which are also inherently poor in nutrients.

Changes in SOC stocks with elevation

The SOC stocks (Mg/ha) of the major soil types to the depth of 60 cm from elevation of 831 to 1598 masl are shown in Table 2. The overall, mean SOC stocks increased from 15.2 t/ha at 928 m to 26.7 t/ha at 1548 m in Fluvisols and from 11.3 t/ha at 1258 m to 44.9t/ha at 1598 m in Cambisols. In the Leptosols, however, the SOC stocks decreased with elevation from 28.9t/ha at 831 to 12.5t/ha at 1083 m.

The present study showed a linear increase in SOC stocks with increasing elevation for Fluvisols and Cambisols. Similar results were shown by Wang *et al*. (2010) whereby SOC increased with increasing elevation due to increased precipitation and reduced temperature, which in turn resulted in low organic matter decomposition rates at higher altitudes, with consequent SOC accumulation. However, Leptosols showed a decreasing trend with increasing elevation. These soils occupy the areas which are more degraded and disturbed, resulting in scanty trees, grass, shrubs, and showing evidence of soil sedimentation due to land degradation and erosion uphill. Recent sedimentation may have altered the soil and water balance, physical and chemical processes, thereby increasing the SOC of the deposited sediments at the lower altitude. The higher amount of SOC stocks in all the surface horizons justifies the need for conservation of intact miombo woodlands vegetation from the lower to the highest elevation.

Changes in SOC stocks with soil depth

Changes of SOC stocks to the soil depth of 60 cm are presented in Figure 3. The average SOC decreased substantially from 19.4 t/ha in the A horizon (top 15 cm) to 13.3 t/ha in the B horizon (30 cm depth) in Cambisols, from 26.3 t/ha in the A horizon (top 15 cm) to 15.6 t/ha in the B horizon (30 cm depth) in Fluvisols, and from 28.9 t/ha in the A horizon (top 15 cm) to 12.5 t/ha in the B horizon (30 cm depth) in Leptosols.

Table 2: Variations of SOC stocks (t/ha) to the depth of 60 cm as influenced by elevation

Elevation (m)	Profile No.	Soil class FAO-WRB	SOC stocks t/ha	Slope gradient	Natural horizons	Horizons depth (cm)	SMR	STR
831	5	Leptosol	28.9	25	Ah	20	Ustic	Thermic
928	3	Fluvisol	15.2	15	Ah, BA, Bw	45	Aquic	Thermic
980	4	Leptosol	19.4	12	Ah	16	Ustic	Thermic
1083	2	Leptosol	12.5	17	Ah, Bw	25	Ustic	Thermic
1241	8	Fluvisol	24	10	Ah, Bw, $2Bgb_1$	60	Acquic	Mesic
1258	9	Cambisol	11.3	10	Ah, Bw, BC	60	Ustic	Mesic
1320	10	Cambisol	15.1	22	Ah, Bt	40	Ustic	Mesic
1377	7	Cambisol	18.6	25	Ah, Bt	35	Ustic	Mesic
1548	6	Fluvisol	26.7	10	Ah, BA, Bt_1, Bt2	60	Ustic	Mesic
1598	1	Cambisol	44.9	1	Ah, BA, Bw_1	60	Ustic	Mesic

The A and B horizons form the main area of interest given by the Kyoto SOC inventory guidelines. This is the active soil depth that is mainly affected by soil management practices Abebayehu (2013). However, the SOC stocks increased at the 60 cm depth relative to the 15 cm depth due to relatively thick layer of soil (30-60 cm) involved which resulted in larger SOC stocks. A study conducted in Ethiopia by Abebayehu (2013) reported cumulative sampling depth to be one of the important factors that affects SOC stocks. As the sampling depth/layer of soil increases, SOC stocks also increase. Thus, overall, deep soil profiles contain larger organic carbon storage than the shallow depths.

The results are consistent with others. For example, a study conducted by Neumann-Cosel *et al*. (2011) in central Panama reported a mean SOC of 28.1±3.9 t C ha^{-1} in the A horizon (top 10 cm), which dropped to 22.7±1.6 t C ha^{-1} in the B horizon in tropical moist forest vegetation type. Usuga *et al*. (2010) reported for Columbian soils with 26 years of forest trees a mean of 33.4 t C ha^{-1} in the A horizon (top 25 cm) which dropped to 14.7 t C ha^{-1} in the B horizon (25- 50 cm) in *Tectonia grandis* tree species and 87.2 t C ha^{-1} (A horizon) and dropped to 57.0 t C ha^{-1} (B horizon) in *Pinus patula* tree species. Studies of Sheikh *et al*. (2009) reported SOC levels for the Indian Himalayan zone soils to decrease from 24.3 g kg^{-1} (≡ 48.6 t/ha) in the A horizon (0-20 cm) layer to 0.2 g kg^{-1} (≡ 0.4 t/ha) in the underlying layer.

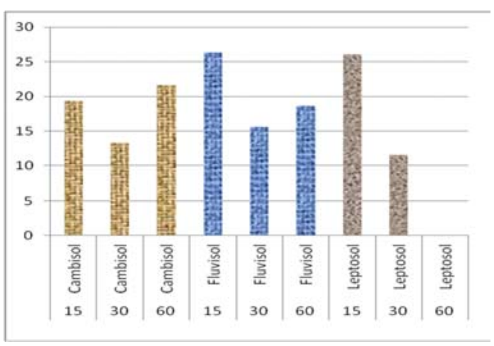

Figure 3: Mean SOC stocks (t/ha) of major soil types to the depth of 60 cm

Conclusion and recommendations

Spatial and vertical variations of SOC storage were observed across elevations and soil depths. Soil organic carbon storage increased with increasing elevation in Cambisols and Fluvisols but strongly

decreased with increasing elevation in Leptosols. Different trends among soil types might have been contributed by the varying site characteristics such as temperature and soil moisture regimes, variation in soil physico-chemical properties and topographical features.

The amount of SOC stored at the surface (A horizon) in each soil type is approximately more than two times that of subsurface horizon (30 cm) depth. The high amounts of carbon stored in the surface horizons, justifies conserving the miombo woodland soils by avoiding fires, grazing, deforestation and cultivation. Thus, land management and conservation strategies for reducing emissions should avoid deforestation and soil degradation.

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Characterization of some soils of the Miombo Woodlands Ecosystem of Kitonga Forest Reserve, Iringa, Tanzania: Physicochemical properties and classification

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Abstract

Understanding the soil types of an area is the basis for sustainable soil use and management. Miombo woodland soils have significant implications in global climate change processes. Few studies have characterized and classified the soils of the miombo woodland ecosystem of Tanzania. The current study was carried out to map and classify soils of the Kitonga Forest Reserve, which is a typical miombo woodland ecosystem, in order to generate relevant information for use and management by stakeholders. The dominant soil types of the miombo woodland ecosystem of Kitonga Forest Reserve were characterized and classified using standard soil survey methods. Ten soil profiles were excavated and described using standard methods to represent soils of the mapped area. Standard laboratory soil physical and chemical analyses were carried out to enable classification of the soils. According to the World Reference Base (WRB) for Soil Resources system the soils were classified as Cambisols, Leptosol and Fluvisols. In the USDA Soil Taxonomy the soils were classified as Inceptisols and Entisols. Different soil types differed in physicochemical properties, hence exhibit differences in their potentials and constraints for management and use. Topographical features played a very important role in soil formation. Sustainable management of miombo woodlands ecosystem soils requires reduced deforestation and reduced land degradation. The information obtained would be useful in planning management strategies of miombo woodlands ecosystem with similar ecological conditions.

Key words: Miombo woodlands ecosystem, soil physico-chemical properties, soil classification, Kitonga Forest Reserve, Tanzania.

Introduction

Soils vary greatly across the landscape and are influenced by topographical features. The soils of the miombo woodland ecosystems are important globally in climate change processes (Munishi *et al.*, 2011). However, few studies have characterized and classified the soils in Tanzania and especially those of the miombo woodlands ecosystem (Msanya *et al.*, 2003). In Tanzania, the miombo woodland ecosystem is found, among other places, in the Kitonga Forest Reserve (KFR). Understanding the dominant soil types and characteristics of the miombo woodlands ecosystem soils in Tanzania would facilitate availability of information on potentials and constraints of soils for different management and uses which will contribute to reduced disturbances and land degradation.

The miombo woodlands, which cover about 31.62 million hectares or 93% of the total forested land area in Tanzania, are important as they provide diverse ecosystem services which support livelihoods to adjacent communities (FAO, 2009). The major aim of the study was to study the dominant soil types in the miombo woodlands in the KFR with the specific objectives:

- to map the soils and their spatial distribution over the study area
- to characterize the soils based on physicochemical properties
- to classify the soils using the World Reference Base (WRB) for Soil Resource and (FAO, 2006) and the United States Department of Agriculture Soil Taxonomy system (Soil Survey Staff, 2010)

- to provide data for use by stakeholders in planning sustainable land management in miombo woodlands.

Materials and methods

Study site

The KFR is located in Kilolo District, Iringa Region, on the northern and southern sides of the Iringa-Morogoro road, at 07°35' - 07°43'S; and 37°07' - 37°10'E. The altitude varies from 660- 1880 m above sea level, with rainfall ranging from 540 mm to 900 mm, with a mean of 720 mm. The temperatures range from 13.5 to 24.7 0C, with maximum temperatures in July to October (Shirima *et al.,* 2011). Figure 1 shows the location of the study area. Detailed site characteristics of the study area are presented in Table 1.

Methodology

Field Methods

Using standard procedures (FAO-WRB, 2006); Munsell Color Co., 1992), ten soil profiles were located using the Global Positioning System (GPS) receiver, and were examined, described and samples collected from natural horizons. In each profile pit, disturbed and undisturbed samples were taken from each horizon for physical and chemical analysis in the laboratory.

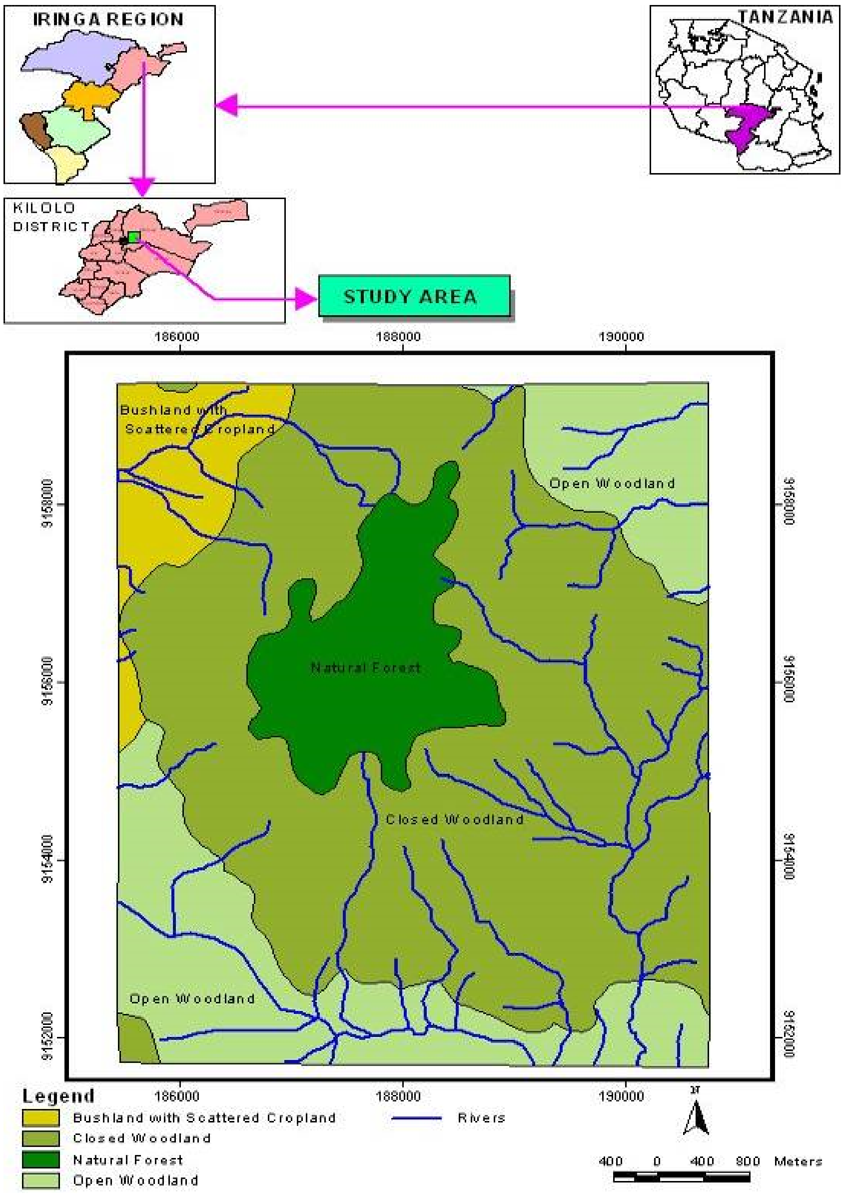

Figure 1: Map showing the study area (Source: Kilolo District Profile, 2010)

Laboratory Methods

Physical and chemical analyses were conducted as follows. The bulk density was determined using the core method (Black & Hartge, 1986), and texture was determined by the hydrometer method (Day, 1965). The pH was measured in water and 1 M CaCl2 at a ratio of 1:2.5 soil: water and soil: CaCl2,

respectively (McLean, 1986). Organic carbon was determined by the wet oxidation method (Nelson & Sommers, 1982) and converted to

Table 1: Salient features of the study area- Kitonga Forest Reserve

Altitude (masl)	Location	Profile No.	Slope gradient	Land form	Slope form	SMR	STR
831	36□ 11□ 15.72□ E 7° 39' 53.68" S	5	25	Lower slope	Straight	Ustic	Thermic
928	36□ 10□ 30.22□ E 7° 38' 32.5" S	3	15	V- Shaped Valley bottom	Concave	Acquic	Thermic
980	36□ 11□ 2.11□ E 7° 39' 45.14" S	4	12	Ridge summit (Lower)	Convex	Ustic	Thermic
1083	36□ 11□ 13.34□ E 7□ 39□ 33.66□ S	2	17	Ridge Middle slope	Straight	Ustic	Thermic
1241	36□ 8□ 55.79□ E 7□ 38□ 54.2□ S	8	10	U- Shaped Valley bottom	Concave	Acquic	Mesic
1258	36□ 9□ 15.73□ E 7□ 38□ 53.92□ S	9	10	Foot slope	Straight	Ustic	Mesic
1320	36□ 10□ 26.8□ E 7° 38' 59.93" S	10	22	Ridge Lower slope	Straight	Ustic	Mesic
1377	36□ 10□ 26.8□ E 7□ 38□ 59.93□ S	7	25	Ridge Middle slope	Straight	Ustic	Mesic
1548	36□ 9□ 41.98□ E 7□ 38□ 49.6□ S	6	10	U-Shaped Valley bottom	Concave	Ustic	Mesic
1598	36° 10' 30.22" E 7□ 38□ 32.5□ S	1	1	Ridge Summit	Convex	Ustic	Mesic

SMR= soil moisture regime STR= soil temperature regime

organic matter by multiplying by a factor of 1.724. Total N was determined using the micro-Kjeldahl digestion- distillation method as described by Bremner and Mulvaney (1982). Extractable phosphorus was determined using filtrates extracted by the Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined by spectrophotometer (Watanabe and Olsen, 1965). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were determined by atomic absorption spectrophotometer (Thomas, 1982).

Soil classification

Using field and laboratory data, the soils were classified to tier-2 of the FAO World Reference Base (FAO-WRB, 2006), and to subgroup level of the USDA Soil Taxonomy (Soil Survey Staff, 2010).

Results and discussion

Physical and chemical properties of the soils

Selected physical and chemical properties of the soils are indicated in Table 2. The soils varied in physicochemical properties. They are well drained, dominantly coarse textured and varied from sand and sandy loam texture in the surface to sandy clay loam in the subsurface. The coarse textured soils with more than 65% sand and less than 18% clay have low nutrient fertility status. Vagen and Winowiecki (2013), in their study conducted in Kenya (Dambidolo) and Tanzania (Mbinga), reported differences in nutrient storage capacity of soils due to varying in sand contents.

According to Baize (1993), EUROCONSULT (1989) and Landon (1991), the majority of soils were grouped as acidic. The soil pH ranged from strongly acid (5.1) to neutral (6.8) with a mean pH of 5.9 which is favorable for the growth of woodlands in mountainous and forest areas. The OC content was rated as very low (0.1%) to very high (4.4%) with mean of (2.6%) (medium). The cation exchange capacity (CEC- NH4OAc) ranged from very low (3 cmol (+)/kg) to medium (18 cmol (+)/kg). Generally, the soils are poor in nutrients. The low nutrient status of the soils across the study area could be attributed to frequent fires and continual deforestation of the miombo woodlands ecosystem. Frost (1996) observed a similar trend in the soils of miombo woodlands in Tabora (Tanzania), which are inherently poor in nutrients but with a wide variation in fertility.

Soil mapping units, soil classification and their relationship to topography

The detailed classification of soils representative of the mapping units of Kitonga Forest Reserve is shown in Table 3. The soils were classified as Cambisols, Leptosols and Fluvisols (FAO-WRB, 2006) or Inceptisols and Entisols (USDA Soil Taxonomy). Different soil types were found under specific topographical features. Cambisols (Inceptisols) were found on ridge summit slopes with convex slopes, Fluvisols (Entisols) were found on U and V shaped valley bottoms with concave slopes, and Leptosols were found on ridge middle slopes with straight slopes (c.f Table 1). This explains the contribution of topographical features (landforms) in forming different soil types. The findings agreed with those of Abebayehu (2013) that topographic features affect physical and chemical properties of the soils. Table 4 gives a summary of the mapping units and their areal extent with Cambisols dominating (70%).

Table 2: Selected physico-chemical properties of soils of Kitonga Forest Reserve

Profile No.	Horizon	Depth (cm)	pH		% Texture			Text.	BD	% OC	%OM	% N	mg/kg	Bases and CEC (cmol(+)/kg				
			H2O	CaCl 2	Clay	Silt	Sand	Class	g/cc				Av. P	Ca	Mg	Na	K	CEC-NH4OAc
1	Ah	0-15	5.2	4	34.3	9.3	57	SCL	1.08	0.42	0.73	0.03	0.62	0.48	0.5	0.23	0.43	6.6
	BA	15- 32	5.46	4.31	34.3	7.3	59	SCL	1.16	0.17	0.29	0.02	0.5	0.53	0.46	0.22	0.36	6
	Bw1	32- 57	5. 6	4.7	30.3	6.6	63	SCL	1.04	0.15	0.26	0.01	0.39	0.63	0.45	0.2	0.29	6.6
	BW2	57- 80	6.7	6.2	14.3	4.6	81	SL	1.22	1.57	2.72	0.11	28.89	4.96	2.2	0.2	0.36	10.4
2	Ah	0- 10	5.9	4.9	22.3	4.6	73	SCL	1	0.62	1.07	0.06	2.3	1.31	2.95	0.26	0.31	6.4
	Bw	10- 25.0	5.2	4.7	10.3	4.6	85	LS	1.1	2	3.46	0.13	9.5	3.04	1.44	0.21	0.27	9
3	Ah	0- 16	5.1	4.4	10.3	4.56	85	LS	1.14	0.4	0.69	0.4	0.5	0.4	1.17	0.16	0.14	5.8
	BA	16- 33	5.3	4.4	10.3	2.56	87	LS	1.1	0.2	0.35	0.1	0.17	0.48	1.19	0.17	0.14	4.4
	Bw	33- 45	6.4	5.8	10.3	4.56	85	LS	1.11	1.25	2.17	0.1	19	3.42	1.13	0.17	0.46	9
4	Ah	0- 16	5.4	4.6	14.3	6.6	79	SL	1.31	1.25	2.17	0.11	6.7	1.69	2.8	0.19	0.46	10
5	Ah	0- 20	6.8	6.2	24.3	12.6	63	SCL	1.21	4.4	7.62	0.25	3.14	10.7	3	0.33	0.52	24
6	Ah	0- 15	6.2	5.9	26.3	10.6	66.1	SCL	1.23	2.1	3.64	0.17	1.4	5.2	2.4	0.3	0.3	16.6
	BA	15- 27	6.2	4.8	20.3	4.6	75.1	SCL	1.31	1.4	2.42	0.08	0.5	2.5	1.3	0.3	0.2	9.4
	Bt1	27- 45	6	4.8	24.3	2.6	73.1	SCL	1.3	1.3	2.25	0.05	0.84	2.7	1.3	0.3	0.1	9.2
	Bt2	45- 60	5.5	4.4	28.3	4.6	67.1	SCL	1.21	1.17	2.03	0.06	0.84	3	1.6	0.4	0.3	9.4
	2BAb	60- 100	5.9	4.4	12.3	8.6	79.1	SL	1.17	1.55	2.68	0.08	19.7	3.4	1.5	0.2	0.2	8.2
7	Ah	0- 17	5.1	4.1	12.3	8.6	79.1	SL	1.21	0.44	0.76	0.03	7.4	2.5	0.9	0.2	0.2	8.6
	Bt	17- 35	6.1	4.4	28.3	4.6	67.1	SCL	1.26	1.62	2.81	0.18	1	2.9	1.1	0.7	0.3	13.2
8	Ah	0-19	6	4.2	8.4	4.6	77.1	S	1.09	1.12	1.94	0.1	0.3	1.5	0.6	0.4	0.2	8.4
	Bw	19-39	6.9	4.4	6.3	0.6	93.1	S	1.11	0.17	0.29	0.01	5.8	0.7	0.3	0.4	0.2	4
	2Bgb1	39-72	6.2	4.5	6.3	0.6	93.1	LS	1.1	0.09	0.16	0.01	2.6	0.6	0.2	0.2	0.1	3
	2Bgb2	72- 130	5.4	4.4	10.3	2.6	87.1	LS	nd	1.39	2.41	0.07	2.4	0.7	0.8	0.2	0.3	7.4
9	Ah	0- 10	6.1	4.4	10.3	4.6	85.1	LS	1.12	0.4	0.69	0.04	2.1	0.4	0.6	0.2	0.2	4.8
	Bw	10- 25.0	5.9	4.2	8.3	2.6	89.1	LS	1.2	0.3	0.52	0.01	0.4	1.5	0.3	0.2	0.2	3.4
	BC	25- 45	6.2	4.3	16.3	4.6	79.1	SL	1.2	1.3	2.25	0.08	1.1	1.5	0.6	0.4	0.1	8.6
10	Ah	0- 17	5.1	4.1	12.3	8.6	79.1	SL	1.2	0.44	0.76	0.03	7.4	2.5	0.9	0.2	0.2	8.6
	Bt	17-35	6.1	4.4	28.3	4.6	67.1	SCL	1.26	1.62	2.81	0.18	1	2.9	1.1	0.7	0.3	13.2

Table 3: Classification of the soils of Kitonga Forest Reserve

FAO- WRB (2006)					USDA Soil Taxonomy (Soil Survey Staff, 2010)			
Profile No	Reference Soil Groups (RSGs)	Prefix Qualifier(s)	Suffix Qualifier(s)	Tier-2 soil names	Order	Suborder	Greatgroup	Subgroup
1	Cambisol	Ferralic	Epidystric, Chromic	Ferralic Cambisol (Epidystric, Chromic)	Inceptisol	Ustept	Drystrustept	Oxic Dystrustept
2	Leptosol	Cambic	Eutric	Cambic Leptosol (Eutric)	Entisol	Orthent	Ustorthent	Lithic Orthent
3	Fluvisol	Fluvic, Haplic	Dystric	Haplic Fluvic, Fluvisol (Dystric)	Entisol	Psamment	Ustipsamment	Lithic Ustipsamment
4	Leptosol	Cambic	Eutric	Cambic Leptosol (Eutric)	Entisol	Orthent	Ustorthent	Lithic Ustorthent
5	Leptosol	Mollic	Humic, Eutric	Mollic Leptosol (Humic, Eutric)	Entisol	Orthent	Ustorthent	Lithic Ustorthent
6	Fluvisol	Stagnic, Umbric	Endoeutric, Humic	Umbric Stagnic Fluvisol (Endoeutric, Humic)	Entisol	Fluvent	Usticfluvent	Oxyaquic Usticfluvent
7	Cambisol	Ferralic	Dystric	Ferralic Cambisol (Dystric)	Inceptisol	Ustept	Drystrustept	Oxic Dystrustept
8	Fluvisol	Fluvic, Stagnic	Dystric, Chromic	Stagnic Fluvic Fluvisol (Dystric, Chromic)	Entisol	Fluvent	Usticfluvent	Oxyaquic Ustifluvents
9	Cambisol	Haplic	Eutric	Haplic Cambisol (Chromic, Eutric)	Inceptisol	Ustept	Drystrustept	Typic Dystrustept
10	Cambisol	Ferralic	Eutric	Ferralic Cambisol (Eutric)	Inceptisol	Ustept	Drystrustept	Oxic Dystrustept

Table 4: Summary of soil mapping units and their areal extent, Kitonga Forest Reserve

Soil mapping units (SMUs)	Soil types (FAO-WRB, 2006)	Area extent of SMUs in ha	% distribution
SF	Stagnic Fluvisol	4	0.52
HF	Haplic Fluvisol	10	1.30
HC	Haplic Cambisol	30	3.89
CL	Cambic Leptosol	115	14.92
FC	Ferralic Cambisol	510	66.15
NR	Natural reserve (not described because of inaccessibility	102	13.23
Total area		771	100.00

Conclusion and recommendations

Leptosols, Cambisols and Fluvisols were identified as the dominant soil types by the FAO- WRB (2006), which was equivalent to Entisols and Inceptisols in USDA Soil Taxonomy classification. Each dominant soil type was found in specific topographical features, and exhibited with varied physicochemical properties. This implies the need for specific land management and conservation strategies for each soil type. The low levels of nutrient status in the miombo woodlands justifies the need for conservation and management strategies including avoiding fires, grazing, deforestation and cultivation, as adaptation and mitigation measures.

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Diagnosis of sources of soil salinisation in selected irrigation schemes in semi-arid lands of Taita-Taveta County in Kenya

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Abstract

Investigations were carried out in five irrigation schemes in Taita-Taveta County to diagnose the extent of soil salinisation to develop effective management strategies for enhanced crop productivity and food security in irrigation schemes where crop yields were declining due to soil salinity. The research involved sampling irrigation waters from the sources, soil from irrigation schemes and testing strategies to minimise soil salinisation and increase maize grain yields. Water analysis showed that water from Kasokoni (1119.9 µS/cm and [Na] of 3.92 me/l), Rama springs (1363.75 µS/cm and [Na] of 5.75 me/l) and Kimala canal (1328.67 µS/cm and [Na] of 4.59 me/l.), which originates from River Lumi, were significantly ($p \leq 0.05$) saline. Water from Njukini (279.2 µS/cm and [Na] of 0.66 me/l), Challa (386 µS/cm and [Na] of 1.16 me/l), Njoro Kubwa (244.4 µS/cm and [Na] of 0.632 me/l), Grogan springs (377 µS/cm and [Na] of 0.73 me/l.) and Lumi springs (207 µS/cm and [Na] of 0.387 me/l) before joining Kasokoni springs were not saline. Kamleza-Kimoringo soils irrigated with water from Njoro Kubwa, of low salinity, were found to be significantly ($p \leq 0.05$) more saline (Ece 1.66 mS/cm) than other soils from other schemes whose Eces were generally below 0.56 mS/cm. These soils were at the lowest part of the irrigation schemes near Lake Jipe and had a clay texture and significantly ($p \leq 0.05$) more soluble salts (Ca^{2+} 20.97 me/100g soil). Soil pH, Ece, [Na^+] and [Ca^{2+}] did not vary with soil depth. It was concluded that the salts could have been deposited through runoff for most of the irrigation schemes and or left by the retreating nearby Lake Jipe for Kamleza-Kimoringo irrigation scheme soils. However, the irrigation water has potential for salinisation. Manure application at 20 t ha^{-1} increased maize grain yield 0.55-4 t ha^{-1} at Kimala scheme.

Key words: salinity, soil salinisation, water sources, quality, amendments, maize grain yields, Taveta irrigation schemes.

Introduction

In Kenya, about 13.49 million hectares of land are salt-affected (KSS, 1982) and land degradation due to salinity in irrigated areas is about 43 million hectares in the world's dry areas (Dregne *et al.,* 1991). These lands are affected by water-logging, salinisation and sodification. Low rainfall (250-500 mm) which is common in the semi-arid lands, is partially responsible for salinisation due to prevailing high (2500 mm) evaporation rates in the semi-arid lands (Stromberg and Tisdale, 1979). In Taveta irrigation schemes, Soil salinisation is threatening crop production. This is magnified by misuse of irrigation water from the available water sources (Itabari and Kizito, 2004). About 15-20% of the once non-saline arable land has been rendered waste land due to soil salinisation and about 800 ha of land in Taveta irrigation schemes is saline (Sijali *et al.,* 2003) . It is estimated that another 5-10% of the arable land will fall under salts if urgent and interventions are not taken. Sijali *et al.,* (2003) reported cases of farmers abandoning their farms after realising that the salt contamination effects on their land had pushed it to non-economic agricultural production. This implies that unless measures are put in place to mitigate the impact of soil salinisation in this district, food production may be unsustainable. In response, the Government of Kenya (GoK, 2004-2014) has enacted a National Environmental policy and National Environmental Action Plan (NEAP) which addresses environmental issues to mitigate against soil degradation aspects like salinity.

Soils are saline if they contain large amounts of soluble salts to interfere with plant uptake of water from soil and its growth (Ayers and Westcot, 1994; Richards, 1954; Chhabra 1996). If soils have Ece >4ds/m, pHe<8.2, ESP<15, then they are saline. The soils are massive, lack structural B horizon and contain very little organic matter (OM) (%org. C < 1). The soluble salts mainly consist of chlorides, sulphates of sodium, calcium and magnesium. Bicarbonates may be present or not and Ece soil increases as exchangeable calcium increase in the soil (Chhabra, 1996).

Salt-affected soils in Taveta District present a major challenge to agricultural production. This contributes to poverty increase to over the 54,000 persons in the District (Census, 1999). Preliminary work in Taveta irrigation schemes (Radiro *et al.,* 2003) indicated that salts increased in the soil during irrigation with water of low salinity on soils of lower salinity led to soil of very high salinity, hence making it difficult to explain whether salts were from irrigation water or from the soil and which water sources were responsible for soil salinisation so that sustainable soil salinity mitigation measures could be implemented. There was a strong feeling that soil salinisation in Taveta irrigation schemes was due to irrigation water that goes through salt containing basement rocks and brings salts to the irrigation schemes through irrigation (Radiro *et al.,* 2003).

Preliminary attempts have determined the source of salinity in Taveta irrigation schemes and extent of soil salinisation in five selected representative schemes as not due to irrigation water used except in Kimala Blocks A and B where significantly saline water from Lumi springs after joining water from significantly saline Kasokoni springs is used for irrigation. All the irrigation schemes have become saline from salts deposited on the surface from floods and runoff as revealed by status of soluble salts as measured by Calcium concentration, soil pH and electrical conductivity of soil extract in both the top and the subsoils. These soil salinity parameters were not significantly different in the top and the subsoil samples which involved analysis of 38 top (0-20 cm depth) and 37 subsoil (20-30 cm depth) samples taken across five representative schemes in Taveta.

The objectives of this study were to (a) determine the status of soil salinisation in irrigation schemes in Taveta (b) determine the relationship between irrigation water and soil salinisation (c) determine the salinity status of irrigation water and establish suitable strategy for management of salt affected soils.

Materials and methods

This study was carried out between 2010-2012 and involved five selected irrigation schemes: (Njukini (37359755E, 9648353N), Kasokoni (37357567E, 9632097N), Challa (37360554E, 9640124N), Kamleza (37354489E, 9614940N)-Kimoringo (37355244E, 9615177N) and Kimala Blocks A and B (37356103E, 9625179N) in Taveta District. These schemes were chosen based on the area they occupy and how involved they were in crop production and severity of salinity reported by farmers. Soils were sampled from 10-12 farms in each irrigation scheme. Both topsoil (0-20 cm depth) and subsoil (20-30 cm depth) were taken from each farm. Each soil sample was collected from 3-5 sampling points in the farm. These samples were mixed and re-sampled to give a single top or subsoil sample. This gave a total of 20-24 soil samples from each irrigation scheme, giving a total of 82 soil samples taken for analysis from the selected irrigation schemes. They were then taken to National Agricultural Research Laboratories (NARL) for complete analysis using modified dilute double acid Mehlich-1 method following the procedures described by Kathuli *et al.* (2007) and Hinga *et al.* (1980). The soils were also analysed for texture and its composition.

Irrigation waters were sampled from all the available water sources used for irrigation. There were eight sources of irrigation waters for all the irrigation schemes in the district. These were: Njukini springs, Kasokoni springs and connection to river Lumi, Challa springs, Rama springs and shallow wells in Njukini, Njoro Kubwa, Lumi Source and Grogan canal. This resulted in eight sources with a minimum of two replicates. This was achieved by sampling the source in duplicate or sampling more than one spring source for each source as seen from water bubbling up from the ground. This resulted in 24 water samples which were analysed for irrigation quality following the procedures of Hinga *et al*. (1980). Site elevation (meters above sea level) was taken at every spot where water samples were collected to relate soil salinity to elevation of the soil.

Strategies for management of salt affected soils

On-farm experiments were carried out to test effect of 20 t ha^{-1} manure, 40 t ha^{-1} trash, 100% gypsum requirement and control on maize grain yields in three irrigation schemes with different soil salinity levels.

All the data were analysed by analysis of variance (ANOVA) using SAS software by running general linear model due to unbalanced replication. Means were separated using Duncan Multiple Comparison tests. Simple and multivariate analyses were carried out on all soil and irrigation water data to determine relationship between water sources and soil salinisation.

Results

Irrigation waters from various sources for Taveta irrigation schemes are shown in Table 1. Salinity levels of water from different sources were significantly ($p \leq 0.05$) different. Irrigation water from Kasokoni springs and its connection point with Lumi river, Rama springs in Njukini and Kimala canal and its inlet from Lumi river had significantly ($p \leq 0.05$) higher salt concentration indicated by the electrical conductivity(Ec µS/cm) than in others water sources. The sodium (Na) concentration from these sources showed a similar trend in Na concentration. A simple regression of electrical conductivity of the water showed a significant ($p \leq 0.05$) relationship between irrigation water Ec µS/cm and [Na] in mill equivalents per litre of water.

Table 1: Characteristics of mean electrical conductivity (Ec µs/cm) and sodium concentration of irrigation waters from different sources in Taveta- irrigation schemes

Water sources	Ec µS/cm	Na^+ me/l	SAR	$SO_4^=$ me/l	Cl^- me/l	HCO_3^- me/l	Elev. masl
Njukini springs	279.2c	0.66b	0.50b	1.76b	2.72b	3.18	981a
Kasokoni springs and lumi joining point	1119b	3.92a	2.01a	29.19a	9.42a	7.85a	784de
Challa springs and farm inlet point	386c	1.16b	0.75b	3.58b	2.95b	3.40b	952b
Rama springs in Njukini	1363.75a	5.95a	2.32a	29.37a	14.93a	8.07a	922c
Kimala canal and inlet from lumi	1328.67ab	4.59a	1.79a	32.60a	13.64a	6.76a	788d
Njoro Kubwa source, Kamleza, Kitogito inlets	244.4c	0.63b	0.39b	1.46b	2.78b	2.95b	763ef
Lumi source	207c	0.39b	0.24b	0.73b	0.93b	3.88b	983a
Grogan springs, Grogan canal	377c	0.73b	0.27b	0.51b	1.17b	2.35b	751f
Lsd ($p \leq 0.05$)	228.17	2.34	0.97	20.23	9.12	1.47	22.14
Grand mean	667.5	2.32	1.06	12.6	6.4	4.8	685
r^2	0.97	0.84	0.81	0.76	0.69	0.93	0.99
CV%	18.99	56	50	89	79	16.8	1.42

Means in the same column followed by same letter are not significantly ($P \leq 0.05$) different, according to Duncan Multiple Comparison test

Simple regression of electrical conductivity of water and sodium concentration of water was highly significant (Ec irrigation water= 233.11 + 189.65 conc. [Na] r^2=0.8173, CV =33.The sodium concentration in irrigation water increased as the electrical conductivity of the water increased showing a significant linear relationship.

Multivariate analysis of electrical conductivity of water from the sources in Taveta irrigation schemes showed that Ec water=242+17.8 [Na] +30.5 SAR +12.8 $SO_4^=$ +41.4Cl^- +12.1HCO_3^- -0.2 elevation (r^2=0.98, CV=10.17). The salinity of the water from the sources was significantly ($p \leq 0.05$) affected by the amounts of sulphates and chlorides in the irrigation waters (Table 1). Sodium adsorption ratio (SAR) of the irrigation

waters which indicates proportion of sodium in the irrigation water did not significantly affect water salinity. The results on soil analysis for investigation on soil salinisation are shown in Table 2. The irrigation schemes had significantly ($p \leq 0.05$) different levels of salinisation. All the soil characteristic properties that are indicative of high salinity namely; soil electrical conductivity (Ec), sodium (Na) and calcium (Ca) concentration were significantly ($p \leq 0.05$) higher in Kamleza-Kimoringo irrigation scheme than in other schemes. This scheme was being irrigated with low Ec water from Njoro Kubwa source. The irrigation schemes being irrigated with significantly higher (Ec 1328.67 µS/cm) saline irrigation water from down stream Lumi river (Table 2) showed no significant salinisation of the soils in Kimala A and B (Table 2). Njukini, Chala and Kamleza-Kimoringo irrigation schemes had significantly higher soluble calcium (Ca) salts than Kimala A and B.

Table 2: Soil salinity and other soil properties in Taveta irrigation schemes

Irrigation scheme	pH	Ec mS/cm	Org. C%	Na me/100g soil	Ca me/100g soil	% sand	%silt	%clay
Njukini	8.16bc	0.47b	2.07a	1.38bc	16.8ab	25b	20c	55a
Challa	8.20bc	0.38b	1.18cd	1.84ab	17.1ab	20b	23c	56a
Kamleza/Kimoringo	8.07c	1.66a	1.51bc	2.13a	19.9a	24b	28b	48b
Kimala A	8.24b	0.51b	1.77ab	0.85c	9.9bc	26b	41a	33c
Kimala B	8.42a	0.56b	1.00d	0.24d	8.2c	50a	11d	39c
LSD(P 0.05)	0.14	0.55	0.36	0.60	8.4	6.13	5.3	6.13
Grand mean	8.19	0.84	1.58	1.39	15	27.5	27	45
CV%	2.23	86	29.83	57	74	29.5	26	18
r^2	0.44	0.61	0.58	0.59	0.41	0.68	0.78	0.70

Means in the same column followed by the same letter are not significantly ($p \leq 0.05$) different based on Duncan Multiple Comparison test

Multiple regression of Ec soil with other soil characteristic properties that affect soil salinisation showed that, Ece soil= 20-1.86pH + 0.04%C-0.02[Na]+0.04[Ca]-0.02% Sand-0.03% Silt-0.02% Clay-0.003 elevation (r^2=0.49, CV=83.7). These results showed that Ec of soil extract was significantly (p = 0.5) affected by amounts of soil exchangeable Ca ($p \leq 0.0008$) and influenced by soil pH and site elevation. This result corroborates the observations of Sijali *et al.* (2003) that soil salinity in Kimala irrigation scheme could be attributed to large amount of soluble calcium salts in soils at Kimala irrigation scheme. The Ece soil was negatively correlated to soil texture, soil pH and elevation. A soil with a total clay plus silt of about 76% and [Na^+] greater than 2.0 me/100 g soil implied high saline soils and soils at lowest elevation would be more saline than soils at higher elevation. This confirms that poorly drained soils have more than 48% clay and 28% silt of fine fraction of the soil (Sijali *et al.*, 2003) and the sodium content could be near threshold of 2.0 me/100g soil) (Hinga *et al.* (1980).

The variation of soil salinity and other soil characteristic properties are shown in Table 3. Soil pH, exchangeable sodium, calcium and percent sand did not vary with soil depth. However, there was significantly (47.34% more clay in the 20-30 cm soil depth. Percent silt (28.7) was significantly (p = 0.05) more in the 0-20 cm depth than in the 20-30 cm soil.

Table 3: Effect of soil depth on soil salinity and other characteristic properties that influence soil salinisation processes in Taveta irrigation schemes

Soil depth cm	N	pH	Ece S/cm	% org. C	Na me/100 g soil	Ca me/100g soil	% Sand	%Silt	%Clay
0-20	38	8.20a	0.83a	1.7a	1.33a	14.42a	28a	28.7a	43.26b
20-30	37	8.20a	0.70a	1.5b	1.34a	15.45a	27a	24.8b	47.34a
LSD ($p \leq 0.05$)		0.0827	0.297	0.212	0.348	4.86	3.54	3.18	3.6

Means in the same column followed by same letter were not significantly ($p \leq 0.05$) different

Results of the field experiment testing effect of manure, trash incorporation, gypsum application and farmers' practices for growing maize in salt affected soils irrigated with saline water is shown in Figure 1. Use of manure at 20 t ha^{-1} in Kimala irrigation scheme irrigated with saline water from Kimala canal increased maize grain yields from 0.55 t ha^{-1} (farmer practice) to 4 t ha^{-1}. Trash incorporation at 40 t ha^{-1} gave a maize grain yield of 2.25 t ha^{-1}.

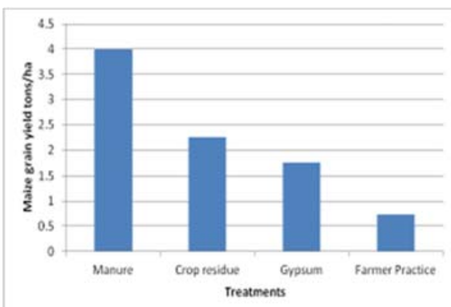

Figure 1: Maize grain yield from a saline soil irrigated with saline water from Kimala canal in Taveta District in 2012

Discussion

The analysis of irrigation water from different sources in Taveta irrigation schemes indicated that significantly (p = 0.05) saline water sources were those from Rama springs (Ec water 1363.75 µS/cm , [Na] 5.75 me/l) in Njukini near Njukini irrigation scheme, Kimala canal/Kimala inlet point from river Lumi (Ec water 1328.67 µS/cm [Na] 4.59) and Kasokoni springs (Ec water 1119 µS/cm and [Na] 3.92 me/l) which lets water into Lumi spring which, at downstream, becomes river Lumi conveying, irrigation water to Kimala A and B irrigation schemes.

The salinity of the water from the sources was significantly ($p \leq 0.05$) affected by the amounts of sulphates and chlorides in the irrigation waters (Table 1). Sodium adsorption ration (SAR) of the irrigation waters which indicates proportion of sodium in the irrigation water did not significantly affect water salinity. Irrigation water is saline and affects crop water availability if it has Ec_{water} greater than 4ds/m = 4mmho/cm = 4000µS/cm and sodium adsorption ratio (SAR) greater than five and/or it has total dissolved solids (TDS) greater than 2000 mg/l (Ayers and Westcot, 1994; Bloem *et al*., 2009; Toth *et al*., 2009). However, levels of Ec_{water} and its SAR gives water quality for irrigation (Ayers and Westcot, 1994, Richards, 1954). SAR=[Na]/$\sqrt{Ca + Mg/2}$ and it measures proportion of sodium concentration in relation to concentrations of calcium and magnesium in the irrigation water. Salinisation by the irrigation water may

be on the increase as it was reported to contain lower levels of sulphates (6.05 me/l) and chlorides (10.6 me/l) by Sijali *et al*. (2003) but it is observed to have increased to 32.60 me/l sulphates and 13.64 me/l of chlorides in 2011 with general decrease in salinity from 3ds/m (3000 µS/cm) in 2003 (Sijali *et al*., 2003) to 1328 µS/cm (1.328 dS/m) in 2011. Elsewhere, it is reported that over irrigation adds more salts to the soil (Bloem *et al*.,2009).

Soil salinisation in Kimala A and B could be partially due to irrigation water drawn from river Lumi which gets salts downstream as it is joined by Kasokoni springs which have a significantly higher Ec water of 1119 µS/cm with [Na] of 3.92 me/l. The source of river Lumi is not saline. It has a significantly lower Ec water of 207µS/cm and [Na] concentration of 0.387 me/l. The water that irrigated highly salty (Ec 1.66 mS/cm) Kamleza-Kimoringo irrigation schemes was of significantly low salinity as indicated by Ec of water from Njoro Kubwa source. A water sample taken from the farms indicated significantly ($p = 0.05$) lower salinity (Kitogito water sample had Ec water of 256 µS/cm with [Na] of 0.75 me/l) water level. This was water drawn from Njoro Kubwa through Kamleza canal with a mean Ec water of 244.4 µS/cm and [Na] of 0.632 me/l. Irrigation water will be saline if it has a Ec water of 4000 µS/cm or 4dS/cm (Toth *et al*., 2009; Richards, 1954) Although some of the water had low salinity, it has potential for soil salinisation if not properly used with strategies to prevent salt accumulation which could lead to decline in crop yields (Ahmed *et al*., 2010). It has been shown that irrigation water with Ec of 500 µS/cm can add 3000 kg of salts ha^{-1} if applied to the field at 10,000 m^3ha^{-1} (3 mm/day) (Bloem *et al*., 2009). These salts would come to the soil surface due to high evaporation rates in the semi-arid lands which is as high as 2500 mm per year leading to further soil salinisation. This means irrigation waters from Kasokoni springs, Lumi springs after being joined by Kasokoni spring water and Kimala canal water from Lumi springs after joining with Kasokoni springs and the shallow well in Njukini have potential for soil salinisation. It was further observed that the Ec of water and Na concentration increased as the source elevation decreased although not significantly. This indicated a possible salt accumulation in soils at lower elevation due to water seeking its level with salts dissolved in it. Multivariate analysis of Ec water from the sources indicated that, sulphates and chlorides significantly influenced the salinity of waters from the sources and this could be the source of salinity in the water sources found to be saline. Sodium concentration as showed by water sodium adsorption ratio (SAR) did not significantly affect the water salinity (Table 1) indicating that the water from the sources contained insignificant amounts of Na and would not pose a problem when the waters are used for irrigation.Soil analysis showed that, Kamleza-Kimoringo scheme was significantly saline because it had significantly ($p \leq 0.05$) higher Ec soil (1.66 mS/cm), exchangeable Na (2.13 me/100 g soil) and higher soluble salts as indicated by significantly ($p \leq 0.05$) high exchangeable Ca (19.9 me/100g soil) (Table 2). This was not corroborated by irrigation water being used to irrigate the schemes. If salts were to come only from water from Njoro Kubwa, then the soils would not be saline. This means salts were brought to this area by another means but not necessarily through the irrigation water being used. Soils are saline if they have Ece >4dS/cm with a pH> 8.5 and sodic if they have exchangeable sodium percentage (ESP) greater than 15 and non-saline, non-sodic if Ece <4dS/cm, ESP<15 and pH<8.5. $ESP=[Na]/\sqrt{(([Ca]+[Mg])/2)}$. Soils can be saline, sodic or both according to risk assessment methods of salinity in USA and Europe (Toth *et al*., 2009; Richards, 1954; Bloem *et al*., 2009).

Regression of Ec soil with soil properties, indicative of soil salinisation showed that Ec soil was significantly ($p \leq 0.05$) related to exchangeable Na and Ca in the soil. The relationships were positive and linear indicating that soil salinity increases as Na and Ca in the soil increases. Calcium salts are sparingly soluble and they would tend to be left behind by water as it seeps into lower soil horizons and hence its high accumulation in the soil. Again if water moves to its lower level with salts dissolved in it, and the Ec water has been shown to increase as elevation decreases, then salts must have moved to this area from another area. Further from this scheme there is Lake Jipe which could have covered this area before and as the water moved, salts were left behind. Similar explanations could be extended to Kimala irrigation scheme (730 m) with mean temperatures of 24.6-23.5^o C and evapotranspiration of 2167 mm per year compared to Njukini (980 m) with mean temperature of 23.5-22.42^o C and ETo of 2079 mm per year (Jaetzold and Schmidt, 1983; Woodhead, 1968). Njukini irrigation scheme had significantly higher organic matter level followed by Kimala. Kamleza- Kimoringo had significantly lower organic matter content and the scheme was at the

lowest elevation (722-724 m) and a shallow water Table (0.3-1 m) and this could have contributed to high salinity from water rise through capillarity and evaporation leaving salts on the soil. The higher (<2.0 % org. C) organic matter content in Njukini could have contributed to decline in soil salinity. It has been observed that, presence of organic matter in soils reduces soil salinization by modification of the soil physical structure (Ahmed *et al.,* 2010) which either allows for improved drainage or provides calcium to replace Na which is responsible for soil salinisation. Sand content in the soil was found negatively related to Ec of the soil. More sandy soil would have low salinity due to improved drainage. Higher percent (28%) silt and (48%) clay in the soil indicated an increase in Ec soil, meaning poor drainage which leads to soil salinization. The higher soil pH is caused by bases brought up to the plough layer by capillarity which is higher in wet sandy soils due to their large pore spaces or salts hanging up in the upper moist soil through hysteresis.

It was also observed that, soil pH, Ece, [Na^{+}] and [Ca^{2+}] did not significantly vary with soil depth from 0-30 cm. However soil clay significantly increased with soil depth while there were more sand and silt in the 0-20 cm depth. This confirms that saline soils are massive and of poor drainage and interventions to manage them should include drainage or other interventions to modify the soil structure for improved permeability to leach the salts past the plough layer.

Results on use of 20 t ha^{-1} manure, 40 t ha^{-1} trash incorporation, 100% gypsum requirement and control for maize planted and irrigated with Kimala canal saline water (Ec water 1328.67 μS/cm [Na] 4.59 me/l) showed higher maize grain yield on fields where manure was used followed by trash incorporation. This results confirms the findings of Choudhary *et al.* (2011) who observed that, application of organic manure at 20 Mg ha^{-1} or crop residues at 6 Mg ha^{-1} on a rice-wheat rotation cropping system irrigated with sodic water resulted in rice and wheat yield increase and a decline in soil pH and exchangeable sodium percent (ESP) and increased infiltration. The rice-wheat rotation cropping system that did not receive manure or crop residues resulted in increased soil pH, ESP, poor soil physical structure and decline in yields over the 15 year study duration. Manure and crop residue incorporation in soil if fully decomposed produces organic acids that have affinity for salts and sodium in the soil. These acids react with these cations reducing their hydration power which is responsible for soil particle dispersion and hence poor infiltration which increases salts and sodium accumulation in the rhizosphere affecting water use by crops leading to decline in yields. In presence of manure or crop residues upon decomposition, there is no salt accumulation and hence increase in crop growth and yields.

Conclusions

The highly saline water sources in Taveta irrigation schemes are Rama springs, shallow wells in Njukini, Kimala canal from Lumi River and Kasokoni springs. The salinity in these irrigation waters is mainly due to high levels of sulphates and chlorides and not sodium. There is potential for irrigation water from Kimala canal to cause soil salinisation particularly in Kimala block A and B irrigation schemes. Njukini springs and Njoro Kubwa springs are not saline. Soil salinity in the highly saline Kamleza and Kimoringo schemes could have been as a result of saline soil deposition rather than from irrigation water. Soil salinisation in Taveta irrigation schemes tend to be highest at lowest elevations, and are attributed to soluble calcium salts in the soil. Use of manure or crop residue incorporation seems to be the way forward for reduction of soil salinisation for increased crop production in salt affected soils irrigated with poor quality irrigation water.

Recommendations and way forward

Salinity in the schemes can be managed through drainage and other interventions that dissolve the salts to move further down the irrigation scheme elevation, and other strategies that remove the salts provided further external salt water intrusion is managed. The irrigation waters from Njukini springs, challa springs, Njoro kubwa springs, Lumi springs before joining Kasokoni springs and Grogan springs are suitable for irrigation provided soils are freely drained and strategies to remove possible salts accumulated are adopted. Strategies to improve the soil structure in these irrigation schemes would be highly required to improve soil drainage and minimise soil salinisation. Strategies for minimising effects of sulphates and

chlorides added in irrigation water from Kasokoni springs, Rama springs in Njukini and Kimala canal from Lumi river on soil should be developed. Use of manure or crop residues for soil salinity reduction in irrigation schemes requires further research to confirm results reported here.

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Soil information to support sustainable food security in Africa: A case study in Burkina Faso

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Abstract

Crop performance and response to management are explained through yield gap analysis and codetermined by soil conditions. Agricultural productivity is limited by soil fertility and the response to soil fertility management is limited by soil water availability. Appropriately scaled soil information permits to extrapolate measured soil-specific response to management from a limited range of experimental site conditions to the wide range of environmental conditions that prevail on the agricultural land using models. The necessary information is being compiled at an increasingly fine resolution through various collaborative international frameworks, considering both historic and newly collected primary soil profile data. The Africa Soil Profile database compiles historic soil data for over 16,000 profile records. These represent only a portion of all the soil profile data that have been collected and documented over decades for the continent. Collaborative efforts are needed to develop comprehensive appropriate data and analysis tools.

Key words: yield gap, soil management, soil information, legacy data, Africa

Introduction

Sustainable food security is codetermined by agricultural crop performance, soil conditions and soil management. Sustainable food security requires within a socio-economically and cultural-politically conducive environment, response to soil management expressed in terms of enhanced soil conditions, or soil health.

Soil health is defined here as the capacity of the soil to function as a living ecosystem (FAO, 2011a or b?) which provides a range of supporting, provisioning, regulating ecosystem and cultural services (MEA, 1995; UNEP, 2012). It is a measure for soil condition and is expressed relative to benchmark criteria and reflected in soil organic matter content as commonly used indicator. Soil management to enhance soil health through increasing soil organic matter content, contributes both to sustainable food security and mitigation of climate change. It is necessary to produce more vegetative organic matter to enable sustainable increase of soil organic matter. The fundamental entry point hereto are plants as they assimilate CO_2 through photo-synthesis, which justifies a continued focus on soil management to increase vegetative, crop, production, either directly or indirectly, for achieving and maintaining soil organic carbon accumulation rates exceeding decomposition rates.

The ongoing debate about improving food security in Africa is about how to enrich Africa's soils (Sanchez, 2002; Gilbert, 2012). According to the Alliance for a Green Revolution in **Africa** (AGRA), crop performance in sub Saharan Africa is limited by nutrient availability on three quarter of the agricultural land. Nutrient balances need to be restored which relates to the restoration of organic carbon levels and requires integrated nutrient and water management practices (Smaling *et al.,* 2011). AGRA's soil health program particularly contributes to the wide spread implementation of integrated soil fertility management practices. Yield gap analyses point at temperature and water limited production largely exceeding nutrient limited and actual production in the vast majority of Africa's farming systems, under given climate conditions, with a positive impact of crop residue management on simulated crop yield (Folberth, 2012).

Taking the spatial and temporal dynamics and cycles of organic carbon and nutrients into consideration one concludes that the overall soil fertility and soil health in the prevailing farming systems cannot be enhanced significantly without any spatial/temporal component of the farming system receiving external inputs in the form of mineral fertilizers. The core of the challenge is to judiciously combine mineral fertilizer use with organic and biological fertilizing practices, integrated into the prevailing risk-averse smallholder farming systems. Risk of investment may well be one overruling argument why resource poor smallholder farmers in Africa, and elsewhere, refrain from fertilizer use and enabling policies and settings are key to reduce the risk (Koning *et al*., 2001). Risk for insufficient response to costly external inputs, for example due to unpredictable rainfall, is codetermined by soil conditions and is to a certain extent manageable given appropriate soil specific information.

A wealth of primary soil data and derived soil information has been collected and documented in the form of reports and maps and is held in numerous national and international organizations and institutions. Collation of this wealth of legacy soil data into a consistent digital format would constitute a major asset for subsequent production of derived and harmonized soil information for assessing major issues such as sustainable food security under climate change in Africa, if made freely accessible. To collate such data in sufficient quantity and quality to coherently map Africa's soil resources at an increasingly fine resolution, facilitative resources and collaborative frameworks need to be put in place to enhance capacity and active contribution and sharing of data, analyses and results. The current state of global and regional soil information has been reviewed for the Global Soil Partnership (Omuto *et al.,* 2012), and includes a discussion of ISRIC's emerging Global Soil Information Facilities (Batjes *et al*. 2013). For Africa, recent developments include the Africa Soil Profiles database (Leenaars, 2013) and products such as the Soil Atlas of Africa (Jones *et al*., 2013).

This paper discusses the relevance of soil data in support of sustainable food security, with a focus on yield gap analysis as illustrated by measured soil-specific crop performance for a case study in Burkina Faso and on the relevance of developing collaborative next versions of the Africa Soil Profiles database.

Materials and methods

Assessing the yield gap

Numerous options exist for improved land and water management, including soil management aimed at improving physical, chemical, biological and/or hydrological conditions (WOCAT, 2007; FAO, 2011; Milne, 2012). Soil management for sustainable food security and climate change mitigation aims particularly at maintained or improved soil health, represented here by as soil organic matter content as an indicator. Crop response to soil fertility management is codetermined by soil conditions, in particular the availability of water and nutrients.

Results and discussion

Figure 1 shows the cereal grain response to two soil fertility management options relative to the control treatment, as measured at the experimental station of Saria, Burkina Faso; high application rate of mineral fertilizers (FM) and high application rate of a combination of mineral and organic fertilizers (FMO). The response to FMO largely exceeds the response to FM and the responses vary strongly over the years. The actual crop performance under the control treatment is nutrient-limited and therefore relatively stable over the years. Alternatively, the multi-year variation of response to FM and FMO is clearly explained by the variation of the performance of the fertilized crop, which is water-limited; differences over the years are due to differences in available soil water associated with the natural variation in rainfall. The treatments should have been well explained beforehand before these results are presented.

Yield gap analysis provides a consistent framework for explaining measured, soil specific, response to management. The yield gap at a given location, or the difference between actual and attainable crop performance, is basically an expression of the degree to which the demand of the crop, for e.g. water or

nutrients, is met by supply. Figure 1 illustrates how the crop's demand for nutrients varied more strongly over the years than the (control) soil's supply of nutrients.

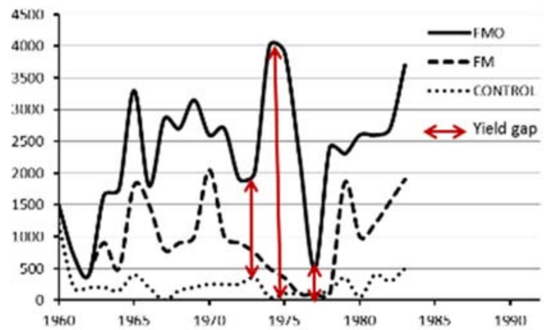

Figure 1: Cereal grain yields measured for 24 years at the experimental station of Saria, Burkina Faso, under three soil fertility management treatments (after Pichot *et al.*, 1981). What is the parameter on the y-axis? If the results by Pichot *et al* were published in 1981, why does Figure 1 show results for some years after 1981?

Subsequently, a fertilizer experiment was setup at the same experimental station, in collaboration with national institutions (Bureau National des Sols and the Institut National des Etudes et Recherches Agricoles), to assess the relevance of soil conditions for explaining crop performance and response to soil fertility management. Average annual rainfall at Saria is 800 mm, potential evapotranspiration 2000 mm and the length of cropping season 100-120 days. A sorghum crop was grown on five plots along a toposequence, developed over granite, using different combinations of nitrogen and phosphorus fertiliser applications rates (see below for details), with four replicates. The soils of the plots differed in water holding capacity and native fertility. Water holding capacity, as determined by rootable depth, gravel content and water retention ranged between 20 and 100 mm. The native soil fertility, as reflected here by the organic carbon content of the A horizon, ranged from 1.6 to 8.1 g/kg.

The toposequence at Saria is described by Boulet (1975) and the soils are classified as 'sols tropicaux ferrugineux lessivés et indurés'. Starting at the upper part of toposequence, plots HA and HB are shallow and moderately deep, gravelly soils on ironpan (skeletic petroferric Lixisols) , followed by plots BA and BC with moderately deep to deep sandy clay soils on ironpan (petroferric Lixisols), and finally plot BD with deep sandy soils of limited rootability due to imperfect drainage (fluvic Lixisols).

The soil-specific crop responses to nitrogen application rates of 0, 30 and 90 kg/ha (with a phosphorus base gift of 39 kg/ha) are shown by Figure 2 in terms of grain yield and above ground dry matter production. Crop response in terms of grain yield is of immediate interest to the farmer, while the response in terms of dry matter will determine farmer's options for soil organic matter management.

Under the control treatment (0 kg N/ha), the differences in crop performance between plots are explained by differences in native soil fertility. This is illustrated in Figure 3 by relating the above ground dry matter production to the topsoil organic carbon content. The differences in native soil fertility are also reflected in the nitrogen and phosphorus base uptake figures.

For the maximally fertilized treatment (90 kg N/ha), the differences in crop performance on the five different soils are largely attributed to the differences in soil water holding capacity, which is illustrated in Figure 4 by relating grain yield to the water holding capacity of the rootable soil. Post-anthesis growth was determined by soil water availability in the experiments, because rainfall stopped at anthesis.

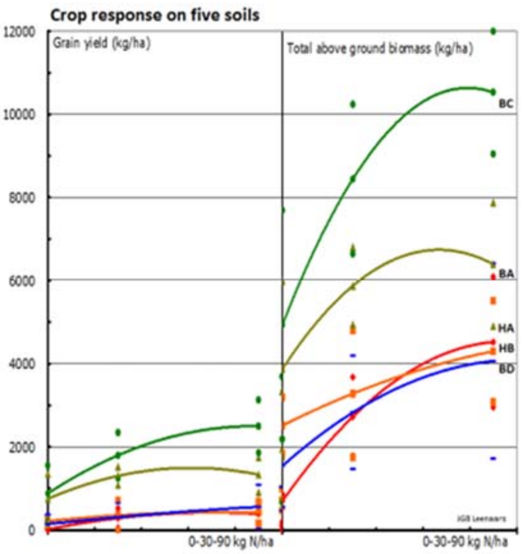

Figure 2: Response to nitrogen fertiliser application on five different soils, with a base gift of 39 kg P/ha (Saria toposequence, Burkina Faso)

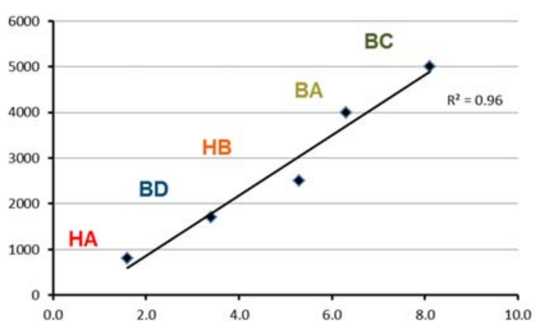

Figure 3: Above ground dry matter production (kg/ha) for the control treatment (0 kg N/ha) as a function of soil organic carbon content (g/kg) of the A horizon of five diferent soils of the Saria toposequence , Burkina Faso

The grain response to nitrogen application was largely explained by the difference between the nitrogen supply from the soil and the crop's nitrogen, the latter being driven by the soil water supply. Or, in other words, "no water, no response to soil fertility management". The higher the soil water availability, the higher the nitrogen use efficiency was in terms of kg grain (and dry matter) produced per kg nitrogen applied. This was also observed for the underlying uptake efficiency and physiologic efficiency. Vice versa, fertilisation improved soil water use efficiency by the crop.

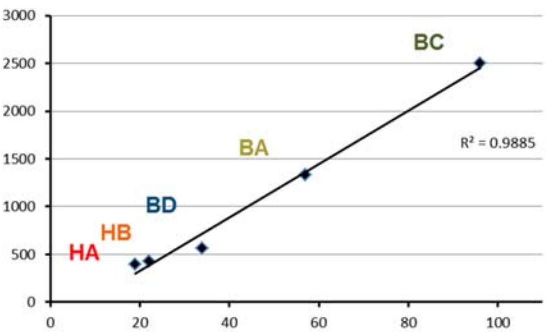

Figure 4: Grain yield (kg/ha) for the 'maximally fertilised' treatment (90 kg N/ha) as a function of the water holding capacity (mm) of the rootable soil (Saria toposequence, Burkina Faso)

As illustrated by the above example, the framework provided by yield gap analysis permits to explain measured soil-specific responses and year-specific responses to management, with the "maximally fertilised" treatment mimicking conditions for water-limited production and the control treatment mimicking those for nitrogen limited production. Once captured through agro-ecologic modelling, and regionally validated, yield gap analysis permits to identify those (soil) conditions that limit crop performance to assess the likeliness of crop response to soil management options, applicable over the wide range of agro-ecologically different conditions that prevail over Africa, given the availability of appropriately scaled and model-specific information on those agro-ecological conditions. With respect to soil conditions, such information is being collected and compiled at continuously increasing resolution, considering both historic primary data and newly collected primary data, in the context of national international initiatives and collaborative frameworks such as AfSIS, Global Soil Map, SOTER, and the Global Soil Partnership (e.g., Sanchez *et al.,* 2009; FAO *et al*. 2012; Omuto *et al*. 2013; Vagen *et al.,* 2013). As the World Data Centre for Soils, ISRIC – World Soil Information is contributing to these collaborative efforts, among others by making the Global Soil Information Facilities available to partners (Batjes *et al*. 2013). The Africa Soil Profiles database, and the associated Africa Soil Maps database, will be discussed here as an example.

Africa Soil Profiles database

The Africa Soil Profiles database, with profile data for over 16,000 profiles (Leenaars, 2013), was compiled within the context of the Africa Soil Information (AfSIS) project. The profile inventory specifies the full lineage to the data sources and data providers. In conjunction with this, the Africa Soil Maps database is being developed: an inventory of legacy soil maps held in various holdings, including those of ISRIC, FAO, WOSSAC, IRD, and University of Ghent (Figure 6). Together, these databases represent an increasingly comprehensive inventory of the legacy soil data for Africa, including both soil maps and associated reports, permitting for digital collation of soil mapping units and profile data. Since the mapping units are derived spatial representations of the profile data, the latter can be georeferenced as points as well as polygons, allowing for a range of applications as, for example, the development of region-specific Soil and Terrain databases (SOTER), ultimately allowing for updates of the Harmonised World Soil Database (FAO *et al*. 2012), and digital soil mapping (Hengl *et al.,* 2013).

The Africa Soil Profile database describes a range of soil properties necessary for a wide range of analyses, including yield gap analysis: soil depth, soil gravel and tension specific water content, as well data on

organic carbon, nitrogen, phosphate and potassium content and pH, CEC and data on morphology and classification where originally provided. For details, see the Technical Report by Leenaars (2013).

Quality of data and information is context or use specific. Typically, the quality of the data, and the functions derived from them (Wösten *et al*. 2013), are considered appropriate to support analyses at continental and national scale. However, they may not be adequate to support the formulation of farm or field specific soil management recommendations, for which more extended and detailed data sets are needed (Paterson and Mushia, 2011). It is the intention to extend the Africa Soil Profiles database through collaborative action, upon the identification of funding, leading to joint next versions of the database and derived products.

Conclusion

Legacy soil data, once digitally presented at the appropriate scale, permit to explain crop response to management and to assess sustainable food security and climate change mitigation and adaptation, for example within the setting of the Global Soil Partnership and similar.

The process of identification, collection, collation, standardization and quality screening of legacy soil data, from a wide range of national and international holdings, is labour intensive yet critical. It is considered cost effective when compared to the collection of new soil data.

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Effects of gyphosate rates and formulations on weed control and maize performance under conservation agriculture in eastern Kenya

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Abstract

Maize production lags behind the population demand in eastern Kenya, and this is attributed to weeds competition with the crop for various growth resources, among other factors. A study was conducted to determine the effects of two glyphosate formulations (Roundup Turbo and Roundup Weathermax) and rates on general weeds control and maize performance. The first (long rains 2011), second (short rains 2011) and third (long rains 2012) season's trial results observed that the glyphosate based herbicides are effective means of weed management in maize grown under zero tillage conservation agriculture systems. Roundup Turbo applied at 2.5 liters ha^{-1} and the three (1.5, 2.5 and 3.0 liters ha^{-1}) tested rates of Roundup Weathermax herbicide gave effective weeds control and improved maize grains and shoot biomass. Both formulations did not have any phytotocixity on the maize. Herbicides treatments had higher net benefits compared to un-weeded and conventionally tilled practices. The crop yields significantly ($p \leq 0.05$) differed between un-weeded and weed controlled treatments (both conventional and herbicide methods). Conventionally tilled treatment gave an average grain yield of 3.6 t ha^{-1} that was not significantly different from those from zero tillage treatments. The lowest grain yield (0.1 t ha^{-1}) was acquired from un-weeded treatment and significantly ($p \leq 0.05$) differed from those of conventional and herbicides treatments. The study concluded that the use of Glyphosate based herbicide is an appropriate and economic approach for weed management in maize grown under zero tillage conservation agriculture systems.

Key words: glyphosate, zero tillage, conventional tillage, weed control, maize yields.

Introduction

Maize is the most important staple crop in Kenya for over 90% of the population with the small holder farming systems accounting for about 75-80% of the total production (Muui *et al.,* 2007). While the crop is mainly grown for its grains, stovers are fed to livestock and empty cobs used as source of fuel for cooking. The average maize yield in Kenya is approximated at 1.5 t ha^{-1}, with most of small-holder farmers producing less than 1.8 t ha^{-1} (Muriithi *et al.,* 1999; Ouma *et al.,* 1999). Weeds competition with the crop for growth resources is singled out as one of the challenges faced by smallholder farmers and therefore limiting maize production (Terry and Michieka, 1987). The deleterious effects of weeds may be managed by use different methods, including hand weeding and herbicide sprays (Berca, 2004).

Hand-hoeing is constrained by limited labour and weeds that are difficult to manage due to their great diversity in terms of species and nutrient scavenging systems (Micheni *et al.,* 2002). Competition for labour during the peak weeding period affects maize production, because labour is utilized for higher income generating activities such as picking coffee and cattle rearing (Ouma *et al.,* 1999).

In a socio-economic study on adoption of herbicide technologies in maize based cropping systems in central Kenya (Muriithi *et al.,* 1999) recognized that the use of herbicides is the most economical method for weeds control in maize production systems. Similarly, Muthamia *et al.* (2004) in conservation tillage studies in the central highland of Kenya reported that farmers have their farm benefits increased by using herbicides for weeds control. This calls for enhanced research on testing and promoting appropriate herbicide. It is therefore on this basis that study was conducted in the humic areas of eastern Kenya to determine the effects of *Glyphosate* based herbicide product on weeds management and maize performance when grown under zero tillage (ZT) conservation agriculture (CA) practices.

Materials and methods

Site

The study was conducted at the Kenya Agricultural research Institute (KARI- Embu) farm on the eastern slopes of Mt. Kenya at 00^0 33.18'S; 037^0 53.27'E; 1420 m asl and in the upper midlands (UM_3) zone. The region experiences 1250 mm average annual bimodal rainfall and warm temperatures, ranging from 21-28 and 16 - 21^0C mean maxima minima, respectively (Jaetzold *et al.,* 2006). The two rainy seasons are the long rains (LR) lasting from March to August and short rains (SR) from October to January (Jaetzold *et al.,* 2006). About 65% of the rains come during the March rains and in some years end in July-August with scanty showers that assist the late maturity maize varieties in grain filling. The eastern Kenya soil are dominated by humic *Nitisols*, which are of moderate to high inherent fertility due to their high minerals, available water and cation exchange capacity levels (Jaetzold *et al.,* 2006). However, over time the fertility has declined due to inappropriate soil management and nutrients depletion (Mwangi *et al.,* 1996; Gitari and Friesen 2001). The farming system is mainly of medium maturity maize varieties intercropped with beans (Waithaka *et al.,* 2006). The crops grain yields have constantly declined due to weed competition in the region.

Experimental design, treatments and blocking

The trials were laid out on a randomized complete block design (RCBD) with four replicates separated by paths measuring 2.0 m. A given replicate had six plots, each measuring 3.75 m (6 rows) x 4.00 m (9 hills of 2 plants each). The treatments were made of three rates (1.5, 2.5 and 3.0 lits ha^{-1}) of Roundup Weathermax herbicide and one rate (2.5 lits ha^{-1}) of Roundup Turbo Table 1). The fifth and sixth treatments were the un-weeded and conventional tilled weed management systems. The six weed management treatments were randomized within and between blocks, and any two plots within a block were separated by a 1.0 m buffer zone path to guard treatments from spilling over between plots. Likewise any two replications were separated by a 2 m buffer zone for the same purpose.

Table 1: Treatments description for Glyphosate based trials for the management of weeds in maize fields in humid areas of eastern Kenya

Glyphosate based herbicides	Application rate (lits ha^{-1})	Active Ingredient (gms Glyphosate lit^{-1})	Tillage method
Roundup Weathermax	1.5	540	Zero Tillage
Roundup Weathermax	2.5	540	Zero Tillage
Roundup Weathermax	3.0	540	Zero Tillage
Roundup Turbo	2.5	450	Zero Tillage
Un-weeded	N/A	N/A	Land left bushy
Hand hoed	N/A	N/A	Conventional Tillage

Trial establishment

The study was conducted for three seasons during 2011 – 2012 rainy seasons and every season the experimental sites were selected in a weedy field that had stayed for over 12 months without any kind of cultivation. Glyphosate herbicide sprays were applied after approximately a week after the on-set of the rains and when the weeds were actively growing. The one week planting delay was meant to allow the weeds to start growing actively after going through a period of "dormancy" observed during dry spells witnessed prior to the start of the rains. Plots were therefore marked out in the weedy field, and planted with medium maturity maize variety (var. DK 8031) spaced at 75 cm (between rows) and 50 cm (between hills). Three seeds were planted using sharp pointed *pangas* by carefully parting the weeds to access the soil, making holes, placing 10 gms (per hill) of N_{23}:P_{23}:K_0 fertilizer material and then sowing the maize seeds. The conventional tillage plots were prepared using conventional *folk-jembe* to achieve fine tilth for maize production. The same tool was used to make planting holes at the recommended plant population.

Treatments application

Herbicide treatments were applied a day after seeding. Adequate amounts of herbicides were drowned from their containers using graduated syringe with a needle before transferring the contents into mixing buckets. The herbicide/water solutions were then transferred into pre-calibrated CP3 15-liter Knapsack sprayers fitted with low volume herbicide application nozzle to deliver 200 - 250 lits hectare^{-1} of the solutions. The solutions were then applied evenly on the weeds in all but hand weeded and un-weeded plots.

Thinning and stem borers management

Immediately after the crop emergence, thinning was done leaving two plants per hill or to maintain 53,333 plants ha^{-1} plant population. The borers start invading maize immediately after the crop emergence causing up 40 % yield loss (Mulaa, 1995; Pingali, 2001). Borer-cide (*Bulldock* 0.05 GR) at the rate of 6.5 kg ha^{-1} was therefore applied every season a month after the crop emergence to control the pest. Two hand-weeding events were conducted only on the conventional plots at 15th and 85th day of the crop emergence.

Data management and reporting

Biophysical and socio-economic data were collected and analyzed using analysis of variance (ANOVA) method via Statistic Analysis System (SAS) computer programme. In addition, net-benefits were computed to determine profitability of the various weed management systems for maize production in eastern Kenya region.

Results

Main weed species at the trial site

Identification of weed species within the experiential area was done the same day of treatment application with the aim getting baseline information on weed species and biotypes within species which may ultimately compete with the crop if not managed. Broad and narrow leafed weeds were found with the couch grass (86%), *Richardia scabra (82%)* and *Oxalis (67%)* dominating the site in all three seasons. Additionally, *Bidens pilosa*, *Galinsoga parviflora*, *Cyperus spp*., *Amaranthus spp.* and *Commelina spp.* were other very common weed species.

Percent (%) weeds suppression

Percent weed ground cover is one of the parameters used to provide guidelines on how weeds are suppressed by herbicides. This was achieved by using a 1.0m^2 quadrant randomly thrown in a given plot, followed by visually recording weed suppression status therein. The activity was conducted three times in a given season as follows:

- Weed suppression event 1 (WS^1): Taken 1 month after the crop/weed emergence
- Weed suppression event 2 (WS^2): Taken 2½ months after the crop/weed emergence.
- Weed suppression event 3 (WS^3): Taken 3½ months after the crop/weeds emergence.

Data gathered from the three events were later worked out into percent weed suppression (% ws) using the following formula:

$$\% \text{ ws} = \frac{(\text{Msut} - \text{Mst})}{\text{Msut}} \times 100$$

Where: Ws = Weed suppression; Msut = Mean score of un-weeded treatment; and Mst = Mean score of a treatment.

The results showed that the critical time that the weeds/crop competes for resources was just before the crop flowering (2½ months after the crop emergence). This clearly witnessed in un-weeded treatment whose %ws differed ($p \leq 0.05$) significantly from those of herbicide and conventional tilled treatments during the three events that the parameter was monitored (Table 2).

Table 2: Percent weed suppression (ws) during different periods of Glyphosate based trials for the management of weeds in maize fields in eastern Kenya

Glyphosate based herbicides	Application rate (lits ha^{-1})	Tillage method	(%) WS^1	(%) WS^2	(%) WS^3
1. Roundup Weathermax	3.0	Zero Tillage	66.0^b	96.3^a	87.5^{ab}
2. Un-weeded	N/A	No Tillage	0.0^d	0.0^d	0.0^d
3. Conventional Tillage	N/A	Conventional	88.5^a	35.0	91.8^a
4. Roundup Weathermax	2.5	Zero Tillage	59.0^b	89.5^b	83.3^b
5. Roundup Turbo	2.5	Zero Tillage	58.8^b	94.8^{ab}	89.0^{ab}
6. Roundup Weathermax	1.5	Zero Tillage	49.5^c	82.8^c	75.3^c
Mean	-	-	53.6	66.4	71.1
LSD (0.05%)	-	-	9.2	5.3	5.8
%CV	-	-	11.4	5.3	5.4

Means with the same superscript letter are not significantly different ($p \le 0.05$); CV = Coefficient of variation; LSD = Least Significant Difference; N/A = Not Applicable

Weed vigour

Information on weed vigour was recorded at 0 (treatment application day), 70 (crop flowering) and 120 (crop physiological maturity) days. This was achieved by visually observing the average weed vigour using a scale of 1 – 4, where 1, 2, 3 and 4 represented very low, low, medium and high weed vigour, respectively. The hand hoed plots were free of weeds resulting from fine and weed-free prepared seedbed. Low weed vigour was recorded in herbicide treated plots at the time of treatment application. The situation changed later to medium weed vigour in conventionally tilled plots calling for the first hand weeding event approximately eight days after crop/weeds emergence. There were declining trends starting from the start to the end of the seasons in weed vigour in all plots where the herbicides were applied.

Crop phytotoxicity

In the study plant phytotoxicity condition was considered to be any deviation from normal morphological or physiological changes due to biotic, abiotic or artificial influence. We therefore focused on scorching of the whole or parts of the plant; de-colouration of plant parts from the normal green colour for a healthy plant; deformation or dwarfing of all or some plants; and extra ordinary maturity of plants. The assessments were done at 30th, 70th and 120th day after the crop emergence using scores of 1, 2, 3 and 4, denoting: low, medium, high and very high phytotoxicity, respectfully. Only plants in un-weeded treatments showed significant differences ($p \le 0.05$) in de-colouration of plant leaves and dwarfing of plants (Table 3). In addition, plants in the said plots died in approximately 10 days earlier than those under conventional or herbicide treated plots.

Maize days to physiological maturity

Crop physiological maturity was arrived at when over 90% of plants in a given plot stopped sinking nutrients into their system due to age effect. Our study recorded an average of 126, 133 and 136 days for DK 8031 maize variety from emergence to physiological maturity in LR 2011, SR 2011 and LR 2012 trials, respectively. The un-weeded plots had the crop maturing significantly ($p \le 0.05$) earlier (approximately 10) than those under hand or herbicides treated plots. This was attributed to weeds withdrawing essential growth resources from the crop which suffered nutrients stress and therefore reached physiological maturity (died) earlier than expected.

Table 3: Crop phytotoxicity score at different periods of Glyphosate based trials for the management of weeds in maize fields in humid areas of eastern Kenya

Glyphosate based herbicides	Application ate (lits ha^{-1})	Phytotoxicity Score		
		1	2	3
1. Roundup Weathermax	3.0	1.5	1.5^{b}	1.5^{b}
2. Un-weeded	N/A	3.0^{a}	3.5^{a}	3.8^{a}
3. Conventional Tillage	N/A	1.3^{b}	1.3^{b}	1.5^{b}
4. Roundup Weathermax	2.5	1.5^{b}	1.5^{b}	1.0^{b}
5. Roundup Turbo	2.5	1.5^{b}	1.5^{b}	1.3^{b}
6. Roundup Weathermax	1.5	1.5^{b}	1.5^{b}	1.8^{b}
Mean	-	1.7	1.8	1.8
L.S.D (0.05%)	-	0.6	0.8	0.8
CV	-	24.5	31.0	28.1

Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = Coefficient of variation; LSD = Least Significant Difference; N/A = Not Applicable

Maize shoot biomass and grain yields

At physiological maturity stage maize shoot biomass and grain yields were determined. The two parameters significantly ($p \leq 0.05$) differed between un-weeded and conventional or the herbicide managed plots (Table 4). The zero tillage treatments had 4.4, 4.3 and 4.0 from Roundup Turbo (2.5 lits ha^{-1}), Roundup Weathermax (3.0 lits ha^{-1}) and Roundup Weathermax (2.5 lits ha^{-1}) treatments, respectively. The yields from zero tillage treatments were not significantly different from one another in the three seasons that the study was conducted. Conventionally tilled treatment gave an average grain yield of 3.6 t ha^{-1} that was also not significantly different from those from zero tillage treatments. The lowest grain yield (0.1 t ha^{-1}) was acquired from un-weeded treatment and significantly ($p \leq 0.05$) differed from those of conventional and herbicides treated plots.

Besides being grown for human food in eastern Kenya, maize is also grown to provide feed to livestock through provision of stovers in zero grazing livestock keeping management systems. The average shoot biomass in the three seasons was 8.1 t $ha^{-1}$from the weed management methods. The three rates, 1.5, 2.5 and 3.0 lits ha^{-1} of Roundup Weathermax had significantly ($p \leq 0.05$) higher biomass yields at 10.5, 9.8 and 9.2 lits ha^{-1}, respectively compared to un-weeded control. Although not significantly different, the conventional treatments gave 7.9 t ha^{-1} shoot biomass yields.

Table 4: Maize shoot biomass and grain yields of Glyphosate based trials for the management of weeds in maize fields in humid areas of eastern Kenya

Glyphosate based herbicides	Application rate (lits ha^{-1})	Shoot biomass (t ha^{-1})	Grain yield (t ha^{-1})
Roundup Weathermax	3.0	19.2^{b}	4.3^{ab}
2. Un-weeded	N/A	1.0^{c}	0.1^{c}
3. Conventional Tillage	N/A	17.0^{d}	3.6^{b}
4. Roundup Weathermax	2.5	19.5^{b}	$4.0^{a\,b}$
5. Roundup Turbo	2.5	21.6^{a}	4.4^{ab}
6. Roundup Weathermax	1.5	20.5^{ab}	4.5^{a}
Mean	-	16.5	3.5
L.S.D (0.05%)	-	1.9	0.9
C.V.	-	7.8	16.3

Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = Coefficient of variation; LSD = Least Significant Difference; N/A = Not Applicable

Net benefits

Economics of different weed management methods was done using data collected during the experiment. The data came from the local agric-stockiest(s), scientists, farmers and partners involved in maize industry in eastern Kenya. For each of the reported three seasons, the exercise assumed that:

- The average annual interest rate for money in a bank savings account to be 12%.
- The DK 8031 took 6 months from planting to marketing using farm-gate prices.
- The herbicides were priced at KES 1200 lit^{-1}. The total cost for any herbicide was therefore based on the rate(s) the product was tested on.
- The number of empty bags needed to hold the grains was based on the total grain yield per treatment; and that the grains were harvested and packaged in 90 kg bags.
- Stovers were sold at KES 2000 t^{-1} to buyers who collected them from the farm using their own labour and transport.
- The grains were sold at farm gate price at Ksh. 3000 per 90 kg bag.
- The formula, N-B = TC – TB was appropriate in working out the net-benefit (N-B). In the formula; N-B = Net benefit; TC = Total Cost: acquired from payment of factors of growing maize; TB = Total benefits: acquired from sale of stovers and grains.

The study realized average net benefits (NB) of KES 99,797, 90,123 and 94,392 for LR 2011, SR 2011 and LR 2012, respectively. The NB from un-weeded treatment was always significantly ($p \leq 0.05$) lower than what was observed from the herbicides and conventionally tilled plots.

Conclusions

Maize is the most important staple food crop in Kenya, but the production lags behind demand in eastern Kenya. While the crop is mainly grown for its grains, stovers are fed to livestock and empty cobs used as source of fuel for cooking. Among other reasons for low production are weeds. A study was conducted to determine the effects of Glyphosate-based herbicides on weeds management and maize performance in eastern Kenya. The first (LR 2011), second (SR 2011) and third (LR 2012) season's trial results observed that the herbicides are effective means of weed management in maize grown under zero tillage conservation agriculture systems. Roundup Turbo herbicide applied at 2.5 lits ha^{-1} and the three (1.5, 2.5 and 3.0 lits ha^{-1}) tested rates of roundup Weathermax herbicide performed comparatively well in terms weeds control and therefore improved maize yields (grains and shoot biomass). The product did not have any noticeable phytotocixity on the crop. Use of herbicides resulted in improved NB compared to results from un-weeded and the conventionally tilled fields.

The yields significantly ($p \leq 0.05$) differed between un-weeded and conventional or the herbicide managed plots. The zero tilled treatments (herbicides treated) were not significantly different from one another in the three seasons that the study was conducted. Conventionally tilled treatment had an average grain yield of 3.6 t ha^{-1} that was also not significantly different from those from zero tillage treatments. The lowest grain yield (0.1 t ha^{-1}) was acquired from un-weeded treatment and significantly ($p \leq 0.05$) differed from those of conventional and herbicides treatments.

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On-farm assessment of water management and soil temperatures in dry season grown maize and tomato in Tabora, Tanzania

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Abstract

Dry season vegetable farming is an important economic activity that generates incomes and sustains food security for smallholders in Tabora Region in western Tanzania. Dry season vegetable growing is an adaptation to climate change challenge among smallholder farmers. The problems of water management and low water use efficiency in tomato (*Lycopersicon esculentum* L.) and green maize (*Zea mays* L.) growing during the dry season are addressed in this paper. Methodologies used include; on-farm assessment of maize/tomato watering schedules through a farmer participatory approach. Soil temperature measurements using WEKSLER (USA) soil thermometers were recorded after maize/ tomato watering after 12, 24, 48, and 72 hours. Results show that in tomato plants soil temperature was maintained at 18^{0}C with watering after 12 hours and the soil temperature increased to 27.9^{0}C with the watering after 72 hours. In maize fields soil temperature was maintained at 22^{0}C after 12 hours of watering and increased to 27.9^{0}C after 72 hours of irrigation. Soil temperatures for non-irrigated soil ranged between 23.3-33.9^{0}C between May and September. Dry season vegetable growing is not supported by water use efficient methods and effective agricultural extension. Dissemination of water use efficient technologies in dry season vegetable growing is urgently needed to help farmers adapt to climate change challenges.

Keywords: dry season, vegetable growing, soil temperatures, water use, Tanzania.

Introduction

Dry season vegetable growing is an important economic activity to farmers in some sub-Saharan Africa. It provides income and improves food security in Ghana (Nakuja *et al*., 2012); Nigeria (Ojo *et al.,* 2011); Uganda (Ssekabembe *et al.,* 2003) and Tanzania (Nonga *et al.,* 2011). Dry season vegetable growing is highly profitable to farmers (Tsoho and Salau, 2012).Constraints to dry season vegetable growing among other things include water shortage and high incidences of pests and diseases as observed in Nigeria (Tsoho and Salau, 2012). Water shortage in irrigation projects has been cited as a major constraint to dry season vegetable farming (Ojo *et al* ,2011; Tsoho and Salau, 2012; Ikilulu, 2006). Dry season farming is even more constrained by access to water in areas where farmers depend on underground water and small hand-dug reservoirs in semi-arid and arid environments as observed in Ghana (IKilulu, 2006). Maize is also grown in dry season agriculture because of its economic importance as observed in Nigeria (Ayotamuno *et al.,* 2000). Water utilization efficiency under farmers' management conditions is sometimes low because of lack of scientific based irrigation schedules which results into over or under irrigating crops (Ojo *et al.,* 2012).Irrigating soil does not only supply water to crop root but under semi-arid and arid conditions, water regulates soil temperatures. Farmers manage soil heat balance by drainage, mulching, and adding organic fertilizers into the soil. Microclimate regulation has a significant ramification on the physiological performance of the plant (Rosenberg *et al.,* 1983). The dark soils absorb more energy and become warmer while the bright soil reflected the energy and remain cold. High soil temperatures under optimum rain fall and soil moisture increase crop biomass production as observed on maize and cucumber crops in Nigeria (Makinde *et al*., 2009). Soil temperature is among major hydrothermal parameters that influence the phonological events in the maize crop (Wielgolaski, 2001). Soil temperature variation among different soil layers exerts a major impact on water flow and transmission within the soil (Prunt and Bell, 2005). Soil moisture creates microclimatic conditions that influence soil microorganisms such as are particularly nematode community structure (Hoschitz and Kaufamann, 2004). It has been found that the thickness of

water films rather than gravimetric soil water content influence nematode activities, feeding and population growth (Yeates *et al.,* 2002; Strong *et al.,* 2004). The study by (Bakonyi *et al.,* 2007) show that soil temperature regulates nematode activities in soil. Dry season vegetable production is considered as an adaptation of farmers towards reducing the negative effects of climate change to farmers' incomes and their food security (Nakuja *et al.,* 2012). Climate change challenge to smallholder farmers in Tanzania is increasing poverty rural communities (Mongi *et al.,* 2010). Vegetable growing during the dry season is an adaptation to climate change practiced by smallholder farmers. However, farmers' efforts to grow vegetables during the dry season have not been supported by appropriate water use efficient technologies and agricultural extension capacity building knowledge. This paper addresses the problems of water use in growing green maize (*Zea mays* L.) and tomato (*Lycopersicon esculentum* L.) among smallholder farmers during the dry season in Tabora region, western Tanzania. Climate change adaptation strategies should include dissemination of technologies for increasing water use efficiency among smallholder farmers in Tanzania.

Methodology

Study area

The study area was carried out at Tumbi-Mapula, (S 05^{0}04'08.4''; E 032^0 41'49.7'' Elevation 1163m. in Tabora region, Tanzania. The study was conducted for the period of April-September 2011-2012. The dominant soils in the study area are Greyic Arenosols with hardpan (cemented sandy) between 86 – 150 cm. Farmers use buckets to collect water and irrigate crops from hand dug shallow wells. Water is physically carried by hands between 2 to 30 meters from water wells to vegetable fields. Termite mounds are often flattened and mixed with sandy soils to improve soil fertility and water retention in vegetable growing fields. Termite mound soils are highly valued by vegetable growing farmers. Small field plots are used by smallholder farmers. The size of each individual field depends on the amount of water available for irrigating crops. The dry season is characterized by significant diurnal temperature differences, high evaporation rates, low atmospheric humidity and high maximum temperatures (Figure1). Soil minimum temperatures range from 22.4^{0}C to 27.2^{0}C, while the soil maximum temperatures range from 31.1^{0}C to 38.3^{0}C.Soil temperatures reach maximum peak in August and September.

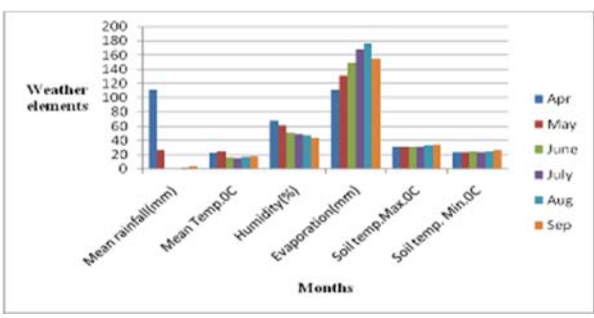

Figure 1: Dry season weather characteristics of Tabora region

Tomato agronomy

The tomato variety "Tanya Mkulima" is the most popular among tomato growers. Tomatoes are planted in rows at the spacing of 50 x 30 cm with two plants per hill. Tomato is grown on raised beds; water concentrating micro-beds are dug carefully between plant rows and between plants to conserve water and to ensure water supplies to tomato roots. The tomato variety, "Tanya Mkulima" is most favored because of its culinary qualities and long shelf life. Farmers use NPK (10:18:24) as a basal fertilizer for both tomato and maize growing. Calcium ammonium nitrate is used for top dressing for both crops. Watering of crops is influenced by availability of in open shallow wells. Field observations indicate that farmers irrigate

tomato and maize after 24 h. However, as the dry season advances water reserves decline in open shallow wells and the crop watering regime changes to 48 h. At the peak of the dry season crops are watered often after 72 h. At the onset of the dry season 10 litres of water is used to water 14-16 tomato/maize plants.

During the peak of the dry season, in the month of September 10 liters of water are used to water between 4 - 8 tomato plants. Field observations show that a single tomato plant receives between 714-1250ml per plant per day or two days. Water conservation methods including mulching are seldom practiced by farmers. Lack of water conservation technologies increase the negative effects of elevated air temperatures to plant growth and have influence on increasing soil temperatures.

Maize agronomy

The maize variety "DK" ex Monsanto is the most the popular among farmers in the dry season. Maize was planted as the spacing of 0.75 x 0.25 m with two plants per hill. Some farmers planted maize at the spacing of 0.30 x 0.75 m with one plant per hill. Maize was grown on flat cultivated fields or on moderately raised beds. Watering was concentrated in micro-catchments dug carefully between plant rows and between plants to conserve water and to ensure water supplies to maize roots. Farmers use NPK (10:18:24) and organic manures such as bat, cattle and goat manures and by-products of local maize brew for basal application. Top dressing fertilization was carried out using Calcium ammonium nitrate at the rate of 5-10 g per hill. Insect pests especially the American boll worms (*Heliothis armigera*) were controlled by the insecticide PROFECRON 720 EC. Field observations further indicated that farmers irrigate maize after every 48 h day. However, as the dry season advanced increased evaporation caused decline of water in open shallow wells subsequently the crop was watered after 72 h. Drying of water in open shallow wells caused farmers to abandon pre-mature maize plants and the little water was used for supporting flowering tomato plants.

Soil temperature measurements

Soil temperature was measured using the soil insalled thermometers; WESLER made in USA.Three soil thermometers were installed in a plot at (0-5 cm) soil depth, six readings were recorded in an area of 200 m^2 the soil thermometers were installed randomly between plant hills. Soil temperatures were recorded at least two hours after watering crops. The mean soil temperature of the field was the mean temperature for the three thermometers in 18 locations in the field. The thermometer were installed very close to the roots of the plant.The temperature of unirrigated adjacent soil was also measured and designated as soil temperature (0 h). Other soil temperature readings were carried out 12, 24, 48 and 72 h after farmers have irrigated their respective fields. This study addressed problems of water management and water use in smallholder vegetable growers' fields and their impact to soil temperatures under elevated dry season air temperatures in western Tanzania. Dry season vegetable growing was poorly supported by agricultural extension staff. Farmers have no access to technologies for increasing water use efficiency in dry season vegetable growing.

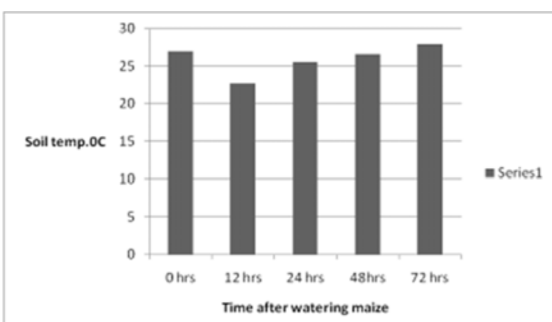

Figure 2: Soil temperatures and irrigation schedules in the maize field

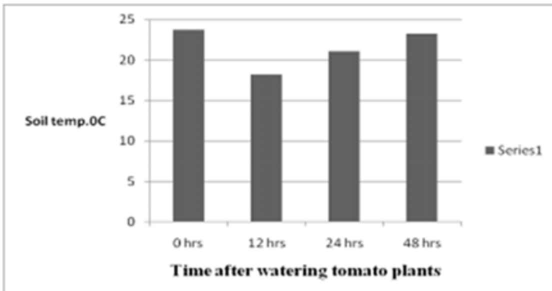

Figure 3: Soil temperatures and farmers watering schedules in the tomato field

Disscussion

Water scarcity is a limitation to dry season vegetable growing in Tabora region in western Tanzania because of the long dry season (Figure1). The dry season is characterized by high evaporation low atmosheric humidity and raised soil temperatures. Farmers' watering schedules are a day and two days for tomato and maize plants respectively. The watering regimes are determined by the economic value of the crop and available water resources access to farmers. Open shallow water wells are owned individually and each farmer can produce or use water according to water discharge in his wells. Farmers have no support of agricultural extension in dry season vegetable production consequently they lack water use efficient methods and water conservation practices for optimizing production. The tomato crop is a high valued crop therefore it is given a high priolity in water resource allocation in dry season agriculture. Tomato plants were irrigated at least after every 12 hours when water is readily available. But, maize plants are irrigigated after 48 hrs when water is readily available in open shallow wells. However, as the dry season advances with increased evaporation maize was irrigated after 72 hours (Figure2). and often was abandoned pre-maturely. Field observations show that soil temperatures in tomato fields were maintained below 27^0C when the crop was watered between 12-24 hours. Water appication in the soil lowers the soil temperatures as observed in other studies (Randas and David, 1934; Cherkasov, 1952; Lin Yi *et al.*, 2011.). Randas and David (1934) and Cherkasov (1952) studied the relation of irrigation under uniformly application of irrigation water. In this study water application was valiable because farmers were using buckets to irrigate crops. Randas and Davis (1934) show that soil temperature remains low in irrigated fields after 4 days of water application. But, in the tropical environment in the Miombo woodland ecosystem in western Tanzania high evaporation and air temperatures have a strong influence on soil temperatures. Extending the watering period of tomato plants beyond 24 hrs resulted into soil temperature raise close to that of the non- irrigated soil with negative effects to the growth of tomato plants (Garwood,1968). Local irrigation schedules as practiced by farmers for the maize crop is shown in (Figure2). According to the soil temperatures recorded in maize, it is evident that maize irrigation should not go beyond 48 hours since after that time the soil temperatures begin to raise sharply close to that of non-irrigated soil. It is evident from this study that farmers are lacking water use efficient methods and water conservation practices to optimize dry season vegetable production. Water use efficient methods should be integrated in climate change adaptation strategies among vegetable growing smallholder farmers.

Ackowledgement

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Land holding and households' probabilities of adopting monoculture in Uganda

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Abstract

In this paper we describe households' land holding and allocation to major crops in Uganda. Descriptive and analytical statistics were derived from the national household data collected by UBoS in 2005/06 and 2009/10. Households' in Uganda owns on average 3.46 acres of land that are utilized for crop production. Central 1 reported the lowest landholding at 2.5 acreas while North-West had the highest at 4.8 acres. Farmers cultivated multiple crops with banana, maize, cassava, coffee and beans allocated the high proportion in that order. Share of land allocated and yields for various crops differed across sub-regions. A Tobit analysis showed that sub-regions and compatibility of crops for intercropping were the major factors that influenced share of land allocated to various crops. In case of adopting one major crop for commercialization farmers would select banana, maize, cassava, bean and coffee in that order. Crops insurance, improving produce markets and infrastructural development will inculcate households specialize on one crop that yield the best.

Introduction

Although agriculture remains one of the most important productive sectors as a source of employment (73%), export earner (46%), contributor to GDP (15%), source of food security and a source of raw material and a market for agro-based industries (UBoS, 2011), the sector is faced with a number of challenges. Since the 1997, the sector performance has been non-impressive reporting growth decline in crops, livestock and fisheries subsectors. Between 2003 and 2008, the agricultural sector experienced a marginal growth of about 1% with both the cash and food crops reporting a decline while fisheries and livestock grew at 3 and 2.7 percent respectively. At the same time, other sectors including industries and services recorded animpressive growth of 9 and 10 percent respectively. Albeit the challenges affecting the sector, it remains important in poverty reduction, food provision for a fast growing population and a primary sector for transforming the economy (GoU, 2010).

The government has developed a blue print on enhancing the role of agriculture in food and income security (MAAIF, 2010).One of the recommendations in improving agriculture is promotion of some agricultural enterprises that were selected based on return to investment; priority within agro-ecological zones; number of households involved; contribution to export; poverty reduction effects; multiplier effects; size of effects and potential future impacts. In this perspective crops that were ranked as priority include maize, coffee, beans, tea, cassava, and banana. The government intends to increase amounts produced of each of the crop through targeted agro-ecological zones. Queries have been raised on the factors that would influence the success of the governments' interventions in agriculture especially with the changing scenario at both macro and micro-levels. (ACBF, 2012). Already the sector's contributions to economic welfare continue to dwindle (UBOS, 2009),with other changes including on quality of labour (Bayamba, *et al*. 2009)and crop enterprises and yields (EMU, 2007) have been observed.

Field survey reports on crop popularity with agricultural households across the country indicate that the same crops being targeted by the government are being propagated by a large proportion of farmers across time and regions (UBoS 2010). The observation implies that the successful implementation of the Agriculture Sector Development Strategy and Investment Plan (DSIP) (MAAIF, 2010)will depend on first understanding factors influencing allocation of land to crops enterprises and yields achieved, and later designing working strategies. One of the pertinent questions is whether there exists opportunity to increase

production within zones through technological adoptions, land expansions and whether farmers have the capacity to harness the sector's proposal.

Already land resources constraint has been reported through limited per capita potential arable land (NEMA, 2009), agro-ecological potential (Wortmann and Eledu, 19990) soil quality potential with stipulation that the high, moderate and fair productive soils are already in use with expansion targeting the poor soil (FAO, 1977) and the fact that the land in use is getting denuded at an alarming rate (NEMA, 2004; Stoover and Smaling1993). Moreover more challenges are being observed on land governance including tenure, ownership and scale of ownership.

This paper addresses factors influencing farmers' choice of crops' enterprises and resources allocation. The policy questions the study addresses are which factors will influence successful implementation of the DSIP's on expansion of targeted crop's enterprises (MAAIF, 2012) and whether implementation of the enterprise expansion would lead to agricultural households transformation (GoU, 2010) . Objectives of the study are to determine whether there are changes in land allocation for main crop in Uganda between 2005 and 2010 and determine factors influencing proportion of land allocation to major crops in Uganda with an aim of facilitating the implementation of the agricultural sector development strategy. The study also assesses the probable income farmers stand to achieve through adoption of various crops considering available land and technologies.

Data and methods

Data sources*:*-The Uganda National Household Survey (UNHS III) data collected in 2005-06 and Uganda National Panel Survey (UNPS) of 2009/10 were used. The two databases were nationally representative and collected by the Uganda Bureau of Statistic (UBoS). In 2005/06, UBoS collected information from 7,421 households with 42,111 individuals from May 2005 to April 2006 (UNHS III). The survey was based on a two-stage stratified random sampling design. In the first stage, Enumeration Areas (EAs) were selected from the 4 geographical regions. In the second stage, 10 households were randomly selected from each of the EA. Following the seven-year Uganda National Panel Programme, UBoS then targeted to re-survey 3,123 households from the same households interviewed in UNHS III of 2005/6. However, it was only able to track 2,888 households out of the targeted households. Therefore the analysis used only 2,566 households of the original targeted were completed.

Data collection in the UNHS III survey was from May 2005 through April 2006 whereas in 2009/10 the same households were visited during the period September 2009 to August 2010 which makes a period of 4.5 years. Further analysis shows that 8.3 percent (214 households) were interviewed during the same month in the two waves of the survey, however households were evenly spread over the survey period in both surveys with a few exceptions as in the month of December (Ssewanyana and Kasirye, 2012).

Across the seasons, at least 51 percent of the households were visited in the same agriculture season given the bi-annual nature of the agriculture season in Uganda. The main agriculture season runs from January to June while the second season runs from July to September. That said, households were visited twice in both waves. During the first visit, agricultural production data was collected on the first cropping season of that particular year (January – June). The second visit collected agricultural production data on the second cropping season of that year (July – December).

Information was collected at individual, household and community levels using the household, agriculture, and price and community questionnaires. The household module captured general demographic characteristics of the household. The agriculture module provided information on household crop farming enterprise particulars with emphasis on land ownership, crop area, agricultural inputs use and agricultural production levels achieved for various crops. Only agricultural household were used in the study with analysis being at household level.

These two databases were longitudinally merged to each other to provide a rich database that would allow for observation over the two periods and cross-sectional information. The longitudinally merged data had

advantages of improving the efficiency of econometric estimates (Hsio, 2007) and allowed us to focus at agricultural activities at the sub-region level. Sub-regions in Uganda are important as they present agro-ecological differentiation which is critical for any agricultural analysis. Merging of the two data files was possible due similarity of the two databases and the fact that the sampling design of the UNPS was designed to revisit some of the very households that participated in the 2005 /06 UNHS. The study interest was to determine land allocation at any time considering existing socio-economic environment of households hence the panel was unbalanced and also considered household that were interviewed at each wave (Chirembe and Williams, 2003). The sample size was 3967 households.

Farmers in Uganda grow a variety of crops ranging from legumes, root tubers, fruits, vegetables and many others. However, for the purposes of this paper, analysis reduces to the five major crops grown in Uganda namely maize, beans, bananas, cassava and coffee (UBoS, 2010) and which happened to be targeted by the DSIP (MAAIF, 2010). Average area for two seasons of the wave panel constituted either total area or area allocated for a particular major crop. Share of land allocated to a crop was fraction of the total area farmers reported to own against that which was used for the crop. In this case summations of proportion of land allocated to cropscould not add-up to unity due to instances of intercropping; the fact that we didn't include all crops managed by farmers and other land uses including settlement, pasture and tree stands. To ameliorate the challenge observed with agricultural commodity prices during the UNPS, price information by ASARECA (Mbowa, *et al*. 2012) were used. Agricultural commodity prices were weekly collected and averaged annually for the years of household surveys in selected urban centres including Kampala, Mbarara, Kabale, Masindi, Lira, Soroti, Arua and Tororo were used. The price data from these urban areas were allocated to respective sub-regions which coincided with various agro-ecological zones. Prices of coffee farmgate prices in different sub regions was provided by coffee development authority

Model Specification

A Tobit model (Tobin, 1958, Amemiya, 1984)was used to estimate coefficient that influence share of land allocated to various major crop by the household. The choice of the model was influenced by the fact that while the dependent variable is continuous, it is censored between two limits. The share of land allocated to various crops ranges between 0 to 100 percent (0 to 1) of the total land owned by a household. Tobit model has been used widely in economic model where the dependent variable represents a proportion of the total (Tobin, 1958; Ekstrand, and Carpenter, 1998; Brehamu and Fufa, 2008; Bayamba, *et al*. 2009; Chibwana, *et al*. 2012). Although Tobit model is substitutable with Ordinary Least Square Mode (OLS), when the proportion of zero among the dependent model decreases, it has been found to be very strong if otherwise and when there are cases of undeclared values (Wilson and Tisdell, 2002). While between the limits the data is continuous and thus making the use of ordinary least square (OLS) a viable option, the use oflatter in this case would have made its estimate biased and inefficient thus violating the basic tenets of best linear unbiased estimator conditions (Milliken and Albohali, 1984).

The Tobit model is defined as follows (Amemiya, 1984)

$$Y_i^* = \beta' X_i + \mu_i \qquad \text{if } L_1 \leq Y_i \leq L_2$$

Whereas the Y_i^* is a vector of the latent variable that is not observed for values less than zero and greater than one; Yi is the observed variable, representing the share of land allocated to a crop by the household, with the value censored at lower limit $L_1 = 0$ and upper limit $L_2 = 1$; β'.is a *KX1*vector of unknown parameters; X_i is the ith observation on K explanatory variables; μ_i are residuals that are independently and normally distributed, with mean zero and a common variance σ^2. In this model we estimate β' and σ^2 on the basis of N observation of Y_i and X_i. The explanatory variables used in this study are described in subsequent section and also shown in Table 1.

Albeit it wide use in econometric, Tobit Model is associated with misspecification due to violation of distributional assumptions ((Milliken and Albohali, 1984). Omitted variables, heteroscedacity and non-

normality all cause Tobit maximum likelihood estimators to be inconsistent. To handle the misspecification challenges presented by the Tobit model, data transformation is always recommended.

The conceptual framework

Households land allocations to various uses is influenced by a number of factors as shown in Figure 1. A household operates like an enterprise with a number of utility maximizing activities that may include settlement area, pasture, undisturbed forest, perennial and annual crops and land that may be left fallow for nutrient replenishment. Allocation of land to different uses and crop enterprises is influence by four main components including natural resources base, facilitative factors (institutional environment and technology) and socio-economic characteristics of the household. Other driver of land allocation is time. The natural resource component is constituted by the quality of the bio-physical characteristics that influence agricultural including soil quality, weather factors and topography. Institutional environment and technology component is constituted with facilitative services that may be provided by government or other development agents. The facilitative services include infrastructural development, technology and produce markets accessibility and prevailing agricultural policies. The household characteristic includes factors as household size and composition, age, education levels, land ownership, welfare, efficiency in factors of production allocation and utilization etc.

Time is an important factor in influencing land allocation as it defines households' aspirations, status of natural resource quality, experience on farming systems and acquaintance with facilitative factors. In this case a household will change amount of resources allocated to different agricultural enterprise as other factors change. In some instances due to changing agricultural environment a household may exit farming to join the off-farm employment. Depending with the levels of engagement with the agricultural enterprise a household that is in off-farm employment may continue allocating land for different enterprises annuals, pasture, perennial crops or undisturbed forest. At the same time a household that was once dependent on off-farm enterprise may enter farming with expectation of land allocation to be influenced by the four components.

Description of the variables

Share of crop: this variable represents the fraction of land allocated to particular crop (maize banana, beans, coffee and cassava) of the total land reported to be owned by farmers. In this study share of land allocated to a crop is the dependent variable. The use of share of land allocated to a crop takes cognizant that the sizes of land owned by farmers various widely and a household can only allocate to use the land it has rights over. The choice of crops to evaluate it allocation of land was influenced by the ones currently being grown by farmers (UBoS, 2010) and the fact that the crop has been targeted for promotion by the government (MAAIF, 2010).

Yield achieved: Yields achieved for the respective crop being evaluated for share of land allocated has been considered as an explanatory variable. Through including yields achieved for respective crop the study wishes to establish the relationship between crop area expansion and efficiency in land resource utilization.

Household head sex:- Gender of household head has been observed to be an important factor influencing decision making in households and access and allocation of land to particular crops.

Household size:- The number of member in a household represent two conflicting front both of which are hypothesized to result to have different impact on share of land allocated to crop. On one hand large household represent driver of more land allocation in response to demand for food and income. Also large households presents availability of more labour force that could be used as a factor of production for the extra land allocated to agricultural production. Since labour intensity for management of various crops differs, household sizes influence crop to be adopted and extent of land provided. On the other hand large households require more settlement area thereby limiting the land to be allocated for agriculture.

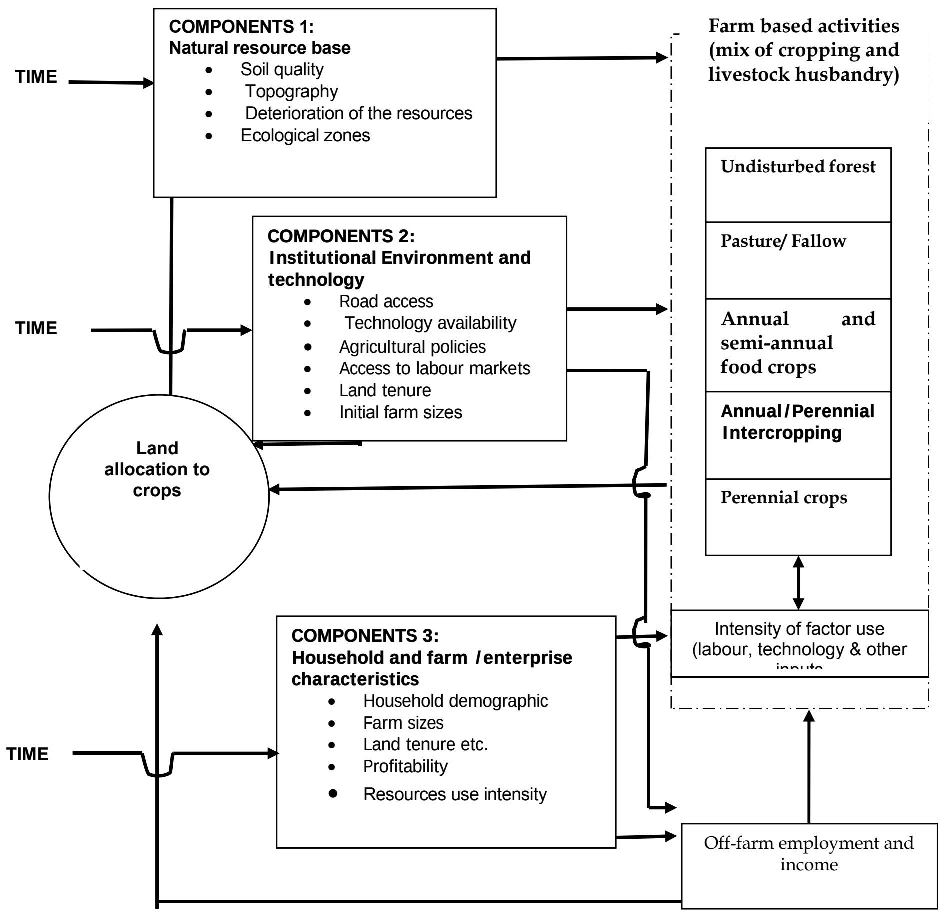

Figure 13: Concept framework farm based factors influencing cropping patterns (adopted with modification from Pichon, 1997

Proportion of adults:-Although proposition of adults in a household is supposed to present the same effect as household size, this variable is more focused to more dependable labour force. If the number of adult in a household is high it indicate that more labour is available which could be allocated to both farm and non-farm chores. A smaller fraction of adults compared to that of children has an implication on the former allocating more time caring for the young members of the family.

Household stock of education in years:-Education has remained a major intervention by the government to improve the quality of its community. Years spent in schools are always assumed to be indicative of the quality of labour. While formal education for household has remained constant that of other members has

remained dynamic with a major query being whether increased education of children does improve household decision making and labour quality. While education has been observed to be positively impacting on agricultural decision making, difficulties have been experienced in requesting the adults to go back for formal education due to their busy economic engagements.

Adults stock of education:- Adults stock of education positively impacts on the quality of decision made in a household. As an explanatory variable the stock wished to establish how this factor will influence share of land allocated to different crops.

Household welfare:- Household welfare has been observed to positively influence agricultural production especially due its ability to provide required capital. Agriculture like any other enterprise requires capital. Some enterprises that are capital intensity will attract better to do farmers than the poor ones.

Year:- A dummy of year has been included as an explanatory variable in this study with 2009-10 represent by 1 while 2005/06 by 0. The year dummy was expected to provide coefficient of change with time. In this case an assumption is made that at any time at the start of farming season a farmer is presented with a challenge to decide whether and which crops to propagate. In this case except for the fact that this decision making happens in two different years, the farmer has at his disposable land and wishes to fulfill his utility and is constraints by his socio-economic factors and other bio-physical factors.

Agricultural produce prices: prices are mostly considered as an important factor influencing any economic production activity. Higher produce farmgate prices are expected to motivate farmers produce more through crop area expansion or intensification through technology adoption.

Technologies adoption: In this study two technologies were used i.e. fertilizer (inorganic) and organic manure utilization. Use of fertility replenishing technologies may present desire of farmers to maximize production or levels of commercialization. Adoption of the technology also presents farmers perception of the quality of the soil/land.

Subregion: - Dummies of sub-region were used in the model as explanatory variables. In this case sub-region represents unique bio-physical and socio-economic characteristic that will influence land allocation and share of land dedicated to particular crop. Bio-physical factors represented by sub-region include weather and edaphic related factors and other crop management that affect locations including pestilence. Socio-economic factors represented by sub-region may include socio-cultural characteristics; agricultural facilitative factors (e.g. market access, credit and technologies etc). For the case of coffee, regions were used as the farmers propagating the crop were observed to be few that they could not be evaluated at the subregion level.

Proportion of other major crops: With limited resources for agricultural production including labour, capital, land and management, decision to allocate resources to a crop enterprise results to opportunity costs of another enterprise (Bagamba*et al.,* 2009). While farmers have adopted various risk averseness strategies through multi-cropping (Ekanyat, *et al*., 2010) cases of trade-off of enterprises are expected. In this study we estimate the coefficient for major crops substitutions among agricultural households.

Literature review

Based on the development stage of a country or settlement two major theories has been applied in explaining land allocation and changes observed. The chayanov's theory which has been favoured for developed societies, stipulates that household size, age structures and dependency levels determines resources allocation to agriculture (Perz, 2002). The Amazonian arguments has largely been used to explain land allocation and dynamism in use in the newly settled areas and stipulates land allocation to be influenced by stage of household life cycle, specific duration of residence and household age (McCracken, *et al*. 1999; Pichon, 1997). Both the theories have their assumptions with a common one being that land is not limiting (Perz, 2002, McCracken, *et al*. 1999). While the two theories may provide insights on factors influencing land allocations in Uganda, the farming system applicable where land is limiting will need attention. Furthermore the two theories are based on rich historical information on settlements (Carmona

et al., 2010) and have categorized agriculture into broader systems including perennial and annual crops, pasture land management and forest land allocations.

Ugandan agricultural concern as far as land allocations is concerned has been raised by desire for increased production through land expansion and zoning of enterprises in an effort to transform agriculture from subsistence to commercial (MAAIF, 2010). Understanding the factors influencing land allocations and share allocation to crops would not only be important for agricultural production, but would go a long way in catalyzing development of other secondary and primary development sector including tourism, industry and manufacturing and services (GoU, 2010). Land resource remains an important factor of production especially for the agricultural households and it has a bearing on the countries development path. Sustainable management of land resources allows it to be the engine of economic transformation (Perz, 2002) yet it is important to understand determinants of utilization, competitive options in use and probable future utility. Land allocation to cropping and dynamism of allocation has been associated with either positive or negative impacts (Pichon, 1997). The best scenario for Uganda would be a positive outcome that would benefit both the peasants and the conservation of the natural resource base (NEMA, 2009).

The National Forest Authority (NFA), 2009 reported an increase in land used for agriculture by six percent while that under settlement (buildings) rose by 165 percent. NFA used satellite imagery to determine change in biomass between 1990 and 2005 Land ownership notwithstanding, agriculture replaced entire forest cover in Mayuge, while in Kibaale, Mukono and Hoima forest cover loss was estimated at 46, 36 and 22 percent respectively. While no specific factor has been associated with the observed changes, agricultural land expansion in the tropic has been associated with high degree of integration of rural areas with national and international economy, population pressure, and poor intensification of agriculture where use of irrigation and fertilizer is low (Barbier, 2004). Expansion of agricultural land and management of existing farms has been recognized as a the major environmental threat in the country impacting negatively on other biomes and water bodies (NEMA, 2009). Soil erosion alone has been listed as the highest environmental cost the country pay due to poor agricultural land use management (NEMA, 2004). Uganda is among African countries with the highest levels of nutrients losses estimated 40kgN, 20 kgP_2O_5 and 40 kgK_2O per annum (Stoorvogel and Smaling 1990). Climate change has become a major threat to agricultural production with impacts to be observed on production activities, land quality degradation, impacts to communities and shifts in weather patterns and farmers agronomic practices (Hepworth and Goulden, 2008). Ascertaining factors that influence household land allocation for agricultural production will compliment macro-level changes that have been identified in formulating development strategies.

Estimation and projections of land planted and production levels achieved for various crops at the districts and national levels has shown an increase for all crops (UBoS, 2005) with impetus to incorporate results for new agriculture census (UBoS, 2010) observed with the recent statistical abstract (UBoS, 2011). Previous UBoS estimation of land area under different crops has been showing banana occupying the largest area in the country and accounting for about more than twice of other largely planted crops including maize and bean (UBoS, 2005). The Census of Agriculture (UBoS, 2010) showed the major four crops grown in Uganda to include maize beans cassava and banana. Among total area covered by the four, maize occupied a third while each crop between cassava and banana accounted for a quarter while bean occupied slightly less than a fifth of the share. In the second season maize was the most popular crop among agricultural households overall and in Eastern and Northern. Overall, maize popularity was followed by beans banana, cassava and sweet potatoes among household. In the first season maize was the most popular crop on farmers' fields followed by banana, beans and cassava. Some discrete factors appear to influence the cropping patterns, land allocations and hence production levels achieved by the agricultural households. Comparison of the UBoS information on land allocation reveals differences in land allocation between seasons and over time.

Little efforts have been made to connect the agricultural bio-physical characteristics, socio-economic welfares and enterprise efficiency. Hence available literature show disjoint between approaches by the social sciences and the natural resource experts. Albeit the general belief that Uganda has a high agricultural potential due to edaphic and climatic factors, some reports show limitation of agricultural

sector due to constrained per capita potential arable land (NEMA, 2009). In the entire country, the highest per capita potential arable land (PCPAL) is recorded in Northern with only a mere 1.5 acres. Eastern has the least PCPAL of about 0.6 acres. In Western, Kiruhura has the largest PCPAL of 2.2 acres while districts like Hoima, Buliisa and Kibaale has PCPAL of 0.3, 0.4 and 0.4 respectively. In the Northern Kitgum, Amuru and Pader have PCPAL of 3.6, 3.4 and 2.4 respectively while Abim, Kaabong, Kotido, Moroto and Nakapiripirit have almost no PCPAL. Bukwo, Kapchorua, Jinja, Mukono, Wakiso and Mbale have PCPAL of less than 0.3 acreas. The low PCPAL indicates that without strategies to improve land productivity and targeting the profitable enterprises agricultural may not yield the desired economic and ecological results.

Wortmann and Eledu (1999) provided an agricultural development strategy that would target crops enterprise with corresponding biophysical and socio-economic characteristics through publication of the agro-ecological zones in Uganda.Thirty-three agro-ecological zones were delineated and defined by considering 25 variables including three climatic variable (mean rainfall, temperature and proportion of annual rainfall that falls in July), six soil variables (percent sand, acidity, organic matter, available P, exchangeable Ca and exchangeable K), two population variables (population density and male: female ratio), four land use types (farmland, woodland, grassland and wetland) and ten food crops (banana, maize, cassava, sweet potato, Irish potato, finger millet, bean, groundnut, sorghum and rice). Later, these agro-ecological zones were aggregated to fourteen.

Agricultural cropping pattern has been changing in Eastern Uganda with land allocation to some crops increasing and vice verse(Ekanyat*et al*. 2010). Drivers of change were reported to include diversification of crops, changes in land fertility, socio-economic instability as a result of local and national conflict which led to fraction of land under cultivation to increase from 46 to 78%. More national based studies are required to quantify changes and establish factors influencing land allocation and be able to provide a better understanding of dynamism of agricultural household production. While paucity of published information on determinants of land allocation in Uganda exists, a number of studies have been reported on labour allocation and diversification strategies by households away from agriculture (Smith *et al*. 2001)

Bagamba *et al*. 2009 in a related study on decisions on labour allocations in central Uganda reported factor influencing household on-farm resources utilization as wages increase and improvement of road infrastructure. Regional differences were observed on how households were influenced on labour allocations by wage rates and infrastructural development. Some factors were considered as push factor for labour from agriculture to off farm employment including conditions of labour markets and productivity/profitability from farm production. Land allocation among agricultural households considers labour dynamism over the year as the latter depicts seasonal competition and complementarities among activities (Shively and Fisher, 2004). In this instance, household shares for off-farm work and forest clearing exhibited positive correlations with their own prices, suggesting labor allocation is responsive to the incentives associated with non-farming activities. Furthermore the poorest households use off-farm employment to supplement agricultural incomes and may also use off-farm employment to reduce income risk. It is apparent that decisions on agricultural land allocations are complex and may provide insights on the actual factors that affect agricultural performance in Uganda.

A Tobit model was used to determine factors influencing adoption and extent of land allocation for Jatropha*curcas* L in Malawi (Mponela, *et al*. 2011). Individual and household characteristics including age, education of household head, availability of labour, ownership of uncultivated land, ownership of livestock and non-farm income influence d land allocation toJatropha*curcas*. Factors that positively influenced extent of land allocation included ownership of cultivated and fallow land, and age and education levels of household head. Number of livestock raised had a negative impact of extent of land allocated to Jatropha while sex, primary occupation and number of adults in the household were not significant. Overall, results revealed that availability of idle land is crucial for fostering the adoption of *J. curcas* as well as the extent of its cultivation. Due to the vulnerability of farmers to food insecurity and return from the introduced biofuel crop, concerns were raised on the need for protection of environment and communities from alienation of tradition food crops.

Chibwana *et al*. (2012), used a Tobit model to regress factors that influenced share of land allocation to maize, tobacco and other crops in Malawi. A positive correlations was observed between participation in the farm input subsidy program and the share of land planted with maize and tobacco in central and southern Malawi To accommodate increased land allocations to maize and tobacco participating households simplified crop production by allocating less land to other crops (e.g., groundnuts, soybeans, and dry beans). Dependent variables considered in this study were household characteristics, including age, gender, and education of the household head; labor availability; farm size; the household's wealth position; and household food security status.

Random-effects Tobit model was used to estimate crops' land allocation decisions for upland agricultural households in Philippines using panel data (Coxhead and Demeke, 2004). The study reported total farm area, crops' expected revenue of various crops (own and cross), wage rate, slope, distance to the road, available farm labour force and the age of household head to significantly affect land allocations to various crops. Other factors including education of household head were not significant in influencing land allocation to various crops. Crop area responses to expected revenues were positive for own-price and negative for cross-price terms. Rise in wages had negative effects on area planted, most especially in the labour intensive vegetable enterprise. Chiremba and Masters (2003), used a panel data to assess the relative productivity efficiency of smallholder in Zimbabwe's land reform and resettlement programme. They found that that although individual farmers often moved towards higher efficiency levels, there was no trend towards the frontier, and farmers' improvements were not consistently correlated with receiving formal credit or extension services, having more experience or education, or using more farm equipment. However they found that despite the relatively large and uniform land area available to each farmer, they had widely varying productivity levels, not overcome by conventional farm services.

Smallholder farmers use a wide range of agro-ecological management techniques, resource management practices, and production strategies specific to their ecological and social environment to minimize risk and to cope with changes and shocks. These techniques can include agricultural intensification, expanded market orientation, intensification of crop–livestock enterprises, or increased capital and labor investment (Delve and Ramisch, 2006). Based on the most serious problems related to the low land productivity that results in household food deficiencies and to low selling prices for crop products in good seasons, farmers' mostly prioritize food security without creating additional risks while acknowledging constraints on the availability of land, labor, and inputs such as fertilizers and seed. Socio-economic characteristics of the household e.g. gender and other intrahousehold differences play a role in resource control, resource use, and decision-making.

Increased production and productivity is associated with an array of advantages including improving incomes received by farmers, reducing food prices and generating spillover to the rest of the economy (ACBF, 2012). Yet, the capacity of developing countries to increase production and productivity has been questioned due to local conditions constraints including location and prevailing socio-economic conditions; marginalization of agricultural producers due to globalization; vulnerability to natural disasters including climate change and variability and insufficient institutional capacity; poor agricultural facilitations in terms of e.g. infrastructure, and diminishing quantity and quality of labour for agriculture due to urbanization. There is paucity of information on the factors influencing land allocations for various crops in Uganda that could facilitate the actualization of the government plan of agricultural production expansion and intensification (MAAIF, 2010). This paper attempts to shed lights on the factors that will influence actualization of the agricultural plan against the background of changing agricultural environment (ACBF, 2012).

Results and discussion

Descriptive findings

Table 1 shows total land holding for households in different regions and subregion in Uganda. The average land ownership among agricultural households has been 3.5 acres. Agricultural households in Central region had the least acreage of land while those in the Northern region had the largest. Size of land ownership among agricultural households differed widely when considered either at the national, region and sub region levels as indicated by high values of standard deviations. Among sub-regions, West Nile farmers had the biggest land parcels of 4.81, followed by those in North, Eastern, South West and Central 2 respectively. On average farmers in Central 1 subregionowned the least land.

Table 1: Land holding by Ugandans (acres) agricultural households by sub-regions

		Observation	Mean	Std Dev.
National	Overall	3678	3.46	4.26
Regions	Central	828	2.91	3.99
	Eastern	933	3.35	4.20
	Western	972	3.23	4.23
	Northern	945	4.29	4.45
Sub-regions	Central 1	411	2.50	3.31
	Central 2	346	3.22	4.40
	East Central	391	3.16	4.19
	Eastern	434	3.70	4.38
	North	477	3.88	3.90
	West Nile	313	4.81	5.05
	western	374	2.95	3.95
	south west	598	3.41	4.40

Considering that the households require land for settlements, land holding in Uganda is small and hence will influence the kind of agricultural system to be adopted. A successful agricultural system with the observed smallholding of land will entail intensification of land use and adoption of high values crops including horticulture and export crops (Jaetzold and Schmitz, 1983). Yet, fields survey results have shown that the major crops grown by households are maize, beans, banana, coffee and cassava (UBoS, 2010). While these crops may not be considered as traditional high value crops except for coffee which is the country leading export, availability of local and regional markets, response for food security and unavailability of infrastructural investments to support growing of high value crops could have hindered their development. The small landholding may only encourage subsistence farming where food security is the main driver of agricultural enterprise. Intensification of land use has been observed where farmers are involved in intercropping and having two cropping patterns (UBoS, 2010) to ensure they maximize returns from the small parcels of land, rain patterns and households labour. Adoption of high yielding technologies especially the use of inorganic fertilizer has remained low thus leading to low yields (Okoboi andBarungi, 2012).

Figure 2 shows share of land allocated to various major crops in 2005 and 2009. In both years, it was allocated the most land 24% in 2009 and 20% in 2005, followed by maize with 23% in 20009 and 19% in 2005. Bean occupied the least land among the major crops with a land allocation of 16% in 2009 and 15% in 2005. Share of land allocated to coffee appeared to have remained constant at 16% in the two years of panel. Share of land allocated to banana and maize increased with a margin of four percent between 2005 and 2009. The increase in share of land allocated to the three crops i.e. maize, banana and cassava did not interfere with land share allocated to other major crop an indication that farmers still have more land that

is not already utilized for agriculture. Farmers could have also intercropped to increase proportion of individual crops area while still maintaining the same size of cultivated land.

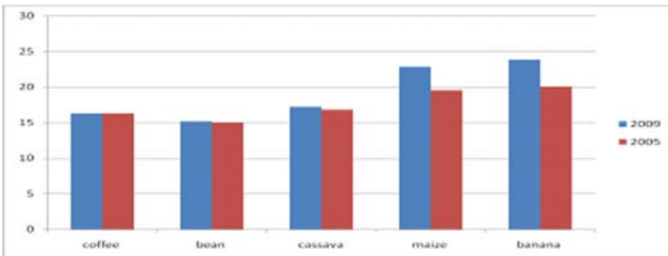

Figure 14: Share of land allocations to different crops in Uganda in 2005 and 2009

Banana was allocated the most land in Central 1 with 33% and in South West with 30%. It got the least allocated in North and West Nile with less than a tenth of land share propagated to the crop in the two subregions. Maize was allocated the most area in Central 2, East Central, Eastern and North subregion. In East Central maize was allocated 32% while in Eastern, North and Central it was allocated 26, 25 and 22%, respectively. About a third of land in West Nile was allocated to cassava growing. Cassava was allocated about a fifth of agricultural household land in East Central, Eastern and the North. Agricultural households' share of land allocated to beans was 25, 19, and 18 percent in Eastern, Central and South West sub-regions respectively.

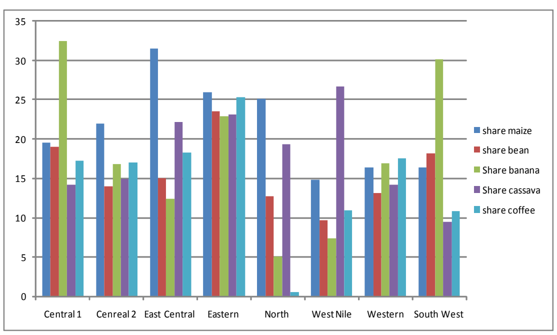

Figure 15: Shares of agricultural households land allocated to major crops in subregions of Uganda

Coffee growing was allocated the least land across the subregions except in Eastern, East Central, Western, Central 1 and Central 2. Across subregion it is observed that no particular crop dominates the household land as in all the cases no major crop was solely allocated more than a third of land resource. In case of zoning and promoting specialization on agricultural enterprises there exist opportunity which is about thrice the current allocations for expansion of any targeted crop. Farmers seem to favour certain crops than others across the subregions a factor which is attributed to the agro-ecological zones and dietary behaviours of the communities. Others factors including market access and crop enterprise promotion by public and private extension services (Okoboi, *et al*. 2011) could also have contributed to the observed results

Growing of crops in suitable agro-ecological conditions is expected to increase resource use efficiency (Jaetzold and Schmitz, 1983). Return to land resource is mostly estimated through yields achieved in a given land area. Figure 2 shows the yields achieved for the major crops in different sub-regions.

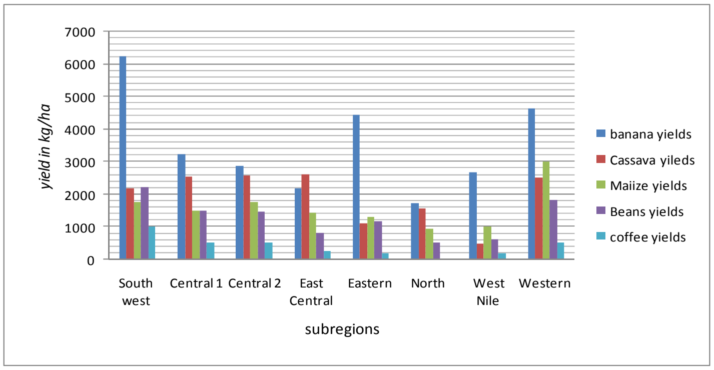

Figure 16: Yields achieved for the major crops in subregions of Uganda

Wide yields differences were observed for the major crops across sub-regions. Banana yield was highest in South West at 6230 $kgha^{-1}$ followed by Western, Eastern and Central 1 respectively. Banana yields achieved in South West was more than twice as high as those reported in the North, West Nile, East Central and Central 2. The yields differences indicates that farmers in the area with low banana yields require more than twice the size of land to achieve production levels as those in South West. The highest cassava yields were reported in East Central, Central 2, Central 1 and Western regions. Maize yields were highest in Western, South West and Central2, while the lowest yields were reported in the North. The North subregion reported the lowest yields on beans at about a quarter of those reported in South West. Highest bean's yields were report in South West, Western, Central 1 and Central 2

In the North coffee yields were not reported due to the low instances of its propagation. South West, Central 2, Western and Central 1 reported the highest yields for coffee. While other factors including farmers' technical efficiency do contribute to high yields, agro-ecological zone were observed as vital in influencing yield achieved for various crops. North and West Nile reported lowest yields for all crops a factor that is also attributable to the fact that the area has been recovering from a conflict that lasted for about two decades. The conflict resulted to communities displacement to camps hence farming activities were abandoned.

Analytical observation

Results of Tobit analysis are shown in Table. 3. Share of land allocated to various crop enterprises were largely influenced by the efficiency in its current production. Land allocated to all food crops including maize, beans, banana and cassava were negatively and significantly ($p \leq 0.01$) related to the efficiency in production as indicated by yields. The negative relationship between efficiency and share of land allocated to crops is an indication that farmers attempts to increase production through expansion rather than intensification. It is important for farmers to improve on efficiency through adoption of high yielding technologies rather than expanding crop area. Share of land allocated to beans was positive and significantly ($p \leq 0.01$) affected by the dummy for year and being in Eastern. Other factors that positively influenced (at significance levels $p \leq 0.05$) share of land allocated to beans included being in South West and share of land allocated to banana and maize. As one moved from Central 1, share of land allocated to beans decreased significantly($p \leq 0.01$) in Central 2 and West Nile, and East Central ($p \leq 0.05$) and Western.

The share of land allocated to beans was negatively related to households with a large number of members ($p \leq 0.1$) and those that were hiring external labour ($p \leq 0.05$).

The positive relationship between share of land allocated to beans and those on maize, banana and cassava implies cases on intercropping of beans with the other major crops. The compatibility of the intercropping allows farmers to increase efficiency of resources (land, labour and management) utilization. To some levels farmers are aware of other benefits from intercropping legumes with other crops including the former fixing Nitrogen estimated at 15-210 $kgha^{-1}$ per season which benefits the later (Dokora and Keya, 1997) and pest control capacities (Abate and Ampofo, 1997). Agro-ecological is a very important factor influencing share of land allocated to beans as was observed on sub-regional coefficients. The agro-ecological zones represent unique climatic factors, population dynamism and socio-economic characteristics. Agricultural commodities' farmgate prices have been associated with increased area expansion and/or intensification for particular crops (Mwaura, *et al*. al. 2011), but in this case it was land expansion in respond to commodity prices was not observed. Some of the reasons associated with farmers' failure to allocate crop area to respond to price incentives is due to opportunities and hindrance presented by agro-ecological zones and also prices elasticity associated with agriculturalproduction. Agro-ecological zones limits production of some crops hence even if farmgate prices were to increase those crops can't be adopted unless intervention that will changes the biophysical production factors are put in place e.g. irrigation and greenhouses. In an agro-ecological zone low prices on a short run may not hinder production of some crops due to their compatibility with prevailing biophysical conditions and major driver of farmers engaging in agricultural production. Farmers engaged in agriculture for commercial purposes will be responsive to prices change more than those addressing food security needs.

Non-agro-ecological factors that influenced share of land allocated to banana included the crop's yield achieved, hiring of labour, use of organic fertilizers and proportion of land allocated to other crops. Households that achieved low banana yields; those allocating bigger proportion of land to maize and those that were hiring labour allocated small share of their land for banana. Farmers allocating higher proportion of land for cassava and beans also allocated larger shares of land to banana. Share of land allocated to banana production was highest in Central 1 as comparison with any other subregion except South West was significant ($p \leq 0.01$) and negative. Pressure associated with limited land in Central 1 and the favourable agro-ecological factors influenced farmers to allocate more land to banana.

Share of land allocated to cassava cultivation was largely influenced by agro-ecological characteristics. Compared to Central 1, share of land allocated to cassava cultivation increased significant ($P \leq 5\%$) in Eastern, East Central, North and West Nile. The share of land allocated to cassava production was significantly smaller in western compared to Central 1. Allocation of land to maize farming has been influenced by the number of members in household and their distribution in age; use of inorganic and organic fertilizer; proportion of land allocated to other major crops, remoteness of household from produce markets; crop's yield and agro-ecological factors.

Share of land allocated to coffee was positive and weakly influenced by share of land allocated to banana cultivation ($p \leq 0.1$) a fact that could be associated with intercropping of the two crops. Households that were more efficient and thus were able to achieve high coffee yield and those that were economically well off were significantly ($p \leq 0.1$) allocating small proportion of land to coffee. Share of land allocated to coffee significantly reduced in Western and Northern compared to the Central Region. The differences in regional land allocation was due to the agro-ecological factors which favoured coffee growing in central and the fact that as land pressure increases farmers tend to utilize more share of land to farming (Coxhead and Demeke, 2004).

Table 2: Tobit Regression results for share of land allocated to crops

Variable	beans	Banana	Cassava	Maize	Coffee
log_owncrop yields	-0.0289 *** (0.005)	-0.014*** (0.005)	-0.036*** (0.0056)	-0.029*** (0.006)	-0.010 * (0.005)
Household head sex	-0.011 (0.015)	0.001 (0.017)	0.003 (0.0168)	0.019 (0.015)	0.025 (0.019)
Household size	-0.005 * (0.003)	-0.003 (0.004)	-0.001 (0.0030)	-0.005* (0.003)	0.00 (0.003)
Adult share in HHold	-0.042 (0.031)	-0.023 (0.036)	-0.035 (0.038)	-0.061 * (0.037)	0.002 (0.040)
Sqrt_totaledu. stock(yrs)	-0.004 (0.006)	-0.004 (0.008)	-0.008 (0.0062)	0.005 (0.0069)	-0.010 (0.04)
log_welfare	-0.013 (0.011)	0.007(0.013)	0.003 (0.0130)	-0.023 (0.015)	-0.029 **(0.0144)
Year dummy (2009=1)	0.11 *** (0.036)	0.016 (0.031)	-0.030 (0.021)	0.040 (0.052)	0.092* (0.053)
Sqrt_ adult edu stock (yrs	-0.001 (0.007)	0.005 (0.007)	0.007 (0.007)	-0.008 (0.007)	0.004 (0.08)
Dummy of labour hiring	-0.026 ** (0.012)	-0.041*** (0.014)	-0.033** (0.014)	0.016 (0.019)	0.018 (0.016)
Dummy of fertilizer use	0.026 (0.025)	-0.002 (0.025)	0.026 (0.036)	0.060* (0.032)	-0.004 (0.033)
Dummy of organic m. use	0.015 (0.015)	0.029 * (0.017)	-0.008 (0.02)	-0.041** (0.019)	0.004 (0.018)
Central 1 (R=Eastern)	-0.060 *** (0.022)	-0.077 *** (0.059)	0.09 (0.043)	0.055 (0.087)	0.033 (0.021)
Kampala (R=Northern)	0.043 (0.036)	-0.208*** (0.024)	0.004** (0.024)	-0.004 (0.024)	-0.110 ***(0.033)
Central East (R=Western)	-0.056** (0.024)	-0.234 *** (0.036)	0.079*** (0.026)	0.135*** (0.027)	-.0.074*** (0.019)
Eastern	0.114 *** (0.023)	-0.116 *** (0.026)	0.173 *** (0.033)	0.064 (0.038)*	_
North	-0.037 (0.026)	-0.234*** (0.046)	0.119*** (0.028)	-0.047 (0.038)	_
West Nile	-0.087*** (0.032)	-0.272 *** (0.029)	0.128 *** (0.029)	-0.116 *** (0.032)	_
Western	-0.04* (0.022)	-0.133*** (0.028)	-0.009*** (0.024)	-0.069 * (0.041)	_
South West	0.049 ** (0.023)	-0.024 (0.024)	-0.069 (0.024)	-0.048 (0.029)	_
log_cropproduce price	-0.058 (0.050)	-0.034 (0.062)	0.070 (0.026)	-0.060 (0.057)	_
log_distance output mkt.	0.006 (0.005)	-0.007 (0.006)	-0.009 (0.005)	0.009* (0.005)	-0.011 (0.007)
Share of land in banana	0.178 ** (0.035)		0.079 * (0.046)	-0.017 (0.048)	0.088** (0.042)
Share of land in maize	0.353** (0.044)	-0.072* (0.042)	0.093* (0.051)		-0.012 (0.056)
Share of land in Coffee	0.068 (0.047)	0.233 (0.051)	0.013 (0.071)	0.025 (0.088)	
Share of land in cassava	0.188 (0.051)*	0.002 ** (0.051)		0.182 *** (0.060)	0.054 (0.092)
Share of land in beans		0.168 *** (0.046)	0.017 (0.065	0.467 *** (0.046)	0.044 (0.064)
_cons	1.04 (0.366)	0.79 (0.408)	0.170 (0.23)	1.173 (0.396)	0.461 (0.165)
/sigma	0.152 (004)	0.172 (0.004)	0.167 (0.005)		0.151 (0.008)
Number of observations	1042	9535	1012	916	532

Robust *t*-statistics in parenthesis *p<0.1., ** p<0.05, ***p <0.01. R represents regions that were used as dummies for the case of coffee. Base for subregion is Central 1 and Region is Central

Table 3 shows the marginal effect of the Tobit analysis on the factors influencing share of land allocated to crops. All crops selected had a higher probability of being allocated land sizeable share of household land. Probability of land allocation to crops was 45, 41, 40, 39 and 18 percent for banana, maize, cassava, bean and coffee respectively. Agro-ecological factors as presented by sub-regions were the constant factors that influenced the probability of share of land allocated to crops enterprises. For the case of coffee, regional factors influenced the probability of the share of land allocated to the crop.

Table 3: Marginal Effect after Tobit for share of land allocated to crops by agricultural households in Uganda

	Beans	banana	maize	cassava	coffee
Log _own crop yield	-0.029 *** (0.005)	-0.014*** (0.005)	-0.029*** (0.006)	-0.035 ***(0.006)	-0.010 *(0.005)
Head of household sex	-0.011 (0.015)	0.001 (0.017)	0.019 (0.015)	0.003 (0.017)	0.025 (0.019)
Household size	-0.005* (0.003)	-0.003 (0.003)	-0.005 *(0.003	-0.001 (0.003)	0.00 (0.003)
Share of adults	-0.042 (0.031)	-0.023 (0.036)	-0.061 *(0.037)	-0.035 (0.037)	0.002 (0.04)
Sqrt_ total stock of edu (yrs)	-0.004 (0.006)	-0.003 (0.008)	0.005 (0.007)	-0.008 (0.006)	-0.010 (0.009)
Log _welfare	-0.013 (0.011)	0.007 (0.013)	-0.023 (0.015)	0.003 (0.013)	-0.029** (0.014)
Year dummy (2009=1)	0.110 ***(0.036)	0.016 (0.031)	0.040 (0.052)	-0.030 (0.021)	0.092* (0.053)
Sqrt_Adultedu.stock (yrs)	-0.001 (0.006)	0.005 (0.007)	-0.008 (0.007)	0.007 (0.007)	0.004 (0.008)
Dummy of hiring labour	-0.026** (0.012)	-0.041*** (0.014)	0.016 (0.015)	-0.033 **(0.0140	0.018 (0.016)
Dummy of fertilizer use	0.025 (0.025)	-0.002 (0.025)	0.060 *(0.032)	0.026 (0.036)	-0.004 (0.033)
Dummy of organic use	0.015 (0.015)	0.028 *(0.017)	-0.041* (0.018)	-0.008 (0.020)	0.004 (0.018)
Dummy of Central 2 (R=Eastern)	-0.060 ***(0.022)	-0.077 *** (0.059)	0.055 (0.087)	0.091 (0.043)	0.033 (0.021)
Dummy of Kampala (R=Northern)	0.043 (0.036)	-0.208 (0.024)	-0.004 (0.024)	0.004 (0.024)	-0.110 ***(0.033)
Dummy of East Central. (R=Western)	-0.056 **(0.024)	-0.234 *** (0.036)	0.135*** (0.027)	0.079 (0.026)	-0.074*** (0.019)
Dummy of Eastern	0.114 ***(0.023)	-0.116 *** (0.026)	0.064* (0.038)	0.173*** (0.033)	-
Dummy of North	-0.037 (0.026)	-0.233 *** (0.046)	-0.047 (0.038)	0.119 ***(0.028)	_
Dummy of West Nile	-0.087 ***(0.032)	-0.272 *** (0.029)	-0.116 *** (0.032)	0.128*** (0.029)	-
Dummy of Western	-0.040 (0.022)	-0.133 *** (0.027)	-0.069* (0.041)	-0.009 (0.023)	-
Dummy of Southwest	0.049** (0.023)	-0.024 (0.024)	-0.048 (0.029)	-0.069** (0.024)	-
log_own commodity price	-0.058 (0.050)	0.034 (0.062)	-0.060 (0.057)	0.070*** (0.026)	-
Log_dist. to output market	0.006 (0.004)	-0.007 (0.006)	0.009 *(0.005)	-0.001 (0.005)	-0.011 (0.007)
Share of banana area	0.178 ***(0.035)	-	-0.017 (0.048)	0.079 *(0.046)	0.088** (0.042)
Share of maize area	0.353 ***(0.044)	-0.072* (0.042)	-	0.093 *(0.051)	-0.012 (0.056)
Share of coffee area	0.068 (0.047)	0.233 *** (0.05)	0.025 (0.088)	0.013 (0.071)	-
Share of cassava area	0.188 ***(0.051)	-0.002 (0.051)	0.182*** (0.060)	-	0.054 (0.092)
Share of beans area	-	0.168 *** (0.04)6	0.467 *** (0.046)	0.017 (0.065)	0.044 (0.064)
Probability of land allocation	0.39	0.45	0.41	0.403	0.176

Robust *t*-statistics in parenthesis *p<0.1., ** p<0.05, ***p <0.01. R represents regions that were used as dummies for the case of coffee. Base for subregion is Central 1 and Region is Central

Conclusion and recommendations

Although wide deviation on land holding in Uganda was observed, most farmers hold small pieces of land. The small land holding limits the production system to be adopted for transforming the agricultural sector. Yet the sustainability of the cropping system is in doubt considering that farmers were observed to respond to demand of increased production through expansion of area under the crop rather than intensification of production through technology adoption. Overall, the major drivers of the share of land allocated to particular major crops were observed to be largely agro-ecological zones, land holding and the quest of increased production. Crops' respective gate farm prices were observed not have motivated farmers to increase share of land allocated to major crops. Price related factors failed to influence share of land allocation to crops as they were damned by the agro-ecological factors. Natural factors dependent agriculture leads to gluts during production seasons that result to low prices. Even where prices are high the agro-ecological systems limit the agricultural commodity to be cultivated.

Although share of land allocated to maize, banana, cassava and beans were observed to have increased in 2009 from the 2005 values, the analytical results were only significant for beans. It is therefore concluded that over the five years the only crop that have reported expansion is beans. Among the conceptualized components that will affect share of resources allocated to agricultural crops as exemplified by crops only the natural resources was the main driver. Other components including time; institutional, environment and technological; and household and farm enterprise were not observed to influence resources allocation to crops enterprise. High levels of inefficiencies were observed in share of land allocations as other important components and factors expected to be responsive to agricultural production and transformation failed to have positive impacts.

It is recommended that to actualize the country's aspiration of increasing agricultural production and productivity through zoning, the respective ministry need to i). target more on increased production through high yielding technologies adoption; ii). ensurethat areas allocated for various crops targeting for zoning coincides with appropriate agro-ecological zones; iii). Provide a holistic approach to land use efficiency where increased production for even intercrops are targeted; iv). Intervene to ensure that farmers maximally enjoy agricultural production even with constraints provided by agro-ecological zoning through improved infrastructure provision and market access for crops. Uniqueness with subregion, agricultural systems entails designing of interventions (e.g. extension materials, irrigation schemes, produce marketing schemes, etc) that target different agroecological zones.

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Mineral and geochemical characterization of the weathering mantle derived from norites in Kekem (West Cameroon): Evaluation of the related mineralization

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Abstract

In West Cameroon, the Kekem weathering mantle derived from norite was investigated in macroscopic, microscopic, mineral and geochemical point of view in order to document and explain the origin of unusual secondary minerals, and the occurrence of medium grade accumulation of rare metals in this area. Thus, this weathering mantle exhibited shallow weathered soil pedon with seven differentiated soil phases. The secondary minerals consist of akaganéite, sepiolite, berthierine and smectite. Silica (SiO_2: 37.2-43.9%), aluminum (Al_2O_3: 16.8-23.7%) and iron (Fe_2O_3: 9.9-15.9%) are the most abundant major elements. Calcium and sodium are almost completely leached, whereas potassium (K_2O: 4.2%) and magnesium contents (MgO: 6.9%) increase with depth. The most abundant trace elements are Ba (3309.0 ppm), Cr (1133.0 ppm), V (638.0 ppm), Sr (428.1 ppm), Zr (238.0 ppm), Ni (227.9 ppm), Co (174.4 ppm), Zn (139.0 ppm) and Rb (102.7 ppm). Chromium with enrichment factor, EF: 9.1-48.1, Cu (EF: 3.0-4.9), Hf (EF: 1.9 - 3.5), V (EF: 1.4-4.0), Nb (EF: 0.9-3.0), Ta (EF: 0.8 - 3.7), Th (EF: 0.9-2.3), U (EF: 0.9-2.8) and W (EF: 0.6-1.8) are enriched in soil phases. The light rare earth elements (LREE) are the most abundant REE in soils, with ΣLREE ranging from 69.5 to 293.4 ppm. The REE in various soil phases are strongly fractionated from La to Dy, with important Eu anomaly. All these results enable to draw that: *(i)* the highly confined alkaline conditions prevailing in this area have contributed to the formation of unusual secondary minerals like sepiolite, akaganéite and berthierine ; and *(ii)* accumulation of rare metals, more specifically Ba, Cr, Sr, Zr, Ni, Co, Zn and Rb, and to some extent Cu, Hf, Sn, Nb, Ta, Th, U and W, in this weathering mantle could have resulted from: relative enrichment during hydrolysis of weatherable primary minerals, slow dissolution of new-formed secondary minerals or relatively resistant primary minerals, intense biological activity with recycling of metals by plants at the soil surface. Overall, the Kekem norites weathering mantle may be compared to a potential deposit with its relatively high accumulation of sepiolite, akaganéite and berthierine, and medium grade concentrations of rare metals (mainly Ba, Cr, Sr and V) in soil phases.

Key words: West Cameroon, Norites weathering mantle, Akaganéite, Sepiolite, Berthierine, Rare metals

Introduction

Norites are basic intrusive igneous rocks composed largely of calcium-rich plagioclase and hypersthene. Their weathering is commonly associated with rare metals and platinum group elements (PGE) mineralization. It is the case in the Bushveld complex in South Africa with platinum (Moyen, 2007 ; Lee, 1996), the Okiep Copper District in South Africa (Hamman *et al.,* 1996), the Stillwater complex in Montana (USA), the Sudbury Basin complex in Ontario (Canada) which is the world's second largest nickel mining region (Ames and Farrow, 2007) and the Gombak norite in Bukit Gombak (Singapore) (Singh *et al.,* 2012). Norites have been described by Kwékam (2005) in Kekem, a part of the Cameroon volcanic line (CVL) with various volcanic products and Neoproterozoic Pan-African basement (Kwékam *et al.,* 2010). They are basic intrusive rocks with high amounts of feldspars (40 to 50%) and pyroxenes (20 to 30%). Additionally, these rocks have 54 to 59% of SiO_2, 4 to 14% of MgO, 5 to 7% of CaO, 3 to 5% of K_2O, and relatively high contents of Ba (2831 ppm), Cr (1321 ppm) and Sr (1602 ppm). In Cameroon, no previous investigations have been carried out on the weathering mantles derived from norites. The only studies were on basic rocks (serpentinite) in the southern region of Cameroon (Ndjigui *et al.,* 2008; Yongue-Fouateu *et al.,* 2006; Yongue-

Fouateu, 1995). These studies indicate that the weathering of serpentinite has led to accumulation of chlorite, smectite, talc, goethite, maghemite, hematite, kaolinite and gibbsite; that the highest concentrations of Ni, Co and Cr are in the saprolite; and that the concentration of U and Th increase upwards in the weathering mantle. This paper deals with a detailed exploration of the weathering mantle of Kekem norites in order to document and explain the origin of sepiolite, akaganéite and berthierine, and the occurrence of medium grade accumulation of rare metals in this area. This calls for detailed investigation of soil phases in this weathering mantle that cover their macroscopic and microscopic organization, characterization of their minerals and mobilization and distribution of their chemical elements.

Regional setting

The Kekem basic intrusive complex is located in the foot-slopes of the southern edge of the *Bamiléké plateau*, between latitudes 5°05′ and 5°10′ North, and longitudes 10°00′ and 10°06′ East. This area is under the influence of the rain forest equatorial climate with more than 2000 mm of annual rainfall and about 23°C of mean annual temperature. Morphologically, it shows an undulating landscape of lowlands which corresponds to the east extension of the *Mbô* plain, a major graben of the Cameroon volcanic line (Déruelle *et al.*, 1991). This area also exhibits numerous mineral springs with whitish foams all around it, indicative of a highly confined alkaline environment. From a geological point of view, the Kekem basic complex is a basic intrusion of about 10 km wide made up of norites and gabbros (Kwékam, 2005).

Norites are predominant with gabbros located mainly at the edge of the massif. These norites, mostly medium grained, are made up of feldspars, pyroxenes and phlogopites. Ilmenite, Cr-rich magnetite, rutile, apatite and zircon are the main accessory minerals. Feldspars display large variation in composition and consist of plagioclase (40 to 50%) and alkali feldspar (<5%). Plagioclases range from labradorite to oligoclase, but oligoclase ($An_{32-55}Ab_{44-66}$) and alkali feldspar ($Or_{32-87}Ab^{12-13}An_{0.3-7}$) are common. Pyroxenes are made up of diopsides (20-30%) and enstatites (20%). Diopside composition is less magnesian ($Wo_{45-46}En_{38-39}Fs_{15-17}$, with XMg equal to 0.72-0.76). Enstatite composition is close to $Wo_{0-3}En_{60-75}Fs_{25-39}$, with XMg equal to 0.61-0.75 and generally poor in Al (Al_{IV}: 0.0 - 0.014 p.f.u). Phlogopite, 10 to 20%, is relatively rich in magnesium, with XMg equal to 0.67 - 0.69. Chemically, the major element contents range from 54.2 to 58.7% for SiO_2, 6.1 to 9.2% for Fe_2O_3 and 3.7 to 13.8% for MgO. The most abundant trace element is Ba (2831 ppm), followed by Cr (1321 ppm), Sr (1297 ppm), in association with Ni (345 ppm), Zr (275 ppm), V (190 ppm) and Rb (156 ppm). Lead (Pb) reaches an average of 22.1 ppm. Concentrations of the rare earth elements (REE) are very high compared to the bulk silicate earths (BSE)(Mc Donough and Sun, 1995), with enrichment rates (ER) varying from 3.4 for Yb to 81.3 for La (not shown). The light rare earth elements (LREE) have higher concentrations (ER: 22.4 to 81.3 times) than the heavy rare earth elements (HREE). The most abundant REE is Ce (101.6 ppm), followed by La (64.0 ppm), Nd (52.4 ppm), with smaller amounts of Pr (12.8 ppm), Gd (9.9 ppm), Sm (9.7 ppm) and Dy (8.2 ppm). Chondrite normalized REE abundance in the Kekem norites (Figure 5) exhibits a typical pattern of the upper continental crust (McLennan, 1989) and also evidence REE enrichment accompanied by strong La to Dy fractionation.

Methods

The Kekem weathering mantle was exposed by hand dug wells cut through the soil to the unweathered parent rock. Soil pedons were differentiated by soil horizons with various soil phases; a macroscopic description of these soil phases was made. After soil profiles excavation, soil samples were collected from the various soil phases, air-dried and crushed into a fine powder prior to mineral and chemical analyses.

Mineral analysis was done using X-ray powder diffraction (XRD) on un-oriented powdered whole samples. The XRD analyses were performed in the MIPROMALO laboratory (Cameroon) using a BRUKER type diffractometer with Cu-Kα radiation, λ: 1.5418Å, with a scan mode between 2θ: 5 - 90°, with 2θ step of 0.002° and a scanning speed of 1°2θ/min. Relative amounts of each mineral in the soil sample were obtained from the intensity of its principal basal reflection. For chemical analyses, the whole samples of

fine grained soil phases were sent to GeoLab (Ontario, Canada) for major, trace and rare earth elements determination and quantification. Chemical elements identification and quantification was performed by the X-ray fluorescence spectrometry method using a Philips XRFSPW1404 spectrometer. Mass contents are reported as percent of oxides (%) for major elements and part per million (ppm) for trace and rare earth elements. In addition, three soil weathering indices were inferred from the major element data. They are: the chemical index of alteration (CIA = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O)]x100$, where CaO* is the content of calcium oxide in fresh rock) (Nestbitt and Young, 1989), the molar ratio SiO_2/Al_2O_3 (Ruxton, 1968) and the bases/R_2O_3 ratio that equal to $[(MgO+CaO+Na_2O+K_2O)/(Al_2O_3+Fe_2O_3+TiO_2)]x100$ (Birkeland, 1999). Chemical mass balance between soils phases were estimated from the calculations of enrichment/depletion factors determined using Ti as immobile element. Enrichment factor (EF) was estimated by the ratio between the content of an element in a soil phase and that of fresh rock according to the relation $EF(X) = (Xi/Ri)/(Xs/Rs)$(Rahn and Mc Cafrfrey, 1979), where *Xi* and *Ri* are the concentrations of the element of interest and that of a reference element (Ti) in a given soil phase and *Xs* and *Rs* are the concentrations of the same elements in fresh rock. The REE concentrations were normalized relative to CI Chondrite (Anders and Grevesse, 1989) to facilitate the comparison of the REE patterns between soil phases. The $(La/Yb)_N$ ratios were calculated to indicate the degree of LREE to HREE fractionation, while the $(La/Sm)_N$ measures the degree of LREE to MREE fractionation. Europium (Eu) anomalies were estimated by comparing the measured concentration of Eu with an expected concentration (Eu*) obtained by interpolation between the normalized values of Sm and Gd, as proposed by Taylor and McLennan (Taylor and McLennan, 1985).

Results

Minerals association and characterization in various soil phases

Vertical organization of the typical soil pedon from this weathering mantle is illustrated in Figure 2.

This weathering mantle exhibits a 2.5 m thick shallow weathered soil pedon with A, B, BC, and C soil horizons (Figure 2). The surface A horizon is 26 cm thick and has a dark brown (7.5 YR 3/4), clayey, fragile, crumbly and fine granular soil matrix (Table 1). Its transition to the underlying B horizon is distinct and regular. This subsurface B horizon is 100 cm thick; is heterogeneous, with pale red (10 R 5/3), clayey, slightly cemented and undifferentiated soil matrix which forms centimetric domains embedded into yellow brown (7.5 YR 5/8) and clayey soil matrix with coarse sub-angular to polyhedral structure. Both soil matrices are cut off by wormlike cavities infilled with dark grey (5 YR 3/1), clayey, fragile and crumbly soil matrix with fine granular structure. The subsurface B horizon grades progressively downward to a 50 cm thick BC horizon which is also heterogeneous, with saprolite boulders and whitish grey domains embedded into the above yellow brown soil matrix. The saprolite boulders are strongly weathered, but still preserve the medium-grainy structure of fresh norites. They comprise a reddish brown (10 R 3/2), silty sand and undifferentiated weathered material with abundant micrometric and polychromatic punctuations. The whitish grey domains are centimetric, whitish grey (10 YR 7/1) in color, clayey and very porous. The saprolite boulders of the BC horizon become bigger with depth and demarcate an almost continuous C horizon between 176 and 250cm. This lowermost C horizon has a pink (7.5 YR 7/4), silty sand, undifferentiated and strongly weathered material with original structure of preserved fresh norites, and partially weathered norites boulders. Fresh unweathered norites occur in the core of these boulders. Thus, macroscopically, the typical soil pedon of the Kekem weathering mantle has differentiated seven soil phases (Figure 2): the *dark brown soil matrix* sampled *KA* in the A horizon; the *dark grey (KB1), pale red (KB2)* and *yellow brown (KBC1) soil matrices* in the B horizon; the *whitish grey (KBC2)* and *yellow brown* soil matrices, and the *reddish brown saprolite (KBC3)* in the BC horizon; and the *pink saprolite (KC)* in the C horizon.

Under the optical microscope, the seven soil phases exhibit six s-matrices: isalteritic, whitish grey, yellow brown, dark grey, pale red and dark brown s-matrices. The isalteritic s-matrix refers to the pink and the reddish brown saprolites. It is made up of both crystal-rich and clayey plasmas. The crystal-rich plasma is similar to more or less weathered crystals of feldspars. In the pink saprolite, it forms a continuous frame representing about 45% of the s-matrix. It falls below 10% in the reddish brown saprolite where it appears as centimetric and diffuse domains embedded into the clayey plasma. The clayey plasma is made up of

brown red ferruginous matrix underlying contours and splittings of not completely weathered pyroxenes, or forming more or less homogeneous veil over the crystal-rich plasma. The whitish grey s-matrix refers to the whitish grey soil phase. It is porphyritic, with a whitish grey and argilasepic plasma that forms continuous matrix densely dissected by micro-cracks. The yellow brown s-matrix represents the yellow brown soil phase. It is also porphyritic, with both yellow brown and dark red plasmas. The yellow brown plasma, making up more than 55% of the s-matrix, is yellow and locally brown in color, clayey and argilasepic. It still contains relics of partially weathered phlogopites and crystal-rich plasma. The dark red plasma did not exceed 10% of the s-matrix. It shows an isotic fabric and forms 2 to 5 mm wide diffuse micro-domains scattered into the yellow brown plasma. The pale red smatrix refers to the pale red soil phase. It is porphyritic, with reddish brown and locally isotic ferruginous plasma. The dark grey s-matrix corresponds to the dark grey soil phase. It is agglomeroplasmic, with grayish, continuous, more or less homogeneous and argilasepic clayey plasma. It still contains isotic micro-domains and abundant packing voids. The dark brown s-matrix represents the dark brown soil phase. It exhibits the same microscopic characteristics as the dark grey smatrix. Thus, at a microscopic scale, the seven soil phases of the Kekem weathering mantle may have differentiated five s-matrices: *isalteritic, yellow brown, whitish grey, pale red and dark grey to dark brown* smatrices.

Minerals association and characterization of various soil phases

Minerals and their relative abundance in various soil phases are summarized in Table 1 and their X-ray diffraction patterns illustrated in Figure 3.

In this weathering mantle, all the soil phases have approximately the same secondary mineral composition, which consist of akaganéite, sepiolite, berthierine and smectite. Partially weathered primary minerals such as phlogopites, feldspars and pyroxenes are still present in some soil phases. Akaganéite (16 to 75% of minerals detected by X-ray) and sepiolite (10 to 44%) are the dominant weathering products. Akaganéite is easily recognized in the X-ray patterns by its basal reflection at 3.32 Å (Figure 3). It occurs in all the soil phases, with the highest values in the yellow brown and the dark grey soil matrices, respectively (40% and 75%) (Table 1).

Table 1: Minerals and relative abundance in soil phases

	Horizon	R	C (176 - 250cm)	BC (126 - 176cm)			B (26 - 126cm)	
Minerals	***Soil phases***	**KR**	**KC**	**KBC3**	**KBC2**	**KBC1**	**KB2**	**KB1**
Akaganéite	relative amounts in %	-	18	16	25	40	21	75
Berthierine		-	3	9	38	8	14	8
Sepiolite		-	44	32	19	34	32	10
Smectite		-	8	16	-	3	4	-
Phlogopite		10-20	20	14	18	15	21	7
Feldspars		40-50	4	7	-	-	8	-
Pyroxenes		20-30	3	6	-	-	-	-

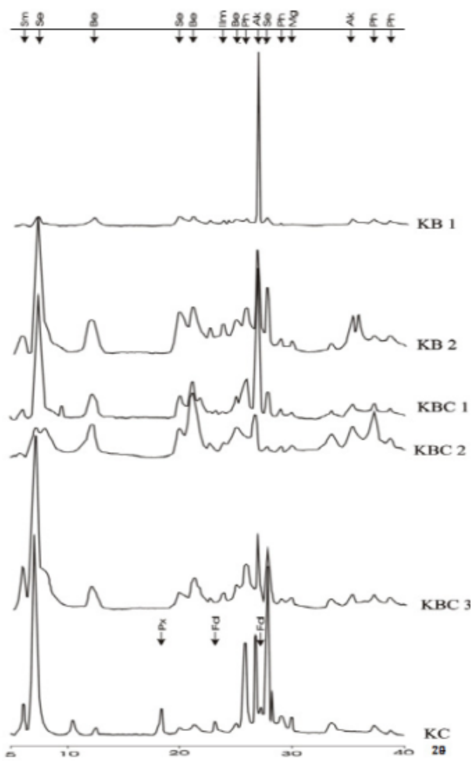

Figure 3: X-ray diffraction patterns of soil phases (Sm, smectite; Se, sepiolite; Be, berthierine; Ph, phlogopite; Ak, akaganeite; Px, pyroxene; Fd, feldspar)

Sepiolite was identified in the X-ray patterns by its major peak around 12.02 Å (Figure 3). Its highest content is in the pink saprolite (44%). It reduces gradually to 10% in the dark grey soil matrix at topsoil. Both the above weathering products are associated with important amounts of berthierine (3- 38%) and phlogopite (7-21%), and relatively low contents of smectite (3-16%) (Table 1). Berthierine also occurs in all the soil phases, with its highest contents in the whitish grey soil matrix of the BC horizon (38%). It exhibits distinct basal reflections at 7.12 Å, 3.54 Å and 2.54 Å, respectively. Smectite also occur in various soil phases, except in the whitish grey and the dark grey soil matrices. In the X-ray diffraction patterns, this mineral displays distinct reflection at 14.15-14.25 Å. Phlogopite, a magnesium rich biotite, is the unique partially weathered primary mineral remaining in all the soil phases. It ranges from 7-21% of the minerals detected by X-ray. In the X-ray diffraction patterns, it shows a basal reflection between 9.9Å and 10.1Å. Pyroxene, another partially weathered primary mineral which represents about 3 to 6% of the minerals, is only reported at soil depths in the pink and the reddish brown saprolites. Feldspar, which constitutes about 4-8% of the minerals, is also a partially weathered primary mineral. It is present within the profile and in the surface horizons.

Table 2. Major, trace and rare earth elements contents and weathering indices in soil phases

Elements	Horizon / Sample	R	C (176 - 250cm)	BC (126 - 176cm)			B (26 - 126cm)		A (0 - 26cm)
		KR	KC	KBC3	KBC2	KBC1	KB2	KB1	KA
SiO_2	Major elements in % of oxides	54.7	40.8	38.7	43.2	40.9	40.1	37.2	41.1
Al_2O_3		15.8	16.8	21.4	22.6	23.7	23.3	18.6	18.3
Fe_2O_3		8.1	14.4	14.4	10.1	10.2	9.9	15.9	12.5
TiO_2		1.3	1.7	1.5	1.4	1.7	1.7	3.0	2.7
CaO		7.0	1.4	0.2	0.2	0.2	0.2	0.1	0.4
MgO		4.6	6.9	1.2	1.5	1.1	1.1	1.0	1.4
K_2O		4.0	4.2	2.5	3.2	2.2	2.1	1.5	3.0
Na_2O		3.1	0.4	0.1	0.1	0.1	0.1	0.1	0.3
SiO_2/Al_2O_3	Weathering index %	2.9	2.1	1.5	1.6	1.5	1.5	1.7	1.9
$Bases/R_2O_3$		99.5	56.5	14.6	19.1	13.2	13.1	10.3	21.1
CIA		52.7	70.9	77.9	78.8	79.6	75.4	79.3	73.4
Ba	Traces elements in ppm	2706.0	3309.0	1197.7	1251.7	241.3	859.9	729.2	1700.2
Co		34.0	47.6	22.0	45.3	14.1	17.8	174.4	43.7
Cr		18.0	1133.0	299.0	213.0	610.0	264.0	381.0	339.0
Cu		6.0	26.9	33.9	28.9	38.1	31.9	53.4	38.0
Ga		24.0	28.2	24.9	24.8	30.4	31.8	26.9	26.2
Hf		1.0	2.5	2.6	2.3	4.6	3.4	6.2	5.3
Nb		9.0	10.8	16.6	14.4	35.2	20.7	35.5	30.4
Ni		116.0	227.9	48.7	53.6	70.8	61.9	81.9	65.4
Pb		20.0	20.1	26.4	23.0	21.1	24.9	28.4	25.4
Rb		83.0	102.7	27.9	20.5	21.2	16.5	40.8	27.5
Sn		1.8	7.9	2.0	1.9	2.5	3.0	4.1	3.8
Sr		1602.0	428.1	310.4	240.0	84.2	191.1	181.8	355.7
Ta		0.6	0.6	1.0	0.9	2.9	1.3	2.6	1.9
Th		3.1	3.7	6.1	3.2	9.2	5.5	9.9	6.1
Tl		0.4	0.5	0.4	0.5	0.2	0.4	1.1	0.5
U		0.8	0.9	1.9	1.3	2.9	1.8	2.8	1.8
V		122.0	247.0	367.0	255.0	638.0	273.0	455.0	361.0
W		0.5	0.4	0.8	0.6	1.2	0.9	1.4	1.1
Y		23.0	16.3	16.9	13.2	12.9	10.7	15.1	11.3
Zn		125.0	139.0	74.0	79.0	75.0	83.0	116.0	106.0
Zr		105.0	86.0	87.0	79.0	171.0	121.0	238.0	210.0
La	Rare earth elements in ppm	52.7	38.7	42.6	10.8	61.6	14.7	57.4	32.9
Ce		85.9	94.4	105.2	31.6	111.6	34.1	163.9	72.8
Pr		10.9	11.0	13.8	4.0	15.9	4.9	14.2	9.1
Nd		46.8	45.3	58.6	17.9	59.1	20.6	51.9	35.4
Sm		9.1	7.9	1.9	4.1	2.5	4.4	4.1	6.4
Eu		4.0	2.1	2.9	1.1	2.1	1.2	1.9	1.7
Gd		8.1	5.5	8.3	3.6	5.4	3.6	5.3	4.4
Tb		0.9	0.7	1.1	0.5	0.6	0.5	0.7	0.5
Dy		3.9	3.8	5.7	2.8	3.6	2.9	3.8	3.1
Ho		0.7	0.6	0.9	0.5	0.5	0.5	0.6	0.5
Er		1.8	1.7	2.1	1.5	1.4	1.3	1.6	1.3
Tm		0.3	0.2	0.2	0.2	0.1	0.1	0.2	0.1
Yb		1.5	1.5	1.5	1.2	1.2	1.1	1.5	1.1
Lu		0.3	0.2	0.1	0.1	0.1	0.1	0.2	0.1
ΣREE	The REE Index	226.9	213.6	307.3	79.9	244.9	90.0	265.7	169.4
ΣLREE		209.4	199.4	293.4	69.5	225.0	79.9	252.8	158.3
ΣHREE		17.5	14.2	13.9	10.4	19.9	10.1	12.9	11.1
a		12.0	14.0	21.1	6.7	11.3	7.9	19.6	14.3
Ce/Ce*		1.0	1.3	1.6	1.3	1.2	1.1	1.0	1.2
Eu/Eu*		1.0	0.5	0.6	0.3	1.6	0.3	0.8	0.4
$(La/Yb)_N$		1.0	0.7	1.1	0.3	0.8	0.4	1.5	0.9

a: ΣLREE/ ΣHREE

Chemical elemental contents, mobilization and redistribution in various soil phases

Major and trace elements contents. Major and trace elemental contents and some weathering indices are given in Table 2. Silica (SiO_2: 37.2 to 43.9%), aluminum (Al_2O_3: 16.8 to 23.7%) and iron (Fe_2O_3: 9.9 to 15.9%) are the most abundant elements in the soil phases. Silica contents decrease significantly from fresh rock to the dark grey soil matrix of the B horizon (SiO_2: 54.7 to 37.2%), and slightly increase up to 41.1% at the soil surface. Inversely, aluminum (Al_2O_3: 15.8 to 23.7%) and iron (Fe_2O_3: 8.1 to 15.9%) contents increase invariably upwards. Calcium (CaO: 7.0 to 0.1%) and sodium (Na_2O: 3.1 to 0.0%) are almost completely leached from all soil phases. However, potassium (K_2O: 1.5 - 4.2%) and magnesium (MgO: 1.0 - 6.9%) contents remain relatively high, generally with increasing values from fresh rock to the pink saprolite (K_2O: 4.0 to 4.2%; MgO: 4.6 to 6.9%). The molar ratio SiO_2/Al_2O_3, related to silica leaching intensity, remains relatively high in all the soil phases (1.5 to 2.1), and decreases slightly towards the surface. The chemical index of alteration (CIA), related to weathering intensity, increases very slightly from the pink saprolite

towards the surface horizons (CIA: 70.9 to 79.6%). Furthermore, the bases/R_2O_3 ratio, giving an estimation of the weatherable primary minerals remaining in soils, decreases moderately upwards from the pink saprolite (56.5%) through the reddish brown saprolite to 10.3% in the dark grey soil matrix.

The most abundant trace element in this weathering mantle is Ba (3309.0 ppm in the pink saprolite), followed by Cr (1133.0 ppm), V (638.0 ppm), Sr (428.1 ppm), Zr (238.0 ppm), Ni (227.9 ppm), Co (174.4 ppm), Zn (139.0 ppm) and Rb (102.7 ppm) in various soil phases (Table 2). Overall, trace elements in this weathering mantle can be grouped into three main categories according to their behavior in the soil phases compared to the fresh rock. They are: elements with increasing contents in soil phases (Cr, V, Cu, Nb, Ta, Th, Hf, Pb, Sn, U and W); elements with decreasing contents in soil phases (Sr and Y); and elements with alternately increasing and decreasing contents in soil phases (Ba, Co, Ga, Ni, Rb, Tl, Zn and Zr).

Major and trace elements balance

Enrichment-depletion of major and trace elements in this weathering mantle was assessed using enrichment factors (EF). These results are presented in Table 3.

Table 3. Enrichment factors (EF) for major and trace elements in various soil phases

	R	C (176 - 250cm)	BC (126 - 176cm)			B (26 - 126cm)		A (0 - 26cm)
	KR	KC	KBC3	KBC2	KBC1	KB2	KB1	KA
SiO_2	1.0	0.6	0.6	0.7	0.6	0.6	0.3	0.4
Al_2O_3	1.0	0.8	1.2	1.3	1.1	1.1	0.5	0.6
Fe_2O_3	1.0	1.4	1.5	1.2	1.0	0.9	0.9	0.7
CaO	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
MgO	1.0	1.1	0.2	0.3	0.2	0.2	0.1	0.1
K_2O	1.0	0.8	0.5	0.7	0.4	0.4	0.2	0.4
Na_2O	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Ba	1.0	0.9	0.4	0.4	0.1	0.2	0.1	0.3
Co	1.0	1.1	0.6	1.2	0.3	0.4	2.2	0.6
Cr	1.0	48.1	14.4	11.0	25.9	11.2	9.2	9.1
Cu	1.0	3.4	4.9	4.5	4.9	4.1	3.9	3.0
Ga	1.0	0.9	0.9	1.0	1.0	1.0	0.5	0.5
Hf	1.0	1.9	2.3	2.1	3.5	2.6	2.7	2.6
Nb	1.0	0.9	1.6	1.5	3.0	1.8	1.7	1.6
Ni	1.0	1.5	0.4	0.4	0.5	0.4	0.3	0.3
Pb	1.0	0.8	1.1	1.1	0.8	1.0	0.6	0.6
Rb	1.0	0.9	0.3	0.2	0.2	0.2	0.2	0.2
Sn	1.0	3.4	1.0	1.0	1.1	1.3	1.0	1.0
Sr	1.0	0.2	0.2	0.1	0.0	0.1	0.0	0.1
Ta	1.0	0.8	1.4	1.4	3.7	1.7	1.9	1.5
Th	1.0	0.9	1.7	1.0	2.3	1.4	1.4	0.9
Tl	1.0	1.0	0.9	1.2	0.4	0.8	1.2	0.6
U	1.0	0.9	2.1	1.5	2.8	1.7	1.5	1.1
V	1.0	1.5	2.6	1.9	4.0	1.7	1.6	1.4
W	1.0	0.6	1.4	1.1	1.8	1.4	1.2	1.1
Y	1.0	0.5	0.6	0.5	0.4	0.4	0.3	0.2
Zn	1.0	0.9	0.5	0.6	0.5	0.5	0.4	0.4
Zr	1.0	0.6	0.7	0.7	1.2	0.9	1.0	1.0

Major and trace elements in various soil phases are grouped into enriched (EF ≥ 1.0), depleted (EF < 1.0) or alternately enriched-depleted (EF ± 1.0) elements (Table 3). Enriched elements are Cr, Cu, V, Hf and Sn. They are enriched in all the soil phases. Cr is the most enriched, with EF between 9.1 and 48.1; followed by Cu (EF: 3.0 to 4.9); V (EF: 1.4 to 4.0), Hf (EF: 1.9 to 3.5) and Sn (EF: 1.0 to 3.4). The highest enrichments of V and Hf are in the yellow brown soil matrix (EF_V: 4.0; EF_{Hf}: 3.5); those for Cu and Sn are in the reddish brown saprolite and in the yellow brown soil matrix Cu (EF_{Cu}: 4.9) and the pink saprolite Sn (EF_{Sn}: 3.4). Depleted elements include Si, Ca, K, Na, Ba, Ga, Rb, Sr, Y and Zn. They are strongly depleted, with EF ≤ 0.2 like in Ca, Na and Sr, or slightly depleted, with EF ranging from 0.5 to 0.9 like in Si, K, Ba, Ga, Rb, Y and Zn. Thus, in all the soil phases of the Kekem weathering mantle, Ca, Na and Sr are almost completely leached,

whereas Si, K, Ba, Rb, Y and Zn are increasingly depleted towards the soil surface, and Ga remains very slightly depleted. Alternately enriched and depleted elements include Al, Fe, Mg, Co, Nb, Ni, Pb, Ta,

Th, Tl, U, W and Zr. Elements such as Nb, Ta, U and W are very slightly depleted in the pink saprolite, but enriched in the other soil phases. Al, Pb, Co, Zr and Tl are invariably depleted and enriched, with EF_{Al}: 0.5 to 1.3; EF_{Pb}: 0.6 to 1.1; EF_{Co}: 0.3 to 2.2; EF_{Zr}: 0.6 to 1.2 and EF_{Tl}: 0.4 to 1.2. Th is slightly depleted in the pink saprolite and the dark brown soil matrix (EF: 0.9), but enriched in the other soil phases (EF: 1.0 to 2.3). Fe, Mg and Ni are enriched in the subsoil, and depleted in the surface horizons.

The REE elements

In the Kekem weathering mantle, abundance of the REE varies from ΣREE: 79 ppm in the whitish grey soil matrix to 307.3 ppm in the reddish brown saprolite (Tab. 2). In general, the REE in various soil phases are more enriched compared to the BSE (Mc Donough and Sun,

1995), with enrichment rates (ER) ranging from 11.5 to 44.8. The LREE are the most abundant, with ΣLREE ranging from 69.5 to 293.4 ppm. The most abundant LREE is Ce (163.9 ppm in the dark grey soil matrix), followed by La and Nd (with values of 61.6 ppm and 59.1 ppm respectively in the yellow brown soil matrix).

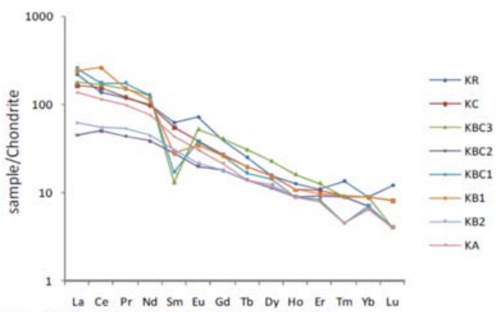

Figure 4. CI Chondrite-normalized REE patterns for various soil phases

Concentrations of the HREE did not exceed ΣHREE: 20 ppm. The REE fractionation index, *a*:ΣLREE/ΣHREE, which ranges from 6.7 to 21.1, highlights important accumulations of the LREE in the soil phases. The highest accumulations are in the reddish brown saprolite (*a*: 21.1) and the dark grey soil matrix (*a*: 19.6). The Eu/Eu* ratio, related to the REE fractionation, varies from 0.9 to 2.3, indicating important fractionation of the REE in various soil phases, with significant Eu anomaly. The Ce/Ce* ratio, ranging from 0.8 to 1.4, points out to a positive anomaly of Ce, except in the yellow brown and the pale red soil matrices. The $(La/Yb)_N$ ratio, which ranges from 6.3 to 36.1, also indicates a strong fractionation of the LREE compared to the HREE. The Chondrite-normalized REE patterns illustrated in

Figure 5 confirm the marked fractionation of the REE in all the soil phases, from La to Dy. This REE fractionation in soil phases is not very significant from Ho to Lu.

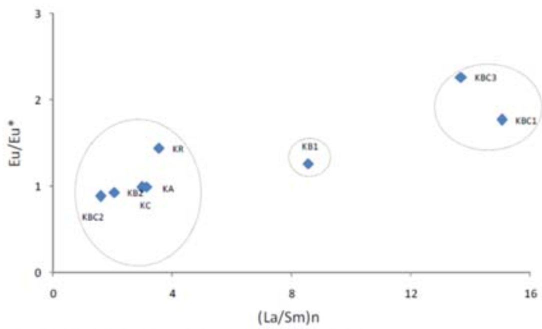

Figure 5. Variation of Eu anomaly versus LREE fractionation in various soil phases

These Chondrite-normalized REE patterns, as well as the variability of the Eu/Eu* as a function of the $La/Sm)_N$ (Figure 5), makes it possible to classify soil phases in this weathering mantle into three main categories: *(i)* soil phases with slightly pronounced LREE fractionation and Eu anomaly represented by the pink saprolite, and the whitish grey, the pale red and the dark brown soil matrices; *(ii)* soil phases with strong LREE fractionation and slightly pronounced Eu anomaly such as the dark grey soil matrix; and *(iii)* soil phases with very strong LREE fractionation and Eu anomaly like the reddish brown saprolite and the yellow brown soil matrix. The norite-normalized REE patterns (not shown) also reveal a significant fractionation of the REE compared to the fresh rock, with the pink and the reddish brown saprolites, the yellow brown and the dark grey soil matrices relatively enriched in LREE.

Discussion

Weathering trends and intensity in the Kekem weathering mantle

In the Kekem weathering mantle, the pink and the reddish brown saprolites have preserved the medium grainy structure of norites that is indicated by the presence of the crystal-rich plasma as well as micrometric and polychromatic punctuations. Chemical weathering with conservation of the rock structure is evenly reported in tropical regions (Nguetnkam *et al.,*

2003; Nahon and Merino, 1997; Yongue-Fouateu, 1986; Delvigne, 1965). It has usually contributed to generation of the saprolites (Nahon, 1991). Moreover, the weathering of norites in Kekem has led to the formation of 2:1 clay minerals (sepiolite and smectite) as well as relatively low leaching of Si, Mg and K to lower soil depths. Presence of these 2:1 clay minerals, with recurrence of mineral springs and low exportation of Si, Mg and K in these environments are indicative of a highly confined alkaline milieu suitable for specific hydrolysis known as bisiallitisation (Nguetnkam *et al.*, 2003). The relatively low values of CIA (70.9 – 79.6%) in soil phases of the Kekem weathering mantle suggest a restrained weathering process in this environment that led to the formation of 2:1 clay minerals. Additionally, in this weathering mantle, the high SiO_2/Al_2O_3 molar ratio (1.5 to 2.1) reinforces the presence of 2:1 clay minerals and relatively low leaching of silica in this environment. Also, the relatively high values of bases/R_2O_3 in various soil phases (10.3 – 56.5%) highlight limited leaching of the alkali cations (Little and Aeolus, 2006), more specifically Mg and K. This can be attributed to sepiolite and smectite development that need important consumption of Mg and K respectively (Kadir *et al.,* 2002). Limited exportation of the alkali cations from the topsoil could be related to persistence of rock fragments (Tematio *et al.*, 2009). All these statements indicate that the Kekem weathering mantle has experienced restrained weathering process with minor pedological differentiation.

Occurrence of specific secondary minerals

The mineral data of the Kekem weathering mantle have revealed the presence of unusual minerals like sepiolite, akaganéite and berthierine.

Sepiolite is a Mg hydrated silicate with general formula [$Mg_4Si_6O_{15}$ $(OH)_2$. $6H_2O$]. It is a poorly crystallized 2:1 clay mineral with a fibrous structure (Kadir *et al.*, 2002). Nickel (Ni), Mn, Fe and Al are the main impurities (Caillère *et al.*, 2004) and may replace Mg in the crystal lattice or associated with H_2O in the channels of the mineral structure (Kadir *et al.*, 2002). Sepiolite is commonly found in weathering products in saline or alkaline environments (Kadir *et al.*, 2002; Singer *et al.*, 1998). But, the configuration of the Kekem area makes it a highly confined alkaline milieu. For instance, the poor drainage in this environment may result to the collapsing lowland structure of this area which belongs to the *Mbô* plain. Its alkaline status may be attributed to mineral springs. Under these alkaline conditions, released Si and Mg may have served in the formation of sepiolite during precipitation under highly confined conditions (McLean *et al.*, 1972).

Akaganéite is an iron oxide-hydroxide/chloride mineral [β- $Fe^{3+}O(OH,Cl)$] with tunnel structure, sheaflike morphology with Ni as impurity (Xiong *et al.*, 2008). It has attracted much investigation because of its sorption, ion exchange and catalytic properties (Fitzpatrick and Shand, 2008). It has since been recognized as a Fe oxide component rarely observed in soils. Nevertheless, the highly alkaline environment provides ideal conditions for its crystallization in soils (Bibi *et al.*, 2011). In the Kekem weathering mantle, akaganéite has been identified as a significant weathering product in the soil phases (16 to 75% of minerals detected by X-ray). In these highly confined alkaline conditions, it apparently forms from dissolution of pyroxene with release of free Fe^{2+}. Under exposure in alternately humid and dry conditions during a long period of time, free Fe^{2+} can be oxidized, leading to the formation of akaganéite (Garcia *et al.*, 2008; Bigham *et al.*, 2002).

Berthierine is a tri-octahedral Fe-rich clay mineral with the general formula [$(Fe^{2+}, Fe^{3+}, Mg, Al)_{2-3}(Si, Al)_2O_5(OH)_4$]. It has a 1: 1 type structure, and is related to the serpentine subgroup of clay minerals. It contains a greater range of minor and trace elements substitution. Berthierine has been very little reported in soils (Kodama and Foscolos, 1981). However, some workers suggested that berthierines in soils may have formed in poorly oxygenated conditions during pedogenesis or hydrothermal alteration (Moore and Hughes, 2000). In the Kekem weathering mantle, berthierines occur in all the soil phases. Thus, in the Kekem area which is like a highly confined alkaline environment, berthierine may probably have formed through the dissolution of feldspars in the presence of Fe-rich solution (Wise, 2007).

Occurrence of rare metals

In the Kekem weathering mantle, medium grade accumulation of Ba (241.0 to 3309.0 ppm), Cr (213.0 to 1133.0 ppm), V (247.0 to 638.0 ppm) and Sr (84.2 to 428.1 ppm) have been observed. Other rare metals like Zr (121.0 to 238.0 ppm), Ni (227.9 ppm), Co (174.4 ppm),

Zn (106.0 to 139.0 ppm), and Rb (102.7 ppm), also exhibit significant accumulations in specific soil phases. The mass balance evaluation reveals that Cr, Cu, Hf, V, Nb, Ta, U and W considerably accumulate in soil phases. The rare metals accumulations in weathering mantles originated from the alteration of basic rocks are well known around the world (Singh *et al.*, 2012; Ames and Farrow, 2007; Moyen, 2007). In the Kekem weathering mantle, it could have resulted from relative enrichment during hydrolysis in association with Fe-oxides (Singh *et al.*, 2002) during which rare metals accumulate due to poor drainage of the percolating groundwater (Yongue-Fouateu *et al.*, 2006). It may also resulted from slow and partial dissolution of the neosynthesis of secondary minerals through weathering (Singh *et al.*, 2002) or incorporation into relatively resistant primary minerals such as Cr-rich magnetite, rutile, apatite, phlogopite and zircon (Lowson *et al.*, 1986). It could lastly be attributed to intense biological activity due to recycling process of metals by plants at the soil surface (Kabata-Pendias, 2001). Copper (Cu), Hf, Nb, Ta, U and W, despite their high enrichment rates, remain little concentrated in all the soil phases. This could be due to the very low concentrations of these rare metals in fresh norites.

In the Kekem weathering mantle, some other rare metals, despites their relative low contents, remain of great interest. They are Pb, Y, La, Ce, and Nd. Their relative low concentrations in soil phases suggest that they may either remain incorporated in more resistant primary minerals and residual heavy minerals (Lowson *et al*., 1986); or are trapped during neosynthesis of secondary minerals (Singh *et al*., 2002), or may be taken up through recycling process of metals by plants (Kabata-Pendias, 2001). In addition, the LREE accumulation in soil phases as illustrated by high $(La/Yb)_N$ values (6.3-36.1) may be attributed to intense REE fractionation (Moroni *et al.,* 2001). Thus, concentration of REE in soil phases highlights the influence of secondary minerals development on the REE redistribution during the weathering process. Moreover, the strong positive Ce anomaly may be linked to oxidation of Ce^{3+} to Ce^{4+} or primary Ce^{4+} in residual zircon minerals because of its oxidation ability, insolubility and stability in lateritic environments (Ndjigui *et al.*, 2008).

Conclusion

This paper focused on the occurrence of sepiolite, akaganéite and berthierine, and medium grade accumulation of rare metals in the Kekem norites weathering mantle. Macroscopic and microscopic organization of various soil phases in this weathering mantle as well as their mineral composition and chemical elements mobilization and redistribution enable us to draw the following conclusion:

- This weathering mantle has been subjected to restrained weathering process with minor pedological differentiation;
- The major weathering process in this area, referred to as bisiallitisation, led to formation of 2:1 clay minerals such as sepiolite and smectite;
- The highly confined alkaline conditions prevailing in this area have contributed to the formation of unusual secondary minerals like sepiolite, akaganéite and berthierine in these soils;
- Accumulation of rare metals, more specifically Ba, Cr, Sr, Zr, Ni, Co, Zn and Rb, and to some extent Cu, Hf, Sn, Nb, Ta, Th, U and W, in this weathering mantle could have resulted from: *(i)* relative enrichment during hydrolysis of weatherable primary minerals, (*ii)* slow dissolution of the neosynthesis secondary minerals or relatively resistant primary minerals, *(iii)* intense biological activity with recycling of metals by plants at the soil surface;
- There is a strong REE fractionation in various soil phases of this weathering mantle from La to Dy, with high Eu anomaly

Overall, the Kekem norites weathering mantle may be compared to a potential deposit with its relatively high accumulation of sepiolite, akaganéite and berthierine, and medium grade concentrations of rare metals (mainly Ba, Cr, Sr and V) in soil phases.

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The sugarcane carbon sequestration potential as a clean development mechanism the case of Kakira Sugar Estates

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Abstract

Soils, and managed agricultural soils in particular, represent a potentially significant low cost sink for greenhouse gases (GHGs) with multiple potential co-benefits to farm productivity and profitability (Jonathan, Ryan and Jeffrey, 2010). The great majority of agronomists and soil scientists agree that most agricultural soils can store more carbon and even a modest increase in carbon stocks across the large land areas used for agriculture would represent a significant GHG mitigation.

Sugarcane accompanied with good farming practices has the potential to sequester considerable amounts of carbon and so contribute to climate change mitigation. However, little has been done to provide relevant information concerning carbon sequestration in crop lands and sugarcane in particular. This research work focuses on finding out the ability of sugarcane to sequester carbon in the soil and involves analyzing four different sugarcane varieties among those grown by Kakira sugar works limited to assess their potential to sequester carbon. It is believed to provide the management of Kakira and other stakeholders the relevant information against which to base decisions for developing CDM projects to mitigate climate change through agriculture. Sugarcane grown in Kakira estates has the potential to sequester carbon between 589.11 to 591.12Tc/ha. Therefore, with proper agronomic practices, carbon sequestration in sugarcane is a potential CDM project.

Key words: Carbon sequestration, sugarcane varieties, soil organic carbon, phytoliths, Bulk density.

Introduction

Policy makers in Uganda, and many other nations, are currently debating how to design, implement and monitor carbon pollution reduction schemes (CPRS) as an important tool to reduce greenhouse gas emissions. Biospheric carbon offsets including soil carbon sequestration have the potential to be important components of any CPRS but numerous uncertainties still exist, especially within the agricultural sector, which are major barriers to effective policy implementation.

Soils, and managed agricultural soils in particular, represent a potentially significant low cost sink for greenhouse gases (GHGs) with multiple potential co-benefits to farm productivity and profitability (Jonathan, Ryan and Jeffrey, 2010, Lal 2004a; Pacala and Socolow, 2004). The great majority of agronomists and soil scientists agree that most agricultural soils can store more carbon and even a modest increase in carbon stocks across the large land areas used for agriculture would represent a significant GHG mitigation. However, currently, there is much uncertainty and debate, particularly within Australia, as to the total potential of soils to store additional carbon, the rate at which soils can store carbon, the permanence of this carbon sink, and how best to monitor changes in soil carbon stocks.

Throughout this research, I will primarily discuss the technical potential, defined by the biophysical conditions of the system, for agricultural land to store additional soil organic carbon (SOC) through improvements in management. It is very important to realize that this technical sequestration potential will likely never be fully realized due to a whole host of economic, social and political constraints

Soil carbon

Soil carbon sequestration is gaining global attention because of the growing need to offset the rapidly increasing atmospheric concentration of carbon dioxide (CO2). This carbon dioxide enrichment is associated with an increase in global warming potential and changes in the amount and effectiveness of

precipitation (McKenzie, February 2010). The increase in atmospheric carbon dioxide concentration also is reducing pH and carbonates ion concentration in the ocean and may adversely affect key marine organisms

The 36% increase in atmospheric carbon dioxide concentration from a pre-industrial level of 280 ppm to 380 ppm in 2006 has been caused mainly by fossil fuel combustion, land use conversion, soil cultivation and cement manufacturing.

Soils contain large amounts of carbon in both organic and inorganic forms. Organic C is found in soils in the form of various organic compounds, collectively called soil organic matter (SOM). The amount of C found in SOM ranges from 40 to 60% by mass. Strictly speaking, SOM includes all living and non-living organic material in the soil (Jonathan, Ryan, and Jeffrey, 2010; Baldock and Skjemstad 1999). The living component includes plants, soil fauna and microbial biomass.

The non-living component, representing the bulk of SOM, includes a spectrum of material from fresh residues and simple monomeric compounds to highly condensed, irregular polymeric structures with residence times varying from days to millennia.

Globally, the top meter of soil stores approximately 1500 Pg as organic C and an additional 900-1700 Pg as inorganic C and exchanges 60 Pg C yr-1 with the atmosphere, which contains 750 Pg C as carbon dioxide (CO2) (Eswaran *et al*. 1993; Schlesinger 1997). The shear size of the soil carbon pool and the annual flux of carbon passing through the soil are two of the reasons that SOC can play a significant role in mitigating GHG emissions.

How clean development mechanism work

A developed country (Annex I party) may invest in a project in a developing country (Uganda). If the project reduces, or avoids GHG emissions, then the Developed country party can claim a portion of the certified emission reduction units (CERUs). CERUs can be used by northern companies to "redeem" emissions against national obligations, or be traded on the open market among others.

Clean Development Mechanism measures recognize that carbon sequestration is effective in reducing emissions of greenhouse gas to the atmosphere. It enables accumulation of sellable CERs, each equivalent to 1ton of carbondioxide which developed countries can count towards meeting their Kyoto targets. Enhancing carbon sequestration in sugarcane cultivation through improved land management and agricultural practices has the potential for reducing emissions to the atmosphere and can be adopted as a climate change mitigation measure. Sugarcane cultivation is an agricultural activity that falls under category two of the CDM projects (Isabirye, 2011).

Status of CDM Projects in Uganda

The potential for Uganda to benefit from CDM is significant; the Uganda Investment. Authority which markets opportunities for CDM and carbon market investment has identified thirty sites suitable for mini-hydro power investment which could generate between 1 -20 MW each; NFA has available large areas set aside for industrial forest plantation in chunks of 500 to 15000 hectares on 49-99 year leases, and the new PoA facility opens up huge potential for programmatic efforts within wood fuel efficiency projects – 93% of Uganda's energy consumption originates from biomass.

Problem Statement

Experiments show that changes in the area under agriculture, land use and land management practices can lead to changes in the biomass stocks and soil organic matter of the upper soil (Ping Chang, 2007). Sugarcane crop residues contain substantial quantities of C and plant nutrients, but there have been relatively few studies of how sugarcane residues enrich the soil and contribute to C sequestration, and a few studies that have been undertaken especially in Uganda, have not been specifically on sugarcane Currently, there is not enough research on the topic of anthropogenic impacts on the formation and loss of soil inorganic C to be able to assess its sequestration potential and it is only the organic C pool that is under consideration for inclusion in various emission reduction schemes. The available scientific knowledge of how local soil properties and climatic conditions affect soil carbon stock changes and carbon fluxes is

insufficient and conflicting (UNEP, 2012). The purpose of this study is to address these knowledge gaps by determining the total carbon stocks in growing sugarcane and sequestration potentials following retention of sugarcane residues. It is also reacting to the UNEP year book (2012) on the benefits of soil carbon, that identifies a Knowledge gap and recommends further research to facilitate accurate predictions of the impacts of climate change on soils, soil carbon and associated ecosystem services at scales relevant to local management, as well as to national carbon inventories.

Significance of the Study

Currently, there is much uncertainty and debate, particularly within Uganda, as to the total potential of agricultural soils to store additional carbon, the rate at which soils can accumulate carbon, the permanence of this sink, and how best to monitor changes in SOC stocks (UNEP, 2012). There is a strong theoretical basis partially supported by a limited number of field studies for significant SOC sequestration potential in several Ugandan agricultural sectors. The general lack of research in this area is currently preventing a more quantitative assessment of the carbon sequestration potential of agricultural soils. To help clarify some of these issues, this research will present both a review of the mechanisms of carbon capture and storage in agricultural soils by analyzing and publishing the potential of a sugarcane crop to sequester carbon plus evidence for SOC stock changes resulting from shifts in agricultural management taking the case of Kakira estates. This study will provide a basis for sugarcane plantation soil management practices for multiple economic, societal and environmental benefits requires integrated policies and incentives that maintain and enhance soil carbon. It will again serve as a stepping stone for other researchers and academicians who would wish to research further on carbon stocks and sequestration in agricultural fields and clean development mechanism projects in Uganda.

Main objective

To access the carbon sequestration potential of sugarcane grown in Kakira sugar estates in relation to different varieties

Specific objectives

- To estimate the total biomass of sugarcane varieties per hectare
- To quantify the total soil carbon for undisturbed soil with in the study area
- To quantify the average carbon stocks per sugarcane variety per hectare in Kakira sugar estates
- To estimate the carbon sequestered by sugarcane at the end of the year with respect to the different varieties grown in Kakira sugar estates

Research hypothesis

The research statements for which the analysis will provide answers are as sugarcane grown in Kakira sugar estates has no significant carbon sequestration potential and sugarcane growing in Kakira sugar estates can not generate significant carbon emission reductions to justify a clean development mechanism project

Geographical location

Kakira is about 106 km east of Kampala, the capital city of the Republic of Uganda. It is located in the district of Jinja, 10 kms from Jinja town on Tororo road. It lies on the northern shores of Lake Victoria and its land scape is made up of scattered hills - with the highest being 1,279m above sea level. On the map, its Latitude – 00 30' North and Longitude – 330 17' East (www.madhvanifoundation.com/downloads/mgm-oct09.pdf). It is the location of the headquarters of the Madhvani Group conglomerate. On a 9,500 hectares (37 sq mi) estate, the Group owns a sugarcane farm and a sugar manufacturing complex, Kakira Sugar Works. They also own a sweets & confectionery factory, Kakira Sweets & Confectioneries Limited. Also on the estate the Group has an electricity generating plant, producing 22MW of power for use on the complex with the excess sold to the Ugandan national grid. Narshibhai Naran Pankhania and family are well known in Kakira. The Madhvani estate at Kakira employs in excess of 7,500 people. The Madhvani Group also owns a private 100-bed hospital; Kakira Hospital and a private airport, Kakira Airport among others.

Litrature review

The United States Department of Energy estimated that the world carbon dioxide (CO2) emissions for 2005 were around 26.33 billion metric tons and were projected to increase to 30.20 billion metric tons by the year 2010. Therefore, as well as reducing atmospheric CO2 by the introduction of new methods of low emission energy production, carbon also needs to be sequestered by as many new and innovative methods as possible. Sequestration of carbon is currently largely dependant on existing forestry or hardwood plantations broadly described as 'woody plants'. However, the land area available for woody plant production has become limited due to the increasing demand for agricultural production. With this in mind a more recent approach has been to look at increasing the world's soil carbon stocks: these have been estimated to be around 2.4 g C m-2 yr–1 (Parr, Sullivan and Quirk, 2009).

Thus with a growing population and increased demand for food production, improving methods to store additional terrestrial carbon, in agricultural soils and degraded landscapes is a logical approach. Nevertheless, uniform results when quantifying soil carbon is not always easily achieved. This is largely due to differences in methodologies, the range of soil carbon fractions and rates of decomposition resulting in both spatial and temporal variability (García-Oliva and Masera, 2004). Moreover, the rigor necessarily required in soil carbon quantification can involve the collection of many samples and costly analyses (García-Oliva and Masera, 2004). An alternative approach to this is to quantify a carbon fraction before it is incorporated into the soil. One natural carbon process that can be calculated before it is integrated into the soil matrix is the phytolith occluded carbon (PhytOC) fraction produced by some plants (Parr and Sullivan, 2004, 2005). Previous studies have indicated that sugarcane is particularly efficient at this process (Sullivan and Parr, 2005, 2007). In their book they discussed the process of PhytOC production in plants, and how this carbon fraction can be increased and accurately quantified.

Phytoliths are found in many plants particularly grasses and are prolific in sugarcane which is grown on around 20 million hectares worldwide (FAO, 2001). Also referred to as 'plantstones' or 'plant opal', phytoliths are silicified cell structures that occlude carbon (Wilding *et al.,* 1967). The silicified epidermal cells of the leaf and stem within all grasses are particularly good at occluding carbon (Parr and Sullivan, 2005). This carbon fraction is likely made up of the internal cytoplasmic organic cellular material (Wilding *et al.,* 1967). Upon harvest in the case of crops, or at maturity with e.g. pasture or native grasses, leaf material is deposited onto the soil surface: phytoliths later become incorporated into the soil matrix during decomposition of the plant organic material.

The occlusion of carbon within phytoliths has been demonstrated to be an important long-term terrestrial carbon fraction (Parr and Sullivan, 2005) representing up to 82% of soil carbon in some buried soils after 2000 years depending on the overlying vegetation type and drainage regime.

Moreover, it has been demonstrated that relative to the other soil organic carbon fractions that decompose over a much shorter time scale, the carbon occluded in phytoliths is highly resistant against decomposition (Wilding *et al.,* 1967; Wilding and Drees, 1974; Mulholland and Prior, 1993; Parr and Sullivan, 2005).

The Sugarcane plant

Sugarcane (Saccharum Officinarum) belongs to the genus Saccharum which is a member of the family Gramineae in the tribe Andrpogoneae (Mukiibi, 2001). It is a tall perennial tropical grass which fillers at the base to produce unbranched stems, 3-4m or more tall, and on average 5cm in diameter. The stem is the economical part and is divided into a series of joints each consisting of a node and an internode. The buds are alternate on the stem and the leaf sheath envelopes the stem for considerable time. By harvest time there are 20-30 internodes on a single stem, each internode being 10-20cm long, depending on climate, edaphic factors and plant introduction. For example a stem might have short and thin internodes in its central portion, reflecting retarded growth during dry weather, and much longer and thicker ones which were developed during wet periods. Individual stems weigh between 500g and 2.0kg. The cane color depends on the variety and on exposure to the sun, which has a darkening effect (Mukiibi, 2001). The most common colors of canes are yellowish green and purple.

Figure 1: A growing sugarcane plantation on Kakira estates

Growth requirements

To do well, sugarcane requires an average rainfall of 1500mm/year well distributed over 9months (Mukiibi, 2001). However, the maximum amount of rainfall required differs considerably, according to the moisture retaining capacity of the soil and temperature levels. Sugarcane can survive normal variations in rainfall around a mean of 1200mm/year but lower rainfall are not suitable.

The growing season should be warm with mean day temperature of 28-30oc. temperatures below 20oc retard growth while those above 30oc reduce photosynthetic rate. Photorespiration increases with temperature. Cane appears wilted irrespective of water supply when temperatures approach 35oc and growth is curtailed. Low temperatures are the most effective means of ripening cane, counteracting adverse factors such as excessive moisture or nitrogen (Mukiibi, 2001).

Sugarcane flourishes on a great variety of soils ranging from the wind-blown sands of the coast of Natal to the heavy intractable clays found in parts of Jamaica. The most favourable soils are those having a superficial layer with average texture and porous subsoil (Blackburn, 1984). However, it has a special liking for light, deep, well aerated and well drained soil (Mukiibi, 2001).

In Uganda sugarcane is suited to large areas around Lake Victoria and according to Hansford (1924), in Mukiibi's book of 2001, it can be assumed that wherever elephant grass grows luxuriantly, it is more than likely that sugarcane will do well. On the other hand, it does not do well on ''murram'' soil.

Planting requirements

It is essential in cane growing to have separate plant nurseries individually tended. This entails rigorous crop protection measures, systematic programming of work and first class management. The seed canes are harvested at 8-10months and 12months at maximum because buds or eyes of older canes are more resistant to the longer hot water disinfection treatment that they require. Only sets from plant cane harvested in nurseries and planted the previous year, are planted.

Commercial fields are planted with plant cane from third stage nurseries. Third stage nurseries are planted with plant cane from second stage nurseries. First stage and second stage nurseries are situated in the centre of the plantation, near the set treatment station. Where as third stage nurseries are situated close to the commercial fields in which they will be planted (Mukiibi, 2001).

Husbandry

Land preparation involves clearing the forest and stump removal, building terraces or ridges to prevent soil erosion, grading the soil slope of the ground in preparation for irrigation by gravity, demolishing large termite hills and creating network of tracks and concrete structures such as bridges and tunnels.

Three eyed sets are planted in furrows at a depth of 20-30cm and 1.5m between the rows and covered with 5-7.5cm of soil. The planting material is obtained from either the harvested cane or from seed nurseries. The sets are planted in rows and they are placed end to end with a slight overlap. Gaps of more than 0.6-0.9m should be filled with sets at earliest opportunity to ensure that the shoots are not shaded out the more advanced growth of the original sets.

In Uganda, cane fields, can be planted at almost any time of the year, though it is best to avoid dry periods in uplands as the plants are then delayed in germination and early growth. The plants should be mature and ready for harvesting in 15-24months depending on the season and variety of cane.

The determination of maturity of a field of cane is one of the most important aspects in managing the plantation. After the boom period of growth, some of the stems change from the vegetative to the reproductive state and produce a reproductive inflorescence called ‘arrows’ or ‘tassels’. A more precise way of determining maturity is by using a hand refractometer which reads a Brix number. For a mature cane, the Brix should be about 20%.

Yields and Production trends

Relatively enormous yields are obtained during the first few years of cultivation after opening from bush or forest (Mukiibi, 2001). The highest tonnage so far recorded in Uganda was for a field on old forest land which gave an enormous crop of 272t/ha. However, the average yield on estates is 90-110t/ha. Yields of 40-60t/ha are considered low. It is expected that a tonne of sugar can be obtained from 11 to 12tonnes of cane although, better outputs have been achieved.

Sugar is the greatest traded commodity in the world in terms of volume and this trade Promotes massive large scale employment in growing the various crops, processing them into sugar, in trade and during consumption in the growing service industries.

Sugar manufacturing is also a relatively carbon neutral and environmentally friendly process, apart from transporting the raw or processed products from one destination to another.

One tone of sucrose (sugar) while being made in the sugar cane plant sinks 1.45 tonnes of carbon dioxide from the atmosphere.

Sugar production and consumption in Uganda and in the East African Community, while small in global terms, is vital to the local economy both in terms of employment and as a provision of taxes for government. However without care, this industry is vulnerable to forces that could make it uneconomic for continued performance in the region. This would be a pity to say the least.

Uganda is not and never will be amongst the lowest cost producers of sugar and therefore we must continue to exercise extreme caution when dealing with the economics of this sensitive product. There are opportunities and threats that need exploiting or mitigation against, not least is the regional treatment by Kenya of COMESA sugar and to a lesser extent but on the global scale are the WTO trade negotiations.

Kakira sugar works limited

Kakira sugar works started in 1930 with varieties like Co-421, Co-945 and Co-449 (Michaeldavis, 2008). The sugar factory has been expanded steadily and is currently operating at a crushing capacity of 6,000 tons cane per day during a 10.5 month crushing season. A confectionery factory within the complex also produces a variety of sweets and toffees and other confectionery items.

Sugar-cane is cultivated on the company's own nucleus estate of over 9,700 hectares (Ha) but the majority of the cane is supplied from 6,000 outgrower farmers with more than 18,000 hectares under cane, for production of 150,000 Tons of sugar per year - making this Uganda's largest sugar producer. To cater to the

needs of the agricultural development of Kakira, the Company established a sugarcane nursery for treated seed cane, a full fledged Agronomy Section with an Applied Research Centre.

Figure 2: Kakira Sugar factory (www.madhvanifoundation.com)

The Company employs over 7,500 people and has been responsible for the socio-economic development of this rural area.

In addition to direct employment, Kakira's activities support the local community – outgrower farmers, cane transporters, ancillary and support industries, etc. This has contributed significantly to the Ugandan Government's poverty alleviation programme. Including dependent families, Kakira Sugar Works provides the means of livelihood to over 75,000 people in the South Busoga region of Uganda.

Current Knowledge of Soil Organic Carbon

Soil organic carbon is of global importance as it is the largest carbon stock in most terrestrial ecosystems (Kiely *et al*. (2005; Eswaran *et al.,* 2000; Jobbagy and Jackson, 2000). Soil organic carbon is of local importance as it is an essential component (58%) of soil organic matter (SOM). It is composed of living biomass, detritus (recognizable dead biomass) and humus (non-living amorphous floral and faunal residues). These SOM 'pools' are the result of factors of soil formation, including climate, topography, parent material, biota, time and human activity (Jenny, 1941). The amount of SOM is determined by the balance between the input of surface litter into the soil profile and losses due to microbial decomposition, erosion and leaching. In mineral soils, high levels of SOM may indicate a fertile soil and the SOM typically decreases with soil depth. Soil organic matter acts a reservoir for nutrients by binding nitrogen, phosphorus, sulphur and other nutrients, and by forming aggregates that are necessary for soil structural stability. Nutrients are then made available to plants through mineralization. The current global stock of SOC is estimated to be

1500–1550 Pg (Batjes, 1996; Lal 2004; Post *et al*. 2001; Schlesinger, 1995), which is double the estimated amount in the earth's atmosphere (720 Pg), and more than triple the stock of organic carbon in terrestrial flora (Baes *et al.,* 1977; Bolin, 1970; Lal, 2004). Peat lands have a disproportionately large amount of soil organic carbon, accounting for a quarter to a third of the global SOC stock (Batjes, 1996; Eswaran *et al.,* 1993; Gorham, 1991; Post *et al.,* 1982), while occupying only about 3% of global land cover.

Even though SOC stocks are heavily influenced at the local scale by land use and management practices, regional and global trends do exist. The most obvious trend is the relationship of SOC to climate. Globally the average SOC stock (to 1 m depth) ranges from 50– 150 Mg ha-1, but can be as low as 30 Mg ha–1 in arid climates and as high as 800 Mg ha–1 in cold climates (Lal, 2004). Soil organic carbon is considered to increase as temperatures decrease and as precipitation increases. Soil organic carbon stocks double or triple for each 10 °C decrease in mean annual temperature (Kiely *et al*. (2005-S-MS-26-M1; Brady and Weil, 1996). Low rates of precipitation limit plant growth and therefore organic matter inputs to the soil. High rates of precipitation often create waterlogged soils, leading to slow decomposition rates, and hence the build-up of SOM. Stocks of carbon in undisturbed terrestrial ecosystems shift from the vegetation pool to the soil pool as one moves away from the equator.

Soil Potential for Carbon Accumulation

The amount of organic carbon stored in soil results from the net balance between the rate of soil organic carbon inputs and rate of mineralization in each of the organic carbon pools described in section 2.4. Schlesinger (1990) compiled data on long-term rates of soil organic carbon accumulation in Holocene age soils. He found a slow rate of carbon increase in soil even after thousands of years. This long-term increase represents accumulations of passive soil organic carbon fractions, which include charcoal and resistant compounds physically protected in organomineral complexes.

Schlesinger (1990) documented long-term rates of carbon storage from 0.2 g C m-2 y-1 in some polar deserts to greater than 10 g C m-2 y-1 in some forest ecosystems, with an average rate of 2.4 g C m-2 y-1 over all ecosystems. Schlesinger (1990) indicates that faster rates of change over short time periods are possible as a result of changes in environmental conditions.

When natural vegetation is converted to cultivated crops, rapid declines in soil organic matter are partly due to a lower fraction of non-soluble material in the more readily decomposed crop residues.

Tillage, in addition to mixing and stirring of soil, breaks up aggregates and exposes organomineral surfaces otherwise inaccessible to decomposers. This result in a reduction in the amounts of intra-aggregate LF-OC and some organomineral SOC. Losses of SOC of as much as 50% in surface soils (20cm) have been observed after cultivation for 30 to 50 years. Reductions, average around 30% of the original amount in the top 100-cm. The large and relatively rapid changes in SOC with cultivation indicates that there is considerable potential to enhance the rate of carbon sequestration in soil with management activities that reverse the effects of cultivation on SOC pools. The refilling of depleted fast turnover LC-OC pools and the active portions of the organomineral pools may result in much higher rates of SOC storage than the slow accumulation of passive soil carbon documented by Schlesinger (1990). Although the time period for high accumulation rates may be relatively short, years or decades, these accumulation rates are of significance for current soil sustainability and carbon management issues.

Carbondioxide conversion to organic matter

The process by which plants convert carbon dioxide into organic matter (Figure 2) is described by Batey, 1988.

The process of photosynthesis converts two chemicals - carbondioxide and water into simple carbohydrates, using sunlight as the energy source. The process takes place within the leaf and other green surfaces of plants. However, only part of the radiant energy from the sun is used in this way. At best, a plant can convert only about 6% of the total incoming solar radiation into stored energy. Water enters the plant mainly through the roots and brings with it essential nutrients.

Carbon dioxide enters as a gas, mainly through holes (stomata) on plant leaves. Stomata open in response to light, but close in the dark and in response to adverse conditions such as lack of water or high temperature. When a crop is growing vigorously and without constraints, a daily inflow, via the stomata, of over 150 kg/ha carbon dioxide is needed.

Water is lost from plants while the stomata are open sometimes over 100 t/ha each day.

In temperate climates, many crops increase their dry weight by about 200 kg/ha each day.

Up to 15% of all the carbohydrate fixed by the plant leaks from roots into the soil and is utilized by soil microorganisms within the rhizosphere.

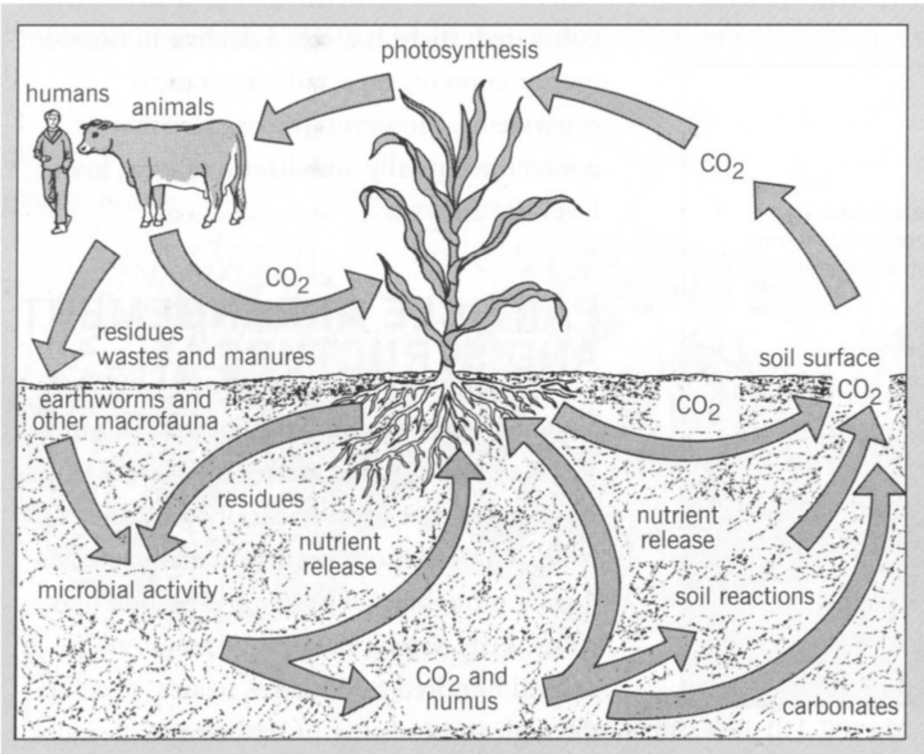


Figure 3: A simplified illustration of the carbon cycle in soil (Dubbin 2001); CO2 = carbon dioxide gas

CDM Application in Agriculture

It is well recognized that human emission of various greenhouse gases (GHGs), including carbon gases, have caused a global climate change, altered the atmospheric balance and led to a rise in global temperature. The potential impacts of climate change on human health, sea level rise, agriculture production, have become a public concern and pose serious risks for sustainable development. Human activities related to deforestation and the burning of fossil fuels and biomass has largely contributed to the increased emissions of carbon gases and other GHGs in the atmosphere. The average annual emissions of world carbon were estimated to be 7.1 billion tons per year during the 1980s.(IPCC, 1996)

Global carbon emissions from fossil fuels alone are estimated to be 5.5 billion tons per year and are likely to increase by 61% by 2015, compared to the base year of 1990. According to the annual forecast of the Energy Information Administration of the

USA, the global emissions of carbon dioxide (CO2) will reach 43.7 billion tons in 2030, up from 25 billion tons in 2003. In a word, climate change has become one of the most important and complex challenges facing humanity in the twenty-first Century.

Reducing GHG emissions by means of Clean Development Mechanism (CDM) under the

Kyoto Protocol is an important example of how market-based approaches can be brought to bear on this challenge. CDM approaches can be practically applied in the agricultural sector of developing countries in achieving sustainable agriculture and rural development, by helping reduce GHG emissions, mitigate climate change, promote sustainable natural resource management, and enhance natural resource resilience. However, the role of sustainable agriculture practices in both reducing GHG emissions and enhancing carbon sequestration has been neglected in the past because the Kyoto protocol had not yet addressed the close linkages between the land use change, agriculture and forestry activities and the Convention to Combat Desertification and Convention on Biodiversity (FAO, 2000). Later a decision was reached to recognize its role because the uncertainties regarding measurement of carbon fluxes – particularly in soils – were then too great and had to be resolved. It has now become well recognized that carbon sequestration is a viable option for capturing carbon under the Protocol and after a consultation in 1999, FAO proposed two options for reducing emissions through agricultural projects. First, increase the sequestration potential of forests and other land types in the soil and second, capture atmospheric carbon through increased vegetation cover and photosynthesis.

Registered projects and projects under validation

To date Uganda has not benefitted from the CDM at any meaningful scale. The West Nile Hydro Power Project (2003) is the only Ugandan project registered with the UNFCCC. However, during the past year eight projects have reached the stage of validation with the Designated Operational Entities (DOE's). Five of these projects are part of the same small scale forestry programme, two are cogeneration projects in the sugar industry, and one is a small scale hydro power project. An overview is given in Table 1 below.

Table 1: Registered projects or projects under validation

Project name	**Status**	**Type/ total CER's (10 years)**	**Methodology Used**
West Nile Electrification Project (WNEP)	Registered	Hydro, 580 kT	AMS-I.D.+AMSII. B.
Uganda Nile Basin Reforestation Project No.3	At validation	Reforestation, 77 kT	AR-AMS1
Kakira Sugar Works (1985) Ltd. (KSW) Cogeneration Project	At Validation	Biomass energy, 681 kT	ACM2+ACM6
Bugoye 13.0 MW run-of-river Hydropower project	At Validation	Hydro, 543 kT	AMS-I.D.
Uganda Nile Basin Reforestation Project No 1	At Validation	Reforestation, 88kT	AR-AMS1
Uganda Nile Basin Reforestation Project No 4	At Validation	Reforestation, 71 kT	AR-AMS1
Uganda Nile Basin Reforestation Project No 2	At Validation	Reforestation,64 kT	AR-AMS1
Uganda Nile Basin Reforestation Project No 5	At Validation	Reforestation, 100 kT	AR-AMS1
Bagasse Cogeneration Project Kinyara Sugar Limited (KSL)	At Validation	Biomass energy,801 kT	ACM6

Source: Econ Pöyry Report no. R-2009-068, 11 June 2009

Challenges to CDM Implementation in Uganda

Although CDM has been perceived as an opportunity through which developing countries can achieve sustainable development while at the same time helping to mitigate climate change, it remains unclear as to whether CDM will in fact deliver the much anticipated sustainable development benefits in light of the current global trends in CDM investments. By February 2007, only approximately 1.5% of the total registered projects were in Africa and one project was in Uganda. Developing PDDs is expensive and requires specialized expertise which is not readily available in Uganda. Currently, the DNA advises independent project developers to have their PDDs and PINs developed by experts in the department of Technology of Makerere University. Apart from the university and a few organizations, the remaining capabilities can only be found at individual level (Econ Pöyry, 11 June 2009).

Other opportunities Uganda can take advantage of

There is a very big potential for Uganda to benefit from CDM projects and besides the vast challenges, several opportunities that Uganda can exploit exist. Among others include those explained in the subsequent sections of this chapter.

CDM Programme of Activities (PoA)

The new Programme of Activities scheme under the CDM allows for bundling of small projects in order to significantly reduce CDM project development costs. For the case of sugarcane cultivation, it is possible to combine carbon sequestration with cogeneration using bagasse and charcoal briquette production

Wood-fuel accounts for 93% of the Uganda's' energy balance, and access to grid delivered electricity is still limited (FAO, 2000). This represents an enormous potential for energy efficiency measures. Efforts within energy efficiency are widely recognized as one of the lowest cost "sources" of energy. An example of an effective energy efficiency measure in Uganda would be to improve fuel efficiency in household cooking and small scale industries. Improvements here would mean that a lot of woody biomass could be saved for other purposes and is a cost-effective to invest in energy-efficiency improvements.

Reducing the Deforestation and Degradation, REDD

Uganda is endowed with areas of forests which are rich in biodiversity such as the Albertine Rift forest, Montaine Forests, Lowland Rainforests, Lake Victoria Mosaics, wooded savannas and lots of Wetlands. Uganda can become a model country in the World Bank initiated Forest Carbon Partnership Facility (FCPF).

Climate Smart Agriculture

Agriculture in developing countries must undergo a significant transformation in order to meet the related challenges of food security and climate change. Effective climate-smart practices already exist and could be implemented in developing country agricultural systems including Uganda (FAO, 2010).

The concept of "Climate Smart Agriculture" is gaining increasing popularity as a unifying concept on climate change and agriculture. It is being promoted by FAO with other partners such Climate Change Agriculture and Food Security Program (CCAFS) .First coined by FAO in 2009, it is defined as 'agriculture that sustainably increases productivity, resilience, reduces or removes Greenhouse Gases (GHGs), and enhances achievement of national food security and development goals' (FAO, 2010). In other words, Climate Smart Agriculture strategies are those that achieve the so called "triple wins" of adaptation, mitigation and development. Climate Smart Agriculture has been at the centre of many global conferences. For instance, it was promoted through the Error! Hyperlink reference not valid. on Climate Smart Agriculture and a global science conference held at Wageningen University in October 2011 and it was at the centre of the third Agriculture and Rural Development Day in Durban held on Saturday 3rd December 2011. The day showcased a number of examples of what Climate Smart Agriculture could mean in practice, including agro forestry and conservation agriculture.

However, climate smart agricultural practices to succeed for a long run will require not only funding but also strong political leadership, supportive and coherent government policies and strategies, land tenure arrangements that make investments worthwhile, and, importantly, access to markets and inputs. On the

other hand Climate Smart Agriculture presents an optimistic message of the future of agriculture in Uganda and Africa as a whole.

Methodology

This chapter presents methods and procedures that were used to collect and analyze data for the study. The main purpose was to achieve the objectives set by analyzing data to test the research hypothesis.

The study was carried out in Kakira sugar estates as a case study since it is one of the leading sugarcane growing and sugar producing companies in Uganda.

Data collection

Most of the data analyzed in this study is basically secondary data got from the agronomy department of Kakira sugar estates and what was missing was got from books, journals, the metrological department in the Ministry of Water and Environment, University and public libraries. The data was later summarized, processed and analyzed to draw conclusions.

The study area

The study area was Kakira sugar estates which is 10 kms from Jinja town on Tororo road. It lies on the northern shores of Lake Victoria and its landscape is made up of scattered hills - with the highest being 1,279m above sea level. On the map, it's Latitude – 00 30' North and Longitude – 330 17' East (www.madhvanifoundation.com/downloads/mgm-oct09.pdf). It is the location of the headquarters of the Madhvani Group conglomerate. On a 9,500 hectares (37 sq mi) estate, the Group owns a sugarcane farm and a sugar manufacturing complex, Kakira Sugar Works.

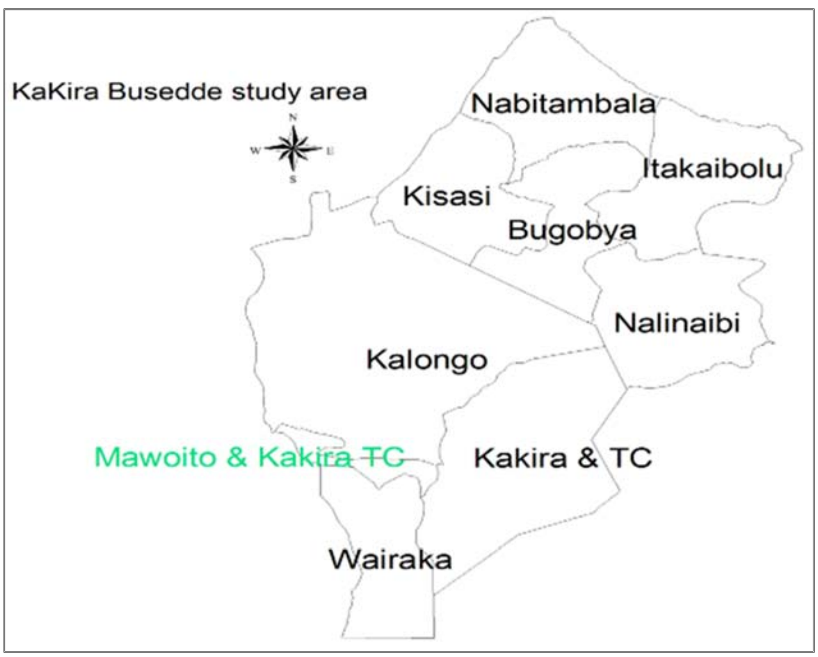


Figure 4: Map showing Kakira and its surrounding areas

Stakeholders' Analysis

Since carbon measurement is currently being debated at several levels to correctly address carbon markets, for instance in the agricultural and forest sectors, the estimations of SOM, carbon stocks and fluxes in sugarcane is targeted to greatly help scientists to monitor and predict sugarcane ecosystems' response to climate change, as well as aiding policy makers when taking land use and management decisions and assisting land managers to gain better access to carbon markets. Other stakeholders include Kakira sugar estate (the case study), commercial sugarcane out growers, Busitema University (most importantly the students in the Faculty of Environment and Natural resource economics) plus all the sugarcane growing and sugar producing companies that would wish to complement their enterprise benefits through carbon trading.

Table 2: Stakeholder Analysis

	Stakeholders					
power, Capacity &influence	Government	Sugarcane farmers	Sugarcane companies	Kakira Sugar estate	Busitema University	Soil Scientists
Adoption of the strategy	1	3	1	1	2	1
Direction of influence	2	3	2	1	1	1
Legal mandate	1	3	2	2	2	1
Technical know how	1	3	2	2	1	1
Financial resources	1	3	2	2	2	3
Research purpose	1	3	2	1	1	1
Total Score	7	18	11	9	9	8

1=High, 2= Medium, 3= Low.

Sample size

The study focused mainly on studying the carbon dynamics in four commonly grown sugarcane varieties on Kakira sugar estates (Co945, Co421, Co449 and R83-2065). These varieties occupy about 85% of the total cane area on the estate (Raju and Misango, 2011). One hectare was considered for each variety and the results got were later up scaled to account for the whole sugar estate of Kakira.

Selection of a carbon simulation model

The RothC-26.3 model published and recommended by the European Soil Organic Matter Network (SOMNET) (http://saffron.rothamsted.bbsrc.ac.uk/cgi-bin/somnet-models) was used in this study for simulating the dynamics of SOC and SOM turnover under the four sugarcane varieties, i.e Co945, Co421, Co449 and R83-2065, commonly grown in Kakira sugar estate(Raju and Misango, 2011). The reasons for the choice of the model are that it represents extremes of a gradient of accessibility, ease of use and having been upgraded to encompass a wide range of ecosystem variability, including crop ecosystems which sugarcane plantation is part.

Carbon stock of sugarcane as biomass

The carbon stock for each of the four sugarcane varieties was calculated as biomass and it involved multiplying each variety's biomass by a conversion factor that represents the average carbon content in biomass. The coefficient of 0.55 for the conversion of biomass to C, offered by Winrock (1997), was generalized here and applied in converting sugarcane biomass to carbon stock.

C = 0.55 × biomass (total). This coefficient was found appropriate in this research paper because it is widely used internationally. Later an average carbon stock as biomass for all the four varieties was calculated.

Total carbon present in sugarcane

The estimation of total C present in sugarcane included the carbon stock as biomass and the SOC present in the SOM. This estimation consisted of converting the SOM value reported at Kakira sugarcane estate to SOC. For estimation purposes, a generic coefficient of 0.57 suggested in the FAO corporate document repository by Natural Resources Management and Environment Department in assessing carbon stocks and modeling win-win scenarios of carbon sequestration and recommended for application in agricultural lands was assumed in order to transform SOM to SOC.

Multiplying the values of SOM by this coefficient and then transforming them from percentage values to tones per hectare was done by computing a weighted average of SOM over the layers of the analyzed soil profiles that represent each soil mapping unit. The weights correspond to the thickness of each horizon multiplied by its soil bulk density.

Simulation modeling of carbon dynamics in soils

Carbon dynamics was modeled using the RothC-26.3 model that computes the changes in organic C, partitioned into five basic compartments: inert organic matter (IOM), decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO) and humified organic matter (HUM).

Incoming plant C was split between DPM and RPM, depending on the DPM/RPM ratio of the particular incoming plant material. That is 59 percent for DPM and 41 percent for RPM (http://www.fao.org/docrep/007/y5490e/y5490e01.htm#TopOfPage).

Input variables required to run the model

The data required to run the model include the following;

Rainfall and open pan evaporation that was used to calculate topsoil moisture deficit (TSMD), as it was easier to obtain rainfall and pan evaporation data, from which the TSMD was calculated, than monthly measurements of the actual topsoil water deficit.

The air temperature (in degrees Celsius) was used rather than soil temperature because it was more easily obtainable for most sites.

The clay content (in percent) will be used to calculate how much plant available water the topsoil can hold; it also affects the way organic matter decomposes.

The DPM/RPM ratio will provide an estimate of the decomposability of the incoming plant material.

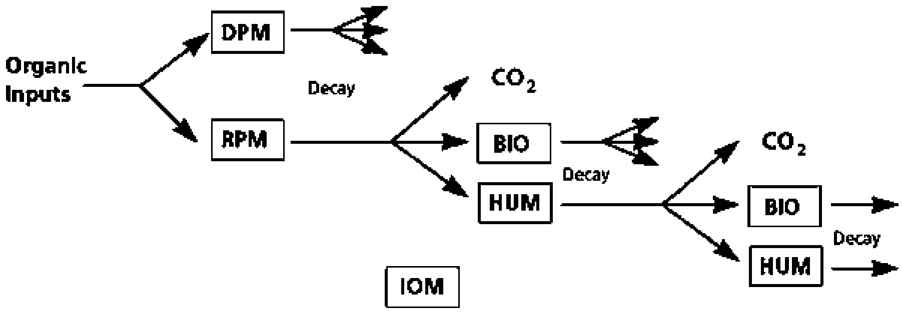
The plant residue input which is the amount of C (tonnes per hectare) that is put into the soil per month, including C released from roots during crop growth. As this input is rarely known, the model will be run "in reverse", generating input from known soil, site and weather data.

Depth of soil (cm).

Apparent density of the soil (bulk density).

Model structure

Soil organic C will be split into four active compartments and a small amount of IOM as recommended for the model. The four active compartments will be: DPM, RPM, BIO and HUM. Each compartment decomposes by a first-order process at its own characteristic rate. The IOM compartment is resistant to decomposition. Figure 9 shows the structure of the model.



RPM: resistant plant material
DPM: decomposable plant material
BIO: microbial biomass
HUM: humified organic matter
IOM: inert organic matter

Figure 5: Partitioning of the basic components of organic matter in the soil inRothC-26.3 (after Coleman and Jenkinson, 1995a**)**

Since the study was looking at a growing sugarcane plantation, an active hectare of sugarcane was assumed and if it contains Y tones of C, this declines to Ye-abckt tones of C at the end of the month.

where: a is the rate modifying factor for temperature;

b is the rate modifying factor for moisture;

c is the plant retainment rate modifying factor;

k is the decomposition rate constant for that compartment; and t is ½ , as k is based on a yearly decomposition rate. Thus, Y(1 - e-abckt) will be the amount of the material in a hectare that decomposes in a particular month.

According to Coleman and Jenkinson (1995a), the decomposition rate constants (k) in per year values for each compartment are set in RothC at: DPM = 10.0, RPM = 0.3, BIO = 0.66 and HUM =0.02 and the same values were adopted.

As variations in soil and climate conditions become modifying factors of the default decomposition rates suggested by the model. In order to cater for the different conditions of soil and climate, the decomposition rates needed modification. And these were calculated as below;

The rate modifying factor (a) for temperature was calculated using the formula below;

$$a = \frac{47.9}{1 + e\frac{106}{\text{tm} + 18.3}}$$

where tm is the average monthly air temperature (degrees Celsius).

The soil moisture deficit (SMD) rate modifying factor (b) was calculated from the 2011 Kakira estate yearly weather data got from the Agronomy department. The maximum SMD was first noted and the SMD later calculated following the guidelines of FAO (http://www.fao.org/docrep/007/y5490e/y5490e01.htm#TopOfPage). Next, the accumulated SMD was calculated from the first month when evaporation exceeded rainfall until it reached the maximum SMD.

Finally, the rate modifying factor (b) used each month was calculated from the following rule:

if acc. SMD < 0.444 max. SMD,

b=1.0

otherwise

$$b = 0.2 + (1.0 - 0.2)\mathbf{x} \quad \frac{(\text{max.}\,\mathbf{SMD} - \mathbf{acc.}\,\mathbf{SMD})}{(\text{max.}\,\mathbf{SMD} - \mathbf{0.44}\text{max.}\,\mathbf{SMD})}$$

The plant retainment factor (c) slows decomposition where growing plants are present. Where soil is vegetated, c = 0.6. Where soil is bare, c =1.0.

Carbon Stock of Undisturbed Soil

This was estimated by taking soil bulk density measurements. It was intended to aid the determination of baseline soil organic carbon so that the ability of sugarcane varieties to add organic carbon to the soil is assessed. Due to financial constraints, it was hard to re-measure the bulk densities at different layers. Therefore, the bulk densities of undisturbed soil at different depth were got from the agronomy department and undisturbed soil at the estate. These were calculated after taking field soil samples using a soil auger, getting their volume, drying them and weighing them. The bulk densities at different layers were calculated from the formula below;

$$\mathbf{D} = \frac{\mathbf{M}}{\mathbf{V}}$$

Where D is bulk density, M is weight of the soil sample and V is the volume.

Having got the undisturbed bulk density together with the percent carbon, the baseline SOC was calculated using the formula according to Peter Donovan (April, 2012) given below;

T = CF x D x V

Where CT is total carbon for the layer in metric tons, CF is the fraction of carbon

(Percentage carbon divided by 100), D is density, and V is volume of the soil layer in cubic meters. The results in both methods will be upscaled to a hectare level.

Soil organic carbon added in the soil by sugarcane

This was calculated without accounting for additions of FYM in order to be able to quantify the total carbon stocks in sugarcane land for every variety in question. A general formula below, as given by Coleman and Jenkinson (1995a) was used.

ms = [(Pai × Cci) - Hi] × Eai

where; Pai are the crop yields, Cci is the harvest intensity ratio (percent of total biomass that is harvested and removed), Hi is the moisture content in plant tissue of that species, and Eai is the crop residues including roots, as a percentage of total plant biomass and ms is the SOC added in the soil by sugarcane.

Integrating the assessment of total carbon stocks to carbon sequestration potential

This related to the assessment of carbon stock aboveground and belowground. Simulation models were used to predict the turnover of SOC in SOM at different time periods and with the values for carbon stocks, the carbon accounting process was completed.

Total carbon stock for Sugarcane

For carbon accounting purposes, the total carbon stock per hectare of sugarcane was calculated from:

$$C_{stock\ total} = C_{ag} + C_{bg}$$

$$C_{bg} = C_{bg-biom+} \ C_{soil}$$

$$C_{stock\ total} = C_{ag} + (C_{(bg-biom+)} \ C_{soil})$$

Where $C_{stock\ total}$ is the total stock of C in the sugarcane ecosystem, including aboveground (C_{ag}) and belowground (C_{ag}) pools. The constituents of the belowground pool are the carbon content in roots and all belowground biomass ($C_{bg-biom}$) and the C in the soil (C_{soil}) as organic C in SOM.

The values of $C_{stock\ total}$ after the estimation of aboveground biomass, its conversion to C, the estimation of C in belowground biomass (roots, etc.), and the modelling of SOM turnover to establish SOC were calculated for a hectare of sugarcane.

The calculated carbon stock values were implicitly believed to assume permanence of the present land-use pattern in the area of study.

Below ground Carbon in sugarcane biomass

Since the above ground carbon for every variety was already calculated as carbon in above ground biomass, the below ground carbon in sugarcane biomass, NB(t) i per hectare for every variety was calculated by multiplying the respective above ground carbon by the root to shoot ratio of 0.25 as given by FAO.

NB(t) i=T(t) X R

where:

NB(t) i = Carbon stocks in below-ground sugarcane biomass at time t (t C/ha)

T(t) = Above-ground carbon in sugarcane biomass

R = Root to shoot ratio (t d.m./ t d.m.)

Carbon sequestration attributable to sugarcane growing

Having assessed the estimates of carbon stock for the sugarcane and the carbon sequestration implicit in sugarcane, a comparison of estimates between baseline and potential carbon stock per hectare for each variety was made. The simple balance was established in algebraic terms by:

Carbon sequestered = potential carbon stock(total) - actual carbon stock(total)

Where the potential carbon stock corresponds to the C in sugarcane and the actual carbon stock corresponds to SOC before the sugarcane project. This comparison yielded the gains or losses in carbon stock resulting from implementing the sugarcane project.

Economic Implication of Carbon Sequestered by Sugarcane

This was illustrated through multiplying the amount of carbon sequestered by sugarcane (in tons) by the per unit global market price of carbon. It was on the results obtained here that conclusions were based as to whether sugarcane plantation farming is a viable CDM project in Uganda, putting in mind all the required input costs. The gross total benefit was got as shown below;

Total benefit = Canerevenue + CDMrevenue

Testing for data validity

Before analysis, data was inspected for validity since the study was based on secondary data. Co-efficient of variation was calculated to check for precision and accuracy as follows;

$$CV = \sigma \div \mu$$

Where CV is co-efficient of variation

σ is standard deviation

μ is mean

Good quality data was judged according to United states EPA (July,2000) guidance for data quality assessment where, data with CV below 10% is good enough and data with CV above 10% but below 20% may be used but not the best.

Data processing and analysis

Data was summarized into tables and analyzed using Excel. The results were illustrated using graphs and formulas for easy interpretation and discussions to draw conclusions.

Results and discussions

This chapter presents the key findings of the study. It starts with findings on the carbon stocks of sugarcane as biomass per hectare with respect to the four of the common varieties grown in Kakira sugar estates (Co945, Co421, Co449 and R83-2065), and goes ahead to look at the total carbon present in sugarcane. It also covers analysis on the carbon leakages in growing sugarcane, baseline soil carbon stocks (undisturbed soil), sugarcane monthly organic matter contribution to the soil, total carbon stock per hectare of sugarcane plantation, carbon sequestration attributable to sugarcane growing and the economic implication of carbon sequestered by sugarcane.

Biomass and Carbon stock of Sugarcane

Efforts were taken to look at how carbon and biomass stocks vary among the four varieties of sugarcane considered in the study. This included only the above ground biomass of sugarcane and the results were as shown in Table 3 below;

Table 3: Biomass and Carbon stocks with respect to Sugarcane varieties

	:Sugarcane Variety					
	Co945	Co421	Co449	R83-2065	Average	STDEV
Cane weight(tc/ha)	119.84	119.18	138.20	115.90	123.28	10.09
% Biomass	75.64	71.71	72.87	74.24	73.61	1.70
Carbon Stock(Tc/ha)	65.91	65.55	76.01	63.75	67.80	5.55

STDEV = Standard deviation

From the Table, the co-efficient of variation for cane weight and percentages were calculated as 8.2% and 2.3% respectively. Both co-efficients are less than 10% making the data good enough to use for further analysis.

As indicated in the Table 1 above, different sugarcane varieties have different biomass composition and so is the case with carbon stocks. Co449 has the highest carbon stock as biomass, followed with Co945, then Co421 and finally R83-2065 although Co945 has the highest percentage of biomass in relation to the total cane plant (if trash and tops are put into consideration), followed by R83-2065. The reason for this is that Co449 contains a higher percentage of tops and trash compared to Co945 and R83-2065. On average 73.61% of the sugarcane is biomass and the differences with respect to varieties were illustrated as in the figure 6 below;

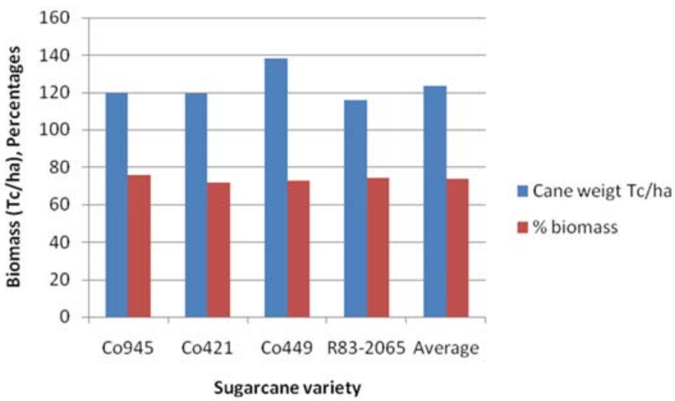


Figure 6: A histogram showing sugarcane biomass with respect to varieties

As seen in Table 3 biomass content is directly related to carbon stocks that is, the higher the biomass, the higher the carbon stock for a sugarcane variety. This explains why Co449 has the highest carbon stock in relation to above ground biomass (76.01Tc/ha). This could partly be explained by the higher cane yield per hectare produced by Co449 compared to other varieties besides other biological, chemical and climatic factors (like the genetic make up of a sugarcane variety, the parentage, soil mineral composition, temperature and rainfall). Figures 7 illustrate the variations of carbon stocks for the four varieties.

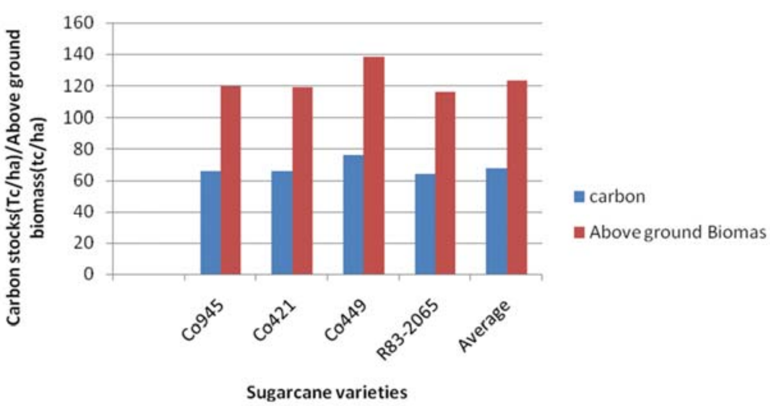


Figure 7: A histogram showing the Carbon stocks with respect to Sugarcane aboveground biomass

As it will be seen later in Table 4, Co449 despite having a higher top and trash percentage compared to Co945 and R83-2965, it still stocks more carbon due to relatively higher cane yield per hectare and so higher tons of carbon per hectare. This suggests that for both economic and carbon sequestration purposes, it is

essential to make an appropriate variety mix of all the varieties to come out with an optimal out put of both.

Carbon stock of undisturbed soil (Baseline)

To be able to understand the additions of carbon in the soil by sugarcane, it is important to first know how much carbon there is in the soils of the study area. The baseline soil carbon was determined from soils of the estate on which sugarcane was not grown. It was calculated using the average bulk densities and percentage organic carbon of the soil.

Table 5: Bulk densities and Organic matter of the soil at different depth

Particulars	Units	Depth (cm)			Average	STDEV
		0-10	**10-30**	**30-50**		
Moisture	%	3.5	3.3	2.5	3.1	0.53
Weight/Volume ratio	g/cm3	1.08	1.14	1.06	1.09	0.04
Organic Carbon	%	2.29	1.62	0.50	1.47	0.90
Undisturbed bulk density	g/100g	1.10	1.08	1.27	1.15	0.10

From Table 6, the co-efficient of variation for undisturbed bulk density at varying depth was got as 8.6% which is with in the good range for quality data to analyze.

The total SOC at different layers (0-10cm, 10-30cm and 30-50cm) were calculated and the results were summarized in a Table as indicated below;

Table 6: Soil carbon stock at varying depth

Depth	SOC (Tc/ha)
0-10cm	25.19
10-30cm	52.49
30-50cm	31.75
Av.	36.48

It can be seen from the Table above that carbon accumulation varies with the depth of the soil. SOC stock in the top layer (0-10cm) is lower than that of 10-30cm (25.19Tc/ha and 52.49Tc/ha respectively). Although there may be other factors leading to this difference, the major reason is that there is a great anthropogenic interference of the soil top layer in terms of cultivation leading to continuous losses in SOC (Sanderman, Farquharson and Baldock, 2010). The results are different but with in the rage of 10.1 to 104.7 got by Baldock (2008) in Mckenzie book (2010) for Eastern Australian dairy regions. For the carbon that is sequestered to the sub-surface (10-30cm), remains relatively stable in the carbon mineral compounds, enabling it to accumulate more in that layer. Depending on the prevailing factors that may influence the bio-geochemical carbon cycle with time, reductions and additions in soil carbon stock continue to the deeper layers mimicking the real process that leads to formation of fossil fuels. To increase carbon stock in the soil requires appropriate techniques to enhance carbon sequestration to the deeper layers of the soil. The dynamics of SOC accumulations are clearly illustrated on a graph in figure 5.

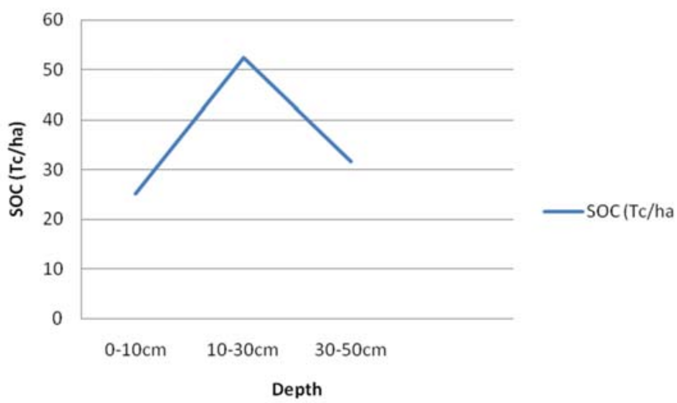


Figure 8: A graph showing the Soil carbon stocks at varying depth

On average, soil stores 36.48tons of carbon per hectare. Soil is a naturally occurring sink for carbon and if enhanced can store it indefinitely for a considerable duration.

Total Carbon Stock for Sugarcane

Total carbon stock per hectare of the four different sugarcane varieties was calculated using an equation that combines the above ground biomass, below ground biomass and the SOC stocks.

The carbon in below ground sugarcane biomass for every variety was calculated by multiplying the respective above ground carbon by a root shoot ratio (R) of 0.25 (www.fao.org), as shown in the Table 6.

Table 6: Below ground Carbon stocks according to Sugarcane varieties

Sugarcane variety	Carbon stock in AG (Tc/ha)	Carbon stock in BG (ABx0.25)
Co945	65.91	16.48
Co421	65.55	16.39
Co449	76.01	19.00
R83-2065	63.75	15.94
Average	67.80	16.95
STDEV	5.55	1.39

AG = Above ground
BG = Below ground

Variety-wise soil organic carbon added in the soil

SOC additions in the soil for every sugarcane variety (Co945, Co421, Co449, and R83-2065) were calculated from the formula indicated in 3.9.1.

SOC additions for Co945

This was done from the Table according to Raju and Misango (2011) on variety-wise partitioning of biomass. From this Table also, the moisture content of the sugarcane plant tissues was found out to be 65.01%.

Table 7: Variety-wise partitioning of bio-mass (plant + 2 ratoons)

Crop cycle	Cane weight		Tops + Trash weight	% over Total
	tc/ha	%	t/ha	
Co945	119.84	75.64	38.60	24.36
Co421	119.18	71.71	47.04	28.29
Co449	138.20	72.87	51.46	27.13
R83-2065	115.90	74.24	40.22	25.76
Average	123.28	73.61	44.33	26.39
STDEV	10.09	1.70	5.99	1.70

Source: Raju and Misango (2011)

Form the Table 7 above, Pai = 119.84

The harvest intensity ratio, Cci was calculated as 3.11 and Hi as 103.00. The crop residues, including roots, as a percentage of total sugarcane biomass, Eai was found out to be 72.21tc/ha and the SOC added in the soil, ms, got as 11601.28Tc/ha. This value can be divided by the number of months the sugarcane stays in the garden to account for monthly additions of carbon. The details of the working are indicated in appendix 2.

$C_{stock\ total}$ *per hectare of Co945*

This was calculated by summing up the carbon in above ground biomass, the carbon in below ground biomass and the SOC was got as 11683.67Tc/ha.

The $C_{stock\ total}$ per hectare for the other varieties were calculated following the same procedures as for Co945 and all the results were as indicated in Table 8.

Table 8: Variety-wise SOC added in the soil and total carbon stocks per hectare

Variety	SOC added (Tc/ha)	$C_{stock\ total}$ (Tc/ha)
Co945	11601.28	11683.67
Co421	9484.57	9566.51
Co449	13512.68	13607.69
R83-2065	10125.46	10205.15
Average	11144.81	11229.56
STDEV	1789.36	1795.52

The co-efficient of variation for SOC added and $C_{stock\ total}$ were respectively calculated as 16.1% and 15.9%. These are above 10% but below 20% hence with in the acceptable limits.

As seen from Table 8, carbon storage differs according to varieties indicating that different sugarcane varieties have different abilities to sequester carbon in the soil. Co449 has the highest capacity to add organic carbon to the soil, followed by Co945, then R83-2065 and lastly Co421. These variations are shown on the graph below;

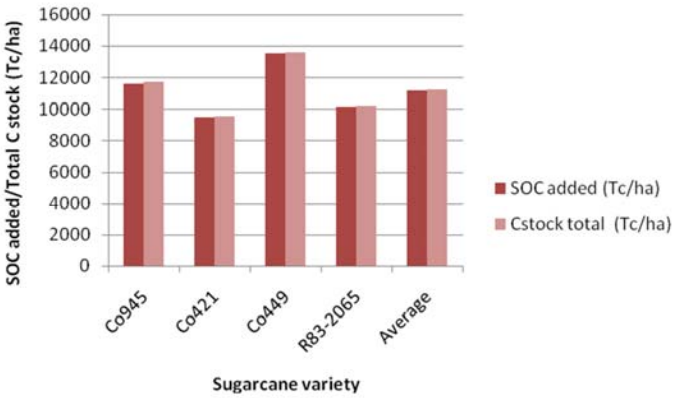


Figure 9: A histogram illustrating the variations in SOC addition and storage for different sugarcane varieties

The variations are partly due to their varying productivity and yield relative to the prevailing soil and climatic conditions and due to the varying chemical and biological composition of each variety that gives them different abilities to cope up with the changing climate. The above results though different from Moundzeo et-al (2011), show that sugarcane when grown under conservation practices add considerable amount of carbon in the soil, agreeing with his argument and that of Parr and Sullivan (2005).

Carbon sequestration attributable to sugarcane growing

Simulations were made to come up with the carbon sequestered by sugarcane varieties so as to be able to ascertain the economic implication of the sequestration potentials. From Table 4.7, average total carbon stock of sugarcane per hectare is 11229.56Tc/ha. If I consider a 19months ratoon, monthly carbon stocks per hectare will be 11229.56 divided by 19 which will give 591.03Tc/ha/month. This implies that sugarcane sequesters a lot of carbon in the soil as it grows. The result is higher than 99.4T/ha obtained by Antonio et-al (2009) in Brazil and indicates that carbon sequestration in crop lands can be higher than that under forest if compared with the 152-234tonnes/ha got by UNEP-WCMC (2010) for biodiversity and ecosystems in Uganda. This confers with Mckenzie (2010) observation.

Carbon sequestered

This was calculated using the RothC-26.3 mode of partitioning the basic components of organic matter. The organic carbon lost during decomposition was calculated and from the RothC-26.3 model, if an active land use contains Y tons of carbon at the beginning of the month, then the amount of material that decomposes in a month per hectare is given by Y(1 - e-abckt)

The rate modifying factor; afor temperature, b for moisture and c for plant retainment were calculated using the 2011 annual weather data that was summarized in the Table in appendix 3. The decomposition rate constant,k, for HUM was taken as 0.02 as given by Coleman and Jenkinson (1995a). The sugarcane plantation was considered vegetated and c taken to be 0.6 and the acc. SMD was found out to be less than 0.444 max. SMD. Therefore b was taken to be 1. The rate modifying factor; a for temperature was calculated using the formula indicated in section 3.8 and found out to be 7.78

tm (average monthly air temperature) was calculated as 46.170c

When 46.17 was substituted for tm in the formula, a was got as 7.78.

Therefore the organic carbon that decomposes = 591.03(1-e-abckt)

Substituting for e, a, b, c, k and t, gave the answer as 5.91Tc/ha/moth

Carbon sequestered = 591.03- 5.91

= 585.12Tc/ha/month. This means with the necessary land use practices, sugarcane is capable of sequestering up to 585.12Tc/ha/month and if registered as a CDM project is capable of generating good revenue for the investor.

Validation of results

For comparison purposes sequestered carbon per month was recalculated from;

Carbon sequestered = potential carbon stock(total) - actual carbon stock(total)

Where the potential carbon stock corresponds to the C in sugarcane and the actual carbon stock corresponds to SOC before the sugarcane project.

From Table 4.7, potential carbon stock(total) is 11229.56Tc/ha and baseline SOC was calculated as 36.48Tc/ha.

Carbon sequestered = 11229.56 – 36.48

= 11193.08Tc/ha

Monthly sequestered carbon = 11193.08 ÷ 19 (19 is the average number of months for a ratoon)

This gave an average answer of 589.11Tc/ha/month for every variety which only differs from the first approach by 2.01Tc/ha/moths.

The productivity and total carbon stock however can be enhanced with good agronomic practices irrespective of the variety as evidenced by the use of farm yard manure in some Kakira estate field as shown below;

Table 9: Effect of green manure on sugarcane productivity and yield

Crop cycle	GM	No GM	GM P	No GM P
	Yield(tc/ha)	Yield(tc/ha)	tc/ha/m	tc/ha/m
Plant	125.29	112.15	5.94	5.16
Ratoon 1	95.26	92.43	5.79	4.96
Ratoon 2	92.37	84.56	5.01	4.76
Average	104.31	96.38	5.58	4.96
STDEV	18.23	14.21	0.49	0.20

Source: Raju and Misango (2011)

Higher productivity and yield eventually leads to higher total carbon stored and sequestered by the sugarcane crop. The changes in yield and productivity indicated in Table 4.7 are illustrated in figure 10.

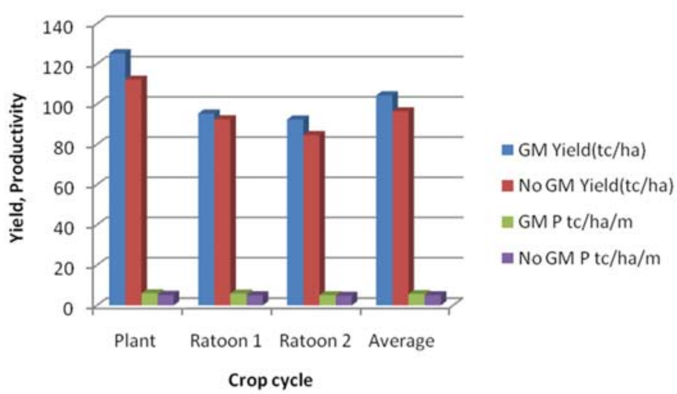


Figure 10: A histogram showing the effect of green manure on Sugarcane productivity and yield

Economic implication of sequestered carbon

Taking the price per ton of carbon to be $23 as stated by www.energyaustralia.com.au (19/05/2013 at 2:32 PM), and if 9,700ha for Kakira sugar estate are considered, then if 589.11tons of carbon are sequestered per ha per month, the whole estate will generate 5,714,367tons of carbon per month. Consequently, the estate has a capacity to earn a gross amount equivalent to 23x5, 714,367 other factors kept constant. This gives a total gross amount of $131,430,441. This when added to the cane revenue boosts the farm total revenue and consequently sugarcane cultivation profitability. For instance, the revenue from carbon sequestered, if was down scaled to hectare level and gave $13,549.53 per hectare. When an average cane yield of 123.28tc/ha was considered and multiplied by 70,000/= (price of sugarcane per tonne, estate price), the cane revenues came out as 8,629,600/= per hectare or $3,082 ($1 was considered to equal to 2,800/=).

The gross total farm revenue was calculated as $16,631.53 per hectare.

Summary of findings, conclusions and recommendations

The summary of findings, conclusions and policy recommendations to the management of Kakira sugar estates limited as well as other stake holders like Busitema university and the government of Uganda plus other academicians including socio-economic, environment and natural resource researchers who may wish to find out further carbon sequestration potentials in agricultural lands.

Summary of findings

From the research, it was found out that sugarcane grown in Kakira estates contain on average 73.61% biomass of which 75.64% is for Co945, 71.71% is for Co421, 72.87% is for Co449 and 74.24% is for R83-2065.

It was also found out that average total soil carbon of undisturbed soil in Kakira estates is 36.48Tc/ha got by calculating and averaging carbon stocks of undisturbed soil at three different layers.

The research again realized that on average total carbon stock of a sugarcane plantation per hectare was 11,229.56Tc/ha. For Co945, it was 11,683.67Tc/ha, Co421 had 9,566.51Tc/ha, Co449 had 13,607.69Tc/ha and 10,205.15 for R83-2065.

Finally from the study, it was found out that carbon sequestered per hectare per month by sugarcane grown in Kakira sugar estate ranged between 589.11 and 591.12Tc/ha. This is higher than that got by Moundzeo

et-al (2011), 80Tc/ha for R570 and Co997 in Niari Valley in Congo. The carbon sequestration differences of several varieties of sugarcane could probably come from the practices used in the different industrial plantations, from rain variability to which Niari Valley is subjected (Moundzeo et-al, 2011) and from genetic values of the different varieties which affect their abilities to photosynthesize.

Conclusions

The results got indicated that the sugarcane grown in Kakira estates has the potential to sequester between 589.11 and 591.12tons of carbon per month per hectare which when removed from the atmosphere and sequestered contributes significantly to climate change mitigation hence the first null hypothesis was rejected.

Considering the trends of global carbon market prices which are increasing, sugarcane grown in Kakira estates if accompanied with good land use and land management practices that enhance carbon sequestration, can potentially sequester carbon and generate significant certified emission reduction credits sellable under clean development mechanism. Therefore, the second null hypothesis was also rejected.

Carbon sequestration in sugarcane is a viable CDM project under the Kyoto protocol. This conclusion agrees with Moundzeo et-al (2011) conclusion. It can be recognized that sugarcane plantations during the growing phase are of paramount importance in the struggle against climate change because of their capacity of carbon sequestration. Their potential to be used in making bio-fuel is also important regarding the implementation of CDM projects under the Kyoto agreement.

Recommendations

Kakira sugar works limited, by the fact that it has high sugarcane acreage, should exploit the potential to increase its profit margins from sugarcane growing as a CDM project. This if combined with the bagasse co-generation can yield good profits and if outgrowers are brought on board at the same time can help enhance their incomes while helping mitigate climate change.

It was realized that carbon sequestration potentials are affected by land use practices. Therefore, it is necessary to enhance carbon sequestration by agricultural crops like sugarcane through burying the biomass remains in form of trash and tops in the soil instead of slashing and burning it. This increase soil organic carbon storage and help improve soil health.

Literature still states that the major draw back for most potential CDM projects in Uganda and Africa as a whole is lack of institutional capacity. It is necessary to build institutional capacity to successfully facilitate the implementation of carbon sequestration projects. The DNA established should serve as the point of contact between international investors and local service providers.

Kakira sugar works and Uganda as a whole should promote proper land use planning and management practices to build up carbon stocks in the soil by increasing the input of organic matter to the soil and/ or decrease the rates of soil organic matter decomposition. These practices may include a combination of the following; tillage methods and residual/stubble management; soil fertility and nutrient management; erosion control, crop selection and rotation.

The National Adaptation Plan of Action for Uganda which was launched in 2007 (Isabirye, 2011), need to be revised to incorporate carbon sequestration in agricultural activities as one of the national climate change adaptation and mitigation strategies.

This research was done under limited time and financial constraint and was the first in Uganda. There is need to research further on sugarcane sequestration potentials including other varieties which have not been captured in this study plus other agricultural crops to enable the building of a strong information bank for policy makers, investors, natural resource and environmental scientists as well as future academicians.

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Evaluation of potential of tree tomato production and marketing in eastern Kenya for improved nutrition and food security

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Abstract

Agriculture in Kenya continues to be the mainstay for the majority of the rural communities. The Agriculture sector constitute of six sub-sectors namely food crops, livestock, industrial crops, fisheries, forestry and horticulture. Among these sub-sectors, horticulture is the largest and contributes to 33% of the GDP and 38% of the export in Kenya. Fruits, vegetable and flowers contribute to the growth of this sector. A tree tomato (*Solanum betaceum*) is scantly grown in Kenya and is used as fresh fruit, juice and in food processing industry. The study was carried out in order to understand the socio-economic and biophysical environment of tree tomato, understand production and marketing potential and identify the main tree tomato production and marketing constraints. A sample of population of all tree tomato producers of Embu County was done in representative sites of Tea-Dairy and Coffee-Dairy Agro-ecological zones in Embu County. A random sampling to select 30 households in each AEZ, to constitute a sample size of 60 households was conducted and information gathered using a structured questionnaire. Results indicated that most of the farmers are either intercropping tree tomatoes with other crops like maize and beans (59%) or planting them in a scattered form within the farm (32%). Main production constraints were pests (20%), diseases (24%) and moisture stress leading to drying up (9%) among others. Most of the farmers (77%) in the study area who sell their tree tomato fruits in the market do not experience any low market demand Study indicated that the main objective of tree tomato production is for household consumption and the proportion of farmers who are producing for both household consumption and market is increasing. This implies that tree tomato has a potential as an economic enterprise and needs to be promoted.

Key words: tree tomatoes (*Solanum betaceum*), underutilised fruit, production, market.

Introduction

The status of tree tomatoes in Embu County

Agriculture in Kenya continues to be the mainstay for the majority of the rural communities. The sector contributes 28% of the gross domestic product as indicated in the world bank report of 2011.

According to IFAD (2011), 79% of the total population live in the rural areas and heavily relies on agriculture for their livelihood. Horticulture in Kenya constitutes of six sub-sectors namely food crops, livestock, industrial crops, fisheries, forestry and horticulture. Among these sub-sectors horticulture is the largest and contributes to 33% of the GDP and 38% of the export of Kenya (GOK, 2010). The sub-sector has received a lot of attention (Vision, 2030; GOK, 2010) over the past decade due to its steadily and sustained growth in terms of its export to Europe (Muendo and Tschirley, 2004). Production of horticultural crops offers an alternative for increased food self sufficiency improved nutrition, generation of income, as well as creation of employment (Ganry,2007; Ganry, 2009).

According to Kenya's poverty eradication strategy paper (PRSP) poverty is perceived as inadequacy of income and deprivation of basic needs and rights, lack of access to productive assets as well as social infrastructure and markets (Republic of Kenya, 2001). Alleviation of poverty and promotion of food security within the farming communities is a major concern in the world today (NAFRP, 1999). Poverty has mostly been associated with, although by no means limited to, certain forms of occupations such as small holder farmers and has been cited as a major cause of food insecurity. In order to diversify the use of sources of income besides coffee and tea, intensification of fruit production contribute for local and international market remains a viable alternative capable of reversing the poor economic status.

Tree tomatoes *(Solanum betaceum)* are a fruit of Andean origin mainly cultivated in Columbia and Ecuador. The fruit is used as fresh fruit, juice and the food processing industry. It has a high nutritional value as it contains ascorbic acid, enzymes, bioflavonoids, it is rich in minerals like chromium, potassium, and magnesium as well as B vitamins and amino acids. According to the national research council (1989) the fruit is very high in vitamins and iron. In Kenya the production of the fruit is little and scanty information about the varieties existing in the various part of the country. It is also coupled with poor agronomic practices.

According to Catalima *et al* (2009) tree tomatoes was first given the botanical name *Solanum betaceum* by a Spanish botanist and later transferred to *Cyphomandra betacea* by Sendner and back to solanum by Bohs (1995). It recommended for its nutritional qualities such as vitamins C, E, B6 and iron Wills and Greenfield (1986). The levels of vitamin B6 plays a role in the synthesis of antibodies by the immune system, which are needed to fight many diseases as reported by Athar *et al*. (2003). Due to the fruit having long production season and flexible uses it is likely to have a bright future (Prohens and Neuz, 2000). The aim of the study was to determine the status of production of tree tomato among the small scale holder farmers and also market outlets for increase food security in Embu County of the Eastern region of Mt. Kenya. With the prevailing weather conditions and its importance the fruit has a potential of improving the livelihood of the farming communities.

Objectives

- To identify the socio-economic and biophysical environment of tree tomato production in Embu county
- Identify the main tree tomato production and marketing constraints in Embu County
- Determine gender involvements in the production of tree tomatoes

Methodology

A sample population of all tree tomato producers was done in representative sites of Tea-Dairy (Kianjokoma) and Coffee-Dairy (Manyatta) Land Use Systems (LUS) of Embu County. Through the help of the Extension staff from the Ministry of Agriculture the farmers growing tree tomatoes were listed. From this list 30 households of the names were randomly selected in each LUS, to constitute a sample size of 60 households was conducted. A structured questionnaire covering all main areas of tomato tree production was developed, pretested and refined to conform to the socio-economic and biophysical realities on the ground. Some of the information collected included year of orchard established, main tree tomatoes' varieties, sources of planting materials and marketing and production constraints among others. Six trained enumerators were recruited with the assistant of extension staff and local leaders on the ground. They were then trained on administration of the refined questionnaire. They then administered the questionnaire in the supervision of the implementing team of scientists in November and December 2012.

After questionnaire administration, data was entered into a spreadsheet, cleaned and analysed by use of SPSS Software. Data analysis carried out included; frequencies, analysis of multiple responses and cross-tabulations.

Results

General characteristics of the tree tomatoes producers

Gender of the tree tomato producers. The results indicated that most of the tree tomato producers in the region are men as shown in Table 1.

Table 1: Gender of tree tomato producers

Gender	Frequency	Percentage
Male	28	63.6
Female	16	36.4
Total	**44**	**100**

Relative sizes of tree tomato orchards. Using the score of small, medium and large sizes, and consensus built between the enumerators and the respondents results indicated that most of the tree tomato orchards are of small (between 5-10) and medium sizes (10-20) (both constituting around 91%), with very few farmers (nine percent) having big orchard size (Above 20) ; as shown in Table 2.

Table 2: Relative sizes of tree tomato orchards

Size	Frequency	Percent
Big	4	9.1
Medium	18	40.9
Small	22	50.0
Total	**44**	**100.0**

Year of the orchard establishment. It was clear from the results that tree tomato production in the area is a recent undertaking compared to other horticultural crops like tomatoes, bananas, cabbages etc. According to the results, the earliest tree tomato orchard to be established in the area was in the early 1990's. Also, the results showed that adoption of tree tomato production in the area of study lagged on till mid 2000's when it started picking up, with the most of the orchards having been established around 2010. The progression of tree tomato orchard establishment in the study area is as shown in figure one. The likely scenario of the drop in the year 2011 could be due to diseases and poor market establishment.

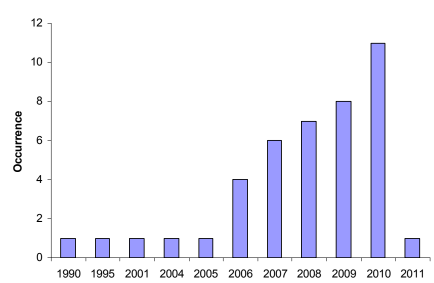

Figure 1 Tree tomato orchard establishment

Main reason for tree tomato Production. The results indicated that the main reason of tree tomato production in the area during the time of the study was household consumption (45%), though production for both household consumption and household income generations was also picking up (21%). Results also indicated that there were some farmers (seven percent) who were producing the tree tomato exclusively for income generation as summarized in figure two.

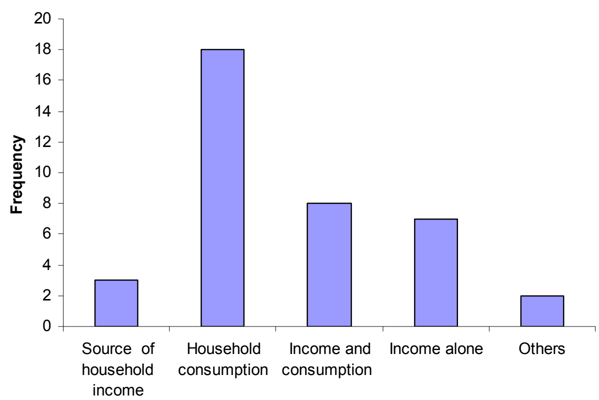

Figure 2 Main reason for tree production

All the respondents indicated that they did not know the specific names of the tree tomato varieties that they grow. However, most of them were able to describe them in terms of the colour and shape of the fruit they produce. Through this description, it was indicated that most of the farmers grow the varieties that have tall elongated shape (28%) and red-inside colour (20%) fruit varieties. Cone shaped and yellow inside varieties are also common in the area, as shown in the summary results in Table three.

Table 3: Description of the main shape/type grown in Embu County

Shape	Frequency	Percentage
Cone shape big	6	12
Dark purple	1	2
Oval	1	2
Red flesh inside	10	20
Red inside-rounded	1	2
Short round	6	12
Tall elongated	14	28
Yellow inside	5	10
Total	50	100

Source of tree tomato planting materials. Results showed that most of the tree tomato producers in the area access their planting materials in form of seed from the local market (45%), though quite a good proportion of them access their planting materials from other farmers (21%). Other sources of tree tomato planting materials in the area include accessing them in form of seedlings from the local market, as well as government organizations.. The summary of planting material sources in the area is as summarized in Table four.

Table 4: Sources of tree tomato planting materials

Source	Frequency	Percentage
Local market seedlings	3	7
Local market seeds	19	46
Other farmers	9	20.5
GOs	2	4.5
Farmers groups	1	3
Others	8	19
Total	42	100

Planting Arrangement. The results indicated that most of the farmers are either intercropping the tree tomatoes with other crops like maize and beans (59%) or planting them in a broadcasted manner within the farm (32%). Very few of the respondents (around five percent) indicated that they plant their tree tomato in an orchard form as indicated in Table 5.

Table 5: Tree tomato planting arrangement in the area

Planting arrangement	Frequency	Percentage
Orchard form	2	4.5
Scattered within farm	14	31.8
Intercropped	26	59.1
Others	2	4.5
Total	44	100.0

Production, marketing and coping mechanisms. Results indicated that tree tomatoes are usually harvested twice/year (two seasons), with no differences in yields between the seasons. It was also indicated that for those farmers who dispose their tree tomato fruits in the market, the buyers do not mainly consider the type of variety one is producing (66%), though some indicated that some buyers are concerned about the variety one is offering in the market (34%). For the latter, they indicated that the varieties that are most preferred in the market are the red inside round and short. This is because they are firm, large and sweet.

The results also indicated that most of the tree tomato fruit buyers in the market do not differentiate prices on the basis of the varieties offered. Thus, around 84% respondents indicated that buyers do not make price differentiation depending on the variety while the rest said buyers do consider the varieties offered in market while offering a price. There was no price differentiation between the two production seasons.

In terms of market demand and supply, most of the farmers (77%) in the area who sell their tree tomato fruits in the market do not experience any low market demand, where by what they supply in the market at any one time is demanded. 22% of the respondents who indicated that there are times that they experience low demand. For those who experience periods of market low demand most of them (80%) also indicated that they do not have any coping strategies with the surplus. The types of coping mechanisms that are used to cope with the low market demand included; increasing household consumption (six percent), giving out to the neighbours (four percent), lowering prices (two percent) and value addition (two percent). The summary of the results on the few low market demand coping strategies are as shown in Table six.

Table 6: Some of the low tomato tree demand coping strategies

Coping mechanism	Frequency	Percentage
Consume	3	6
Given out to neighbours	2	4
Go to waste	37	74
Sell cheaply	1	2
Value addition	1	2
Total	50	100

On the supply side, the results indicated that most of the times, tree tomato producers' supply less than the quantities demanded in the market. Thus, 71% of the respondents indicated that they always supplied less than what was demanded in the market

Tomato Tree Production Constraints and Associated Coping Strategies. The results indicated that most of the tree tomato producers (71%) experience a number of production constraints with the main ones being; pests(20%), diseases (24%)and moisture stress leading to drying up (nine percent) among others. A summary of the main tree tomato production constraints identified in the area are summarized in Table seven.

Table 7: Main tree tomato production constraints

Constrain	**Frequency**	**Percent**
Diseases	30	50
Dieback	5	8
Negligence	4	7
Lack of seedlings	1	2
Insect pest	15	23
Cost of chemicals	1	2
Transport cost	1	2
Water	2	4
Wild animals	1	2
Total	**60**	**100**

As much as a wide range of production constraints do prevail in the area, some of the farmers (27%) indicated that there are no coping mechanisms to mitigate against them, with only 20% indicating they have some coping mechanisms. Some of the main coping strategies to production constraints included spraying (56%) and irrigating the crop (seven percent). A summary of the main coping strategies to the identified production constraints are shown in Table eight.

Table 8: Main coping strategies to tree tomato production

Constraint	Frequency	Percentage
Crop rotation	1	2
Irrigating	4	7
No action	20	27
Partnering	1	2
Replant	2	4
Scaring	1	2
Spraying	32	56
Total	54	100

Tree tomato produce marketing arrangements. Most of the tree tomato producers (77%) appeared not to have any marketing arrangements for their tree tomato produce, with the buyers of the produce or suppliers of inputs. Summary of the marketing arrangements are as shown in Table nine.

Table 9. Tree tomato market arrangement

Market arrangement	Frequency	Percentage
With market arrangement	10	19
Without market arrangement	44	81
Total	54	100

Production and marketing institutions and constraints to tree tomatoes improved production. Results indicated that there are very few organizations/institutions that are involved in either production and/or marketing of tree tomatoes in the area. Most of the respondents (86%) reported that they do not know of any tree tomato production and/or marketing organization in the area while a small proportion (14%) indicated that they know of some organizations that are involved in the same. The results also showed that most of the tree tomato producers (95%) are not aware of any organization outside the area that supports tree tomato production and/or marketing.

In terms of broader agricultural production and marketing organizations, half of the respondents indicated that they do not belong to any marketing organizations that exist include coffee and dairy societies, and tea factories.

Discussions

It's evident that at the moment, tree tomato production is dominated by men and it's a recent undertaking in the area of study. The level of adoption is also low though progressing and also the main reason of production in the area is household consumption. The planting arrangement is an agronomic practice and therefore most of the farmers are intercropping or scattering them in the farm due to inadequate skill and the use of the right spacing of 3x3mand low level of awareness. It is also clear from the results that the quantities of tree tomato produced in the area do not meet the market demand. The tree tomato varieties grown in the area are also not known and there is insignificant market price differentiation due to varieties offered. As reported (Haq and Hughes 2002;Ravindran 2002) not much of the information is known as the fruit is not fully utilised in Kenya and not much of the information is known about the fruit.

Tree tomato production and marketing in the area have a number of challenges as indicated in Table eight and Table six diseases and insect pest being the major problems. However, they have coping mechanism with most farmers turning to chemicals and the surplus to household consumption or giving it to the neighbours. It is a common practice in the communities' to borrow planting materials from one another. Some collect wildlings, cuttings or seeds from the forest or from their farms. This compromise the quality of planting material which is key factor in achieving a good product. Clean planting materials would curb the various pest and diseases particularly those that affect the tree tomatoes. There are no organizations that promote production and/or marketing of tree tomato in the area and farmers are not aware of any outside the study areas. The crop being underutilised in the area may have contributed to lack of organised groups in terms of both production and marketing.

Conclusions

The fact that tree tomato production in the area appears to be a recent undertaking in the area its production at household production, the proportion that is producing for both household consumption and market is increasing; hence an implication of its enterprise potential in the area, if well promoted. The market demand of tree tomato in the area outstrip the market supply, hence there is a great potential for its production and marketing for improved household food security and nutrition, improved household incomes and poverty reduction. Inadequate awareness of any institutions that are involved in tree tomato

production may be an indication that there is limited extension service provision about the same. Due to the fact that there are a number of problems in both production and marketing it forms a basis of research intervention particularly on insect pest and diseases. This may go hand in hand with its promotion to give an opportunity to the farmers to maximise production at minimum costs and hence maximise on the incomes from this new enterprise.

Recommendations

There is therefore need to enhance promotion of tree tomato production in the area of study because it has both production and marketing potential. It is also imperative to build farmers' production capacities for appropriate agronomic practices like spacing, weeding, and watering to exploit the production potential and improve the supply in the already existing markets. Awareness creation on most appropriate varieties for the region is also very important so that farmers can utilize the most desired varieties to enhance their food and nutrition security as well as improve their household incomes. Research and extension service providers need to put more effort to improve on the adoption of appropriate tree tomato varieties in the area for the farmers to increase production and improve on satisfying the existing markets.

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Resource use efficiency in rice based farming systems: A case of upland and paddy rice in Namasagali sub-county Kamuli District

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Abstract

Rice is an emerging and one of the important cereal crops grown in Uganda. Being a relatively new crop, farmers are faced with a challenge of effectively utilising resources and their combination for maximum productivity and therefore profit. Therefore the study identified the determinants of efficient rice production in Namasagali sub-county with a backdrop of ensuring food security and enhancing the sustainable use of wetlands. These were attained through the use of a logistic regression and the Cobb-Douglas production function model to find the determinants and the level of technical efficiency respectively. Results show that out of the 11 factors assessed, 7 of them were found significant at 5% level of significance. Land size devoted to rice cultivation was the most significant factor determining technical efficiency of rice cultivation in the area. Others are education level, experience, motive of the farmer, family size, labour and use of ox-plough. However, rice type, fertilizer application, gender and land ownership were found insignificant in determining technical efficiency in the area. The Cobb-Douglas results exhibit that the farmers in Namasagali sub-county are generally technically inefficient due to decreasing returns to scale of production, implying that key factors of production are over-utilized. It is therefore recommended that farmers should shift to upland rice cultivation especially NERICA 4 the high yielding one so as to divert attention and ensure limited exploitation of wetlands.

Keywords: resource use efficiency, technical efficiency, rice, wetland, upland, Uganda.

Introduction

According to (27), rice is an emerging crop with foreseen positive benefits towards the livelihoods of farm households and processors in Uganda. It is a major intervention identified in the Ministry of Agriculture Animal Industry and Fisheries (MAAIF) development Strategy and Investment Plan (DSIP) 2009/10 - 2013/2014 for food security and poverty reduction in Uganda (11). Introduced in 1942, rice is mostly grown in wetlands by smallholder farms mostly in eastern Uganda. The consumption estimate of 225,000 t is more than the produced 165,000 t. In view of the current population growth rate of 3.2%, the gap between production and demand for rice is expected to increase. Uganda adopted NERICA 1, NERICA 4 and NERICA 10 varieties in addition to the old lowland varieties. Since the introduction of upland rice in 2002, rice farming has grown from 4,000 farmers to over 35,000. From the earlier releases of three upland rice varieties in Uganda in 2002, farmers earned USD 9 million (14.9 billion) in 2005. In the process, the country has seen rice imports drop between 2005 and 2008. This saved the country about USD 30 million in foreign exchange earnings.

However, with continuous cultivation farmers are experiencing low and declining rice yields, affecting their income and food security (27). Yields as low as 0.9-1.1 t ha^{-1} have been recorded on farmers fields (27). Production is constrained by low and declining nutrient and lack of water, pests and diseases, lack of information on the optimal use of resources, ineffective marketing and extension system and inadequate policies on agricultural inputs and finance (27; 11). These factors are exacerbated by climate change. Furthermore, the inappropriate rice cultivation practices have affected wetland biodiversity and water conservation functions of the wetlands. Upland rice varieties are promoted to reduce pressure on wetlands and thus sustain wetland ecological functions amidst rice cultivation. This study identified the economic benefits and determinants of efficient rice production in Namasagali sub-County with a backdrop of ensuring food security and enhancing the sustainable use of wetlands.

Materials and methods

The study area

Namasagali sub- County is bound on the east by Nile River in Kamuli District, and 60 km North of Jinja town in Uganda. It is endowed with land resources of which wetlands and floodplains are prime for rice cultivation. The area is characterised by a bi-modal rainfall with peaks in March-June and August – November with the March-June peak as the major one. The annual average rainfall is 1,350 mm with a mean monthly rainfall of 75-100 mm (19). There has been a trend of pronounced dry seasons in this sub county over the recent years. Temperatures in most areas of the sub-County are 9-25° C.

Maize is the staple food crop In Namasagali. Therefore, the analysis of rice as a source of food security was made in comparison to maize. Rice cultivation is a new enterprise. Rainfed upland and paddy rice varieties are grown with an increasing tendency of farmers growing upland rice in wetlands, especially during the dry seasons. Upland varieties grown include NERICA 1, NERICA 10, NERICA 4 and NARIC 1 while the paddy varieties include *Kaiso* and *Super* with *Kaiso* dominating. *Kaiso* was considered in this study.

Both qualitative and quantitative data was collected using crop yield surveys, individual interviews using a pre-tested structured questionnaire. Parameters collected and analysed included crop yield, the cost of purchasing or hiring land, cost of planting materials, labour (Ploughing, weeding, bird chasing, harvesting, bush clearing), sun-drying, cost of drying material, transport costs from fields to homes and from homes to processing mills, bio data, aspects related to sustainable wetlands use and food security.

Both purposive and snowball sampling techniques were used to collect data from rice growers. Fifty households was sampled from the villages of Bwizza, Kakaanu, Nalwekomba, Kapalaga, Kisaikye, Namakoba, Malugulya, Kabbeto and Mutukula.

Field plots measuriing 2 × 2 m were diagonally established in farmers' plots during the April-August season of 2012. Quantities of grain from these plots were translated in crop yields with averages used for statistical analysis.

STATA11 and MINI TAB 15 programs were used to analyse data. Descriptive, cross tabulations, cost-benefit analysis, logistic regression model and Cobb-Douglas production function models were used to analyse the data.

Logistic regression model

A logistic regression model was used to analyse the factors that determine rice yields as well as the technical efficiency in rice production especially the socioeconomic factors that could not be analysed by the Cobb-Douglas production model. It was preferred to other models such as probit and logit because of its mathematical simplicity. The logistic regression model was chosen because its dependent variable is binary and can only take two values. It also allows for estimation of the probability of a certain event occurring. The general operational model was as follows:

$$\text{Logit}(P_i) = \text{In}(Pi/1\text{-}Pi) = \alpha + \beta_1X_1, + \ldots\ldots + \beta_kX_k + v$$

Where The ratio Pi/1-Pi is the odds ratio, Pi - probability that a farmer is efficient, 1-Pi - probability that a farmer is not efficient, Xi - various independent variables, B_I- estimated parameters, V - stochastic term.

Therefore the model for analysis is as stipulated below

$$\text{Yield} = \beta_0 + \beta_1\text{VARIETY} + \beta_2\text{Fsize} + \beta_3\text{Landownership} + \beta_4\text{Rlandsize} + \beta_5\text{Rexperience} + \beta_6\text{Rmotive} + \beta_7\text{Hirelab} + \beta_8\text{oxplough} + \beta_9\text{Fertiliser} + \beta_{10}\text{Education} + B_{11}\text{Gender}$$

Cobb-Douglas production function model

This production function was used to analyse the factors that influence rice production especially those that are concerned with technical efficiency. The reason behind using this type of production function is that it is linear in its logarithmic form, and allows for the usage of Ordinary Least Squares (OLS) which was

also applied in the above specified linear regression model. It has been also widely used for production function analysis by many researchers worldwide. In theory it is expressed as below:

$$Y = AL^{\alpha}K^{\beta}$$

Where Y= output; A- constant; L- labour; K-capital; U- error term α and β - elasticises of production.

For constant returns to scale, the sum of the coefficients, β and α must be equal to one (K=1). For increasing returns to scale, they must be greater than one (K>1), and for decreasing returns to scale they must be less than one (K<1).

The model was used mainly because of its mathematical simplicity. It also has limited effect on empirical efficiency measure and not exclusive to labour and capital alone but also other production inputs. Short-comings of this function model include the inability to represent all the three stages of the Neo-classical production function thereby representing one stage at a time and lastly the elasticities in this model are constant regardless of the amount of inputs used. The specific model for this study relating to the production of Y, to a given set of inputs X, and other conditioning factors is presented as follows:

$$Y = a\ X_1^{b1}X_2^{b2}X_3^{b3}X_4^{b4}X_5^{b5}X_6^{b6}\ v$$

Where Y- total yield of rice produced (kg), X_1- land devoted to rice (acre), X_2- quantity of seeds used (kg), X_3- fertilisers used (kg), X_4- pesticides used (in kg), X_5- labour used (in days), X_6-capital/ox plough, β1…..β5 are parameters to be estimated and v-error term.

To allow for use of the Ordinary Least Squares procedure, the Cobb-Douglas production function was linearised using logarithms.

Taking logarithms on both sides, the model would be:

$$\ln(Y) = \ln(a) + \ln\beta_1 X_1 + \ln\beta_2 X_2 + \ln\beta_3 X_3 + \ln\beta_4 X_4 + \ln\beta_5 X_5 + \ln\beta_6 X_6 + v$$

Results

Social characteristics

Rice is a new introduction in this part of the country with about an equal number growing upland and low land rice type. With an average household size of 6 (Table 1) and the youthful majority of rice farmers who use an average of 1.3 acres (Table 1), the rice enterprise is sure of a reliable supply of labour mostly literate to support the rather labour intensive rice enterprise. This observation is in line with the country's population structure that is dominated by youths (35).

Table 1: Descriptive statistics of some social characteristics

Variable	Observation	Mean	Std. Dev.	Min	Max
Age	50	36.2	9.2	22	56
Family size	50	6.1	2.4	2	14
Experience	50	6.5	3.6	2	16
Seeds	50	42.1	25.2	14	140
Rice acreage	50	1.3	0.8	0.5	4

Analysis of rice production as a source of food security

According to (17), it requires 1700 kg of maize to feed a single family of 6 people annually and 0.63ha of land is required to produce the equivalent maize grain. Therefore it costs USD 816 to feed a family of 6 people with maize flour for a period of one year. The net returns from rice grown on land equivalent to 0.63 ha of all the rice varieties are paddy (USD 963.46), NERICA 1 (USD 884.77), NERICA 10 (USD 884.77)

and NERICA 4 (USD 1,171.93) (Table 2). It is evident that rice growing can serve to ensure food security in the area since the farmer can be in position to buy food and remain with surplus income to invest in other economic activities including saving for future investment.

Table 2: Rice net revenue versus the price of maize meal required to annually support a family of six

Variety	Land size(ha)	Milled (kg)	Net revenue (USD)
Paddy	0.63	2028	963.46
NERICA 1	0.63	1825.2	884.77
NERICA 10	0.63	1825.2	884.77
NARIC 3	0.63	1926.6	956.56
NERICA 4	0.63	2230.8	1,171.93

Maize flour of 1700 kg produced from 0.63 ha cost 2040000; 1700 kg of maize flour is the quantity required to annually support a family of 6people in the study area (17)

Costs-Benefit Analyses for the different rice varieties

The benefits of growing paddy rice are generally close to upland rice varieties with the exception of NERICA 4 that portrays superior benefits (Table 3). This therefore implies that farmers as well can start growing upland rice varieties instead of the paddy rice varieties. This will enable them to enjoy the benefits of upland rice while conserving the wetlands to ensure flood control, sinking functions, resource base, among others; this was also noted by other researchers (18).

Table 3: An economic analysis for cultivating one acre of rice

	Varieties			
		Upland		
Parameter	Paddy	NERICA 1 & 10	NERICA 4	NARIC 1
Net Income per acre (USD)	617.6	567.16	751.24	613.18
Benefit – cost ratio	1.54	1.50	1.90	1.60

1700 kg of maize flour x 0.48 (mart price) = USD 816

Logistic regression model result

The seven significant variables; family size, farmer's experience in farming, land size devoted to rice, use of ox plough, education level, cost hiring labour and the motive of growing rice. It does indicate the importance of these factors in rice cultivation (Table 4).

Farmers' farming experience

It is positively significant at 5% level of significance ($p>t$ =0.043), (Table 5), with the implication that there is a positive relationship between the farmers' experience in farming and the rice output that is likely to be harvested. The more experience a farmer has, the better the use of available resources. It is a pointer to the improvement of productivity and technical efficiency. According to (16), many rural rice farmers have low levels of education but with much experience in rice production that enables them to harvest rice yields since they are versed with the field practices.

Table 4: Logistic regression model results

Yield	Coefficient	Std. err	T	P>|t|
Variety	323.6	328.4	0.99	0.330[ns]
Family size	-219.1	63.7	-3.44	0.001[**]
Landownership (acre)	-117.8	136.9	-0.86	0.394[ns]
Land size (acre)	1482.2	87.3	16.9	0.000[**]
Experience (yrs.)	84.9	40.8	2.08	0.043[*]
Motivation	68.4	189.7	3.63	0.001[**]
Labour (days)	40.0	408.1	2.06	0.045[*]
Ox plough	931.4	376.3	2.48	0.017*
Fertiliser (kg)	301.2	426.5	0.71	0.484[ns]
Education level	42.0	2.9	14.37	0.04[*]
Gender	329.6	243.6	1.35	0.182[ns]

Number of observations = 50, Prob>F =0.0158, R-squared=0.682, Adjusted R-squared=0.668; *= Significant at 0.05 level, ** = highly significant at 0.01, ns= not significant at all levels

Table 5: Cobb-Douglas production function model results

Variable	Coefficient of elasticity	Std error	t- ratio	Significance
Land size(acre)	0.310	70.3	10.23	0.000
Seeds (kg)	0.281	2.0	9.32	0.002
Fertiliser (kg)	0.250	40.4	9.32	0.024
Ox plough	-0.194	376.2	-2.48	0.017
Pesticides(kg)	0.066	251.5	1.35	0.182
Labour (days)	-0.099	40.0	-3.04	0.044
Constant		49.1	2.36	0.008

Adjusted R- squared = 0.67, Sum of b's = 0.543, Sum of obs = 50

Education level

There is a positive significant linear relationship between the efficiency in rice growing and the level of the farmer's education. Greater schooling could enhance farm efficiency, either through acquisition of knowledge relevant to agriculture and the usage of available resources efficiently or enhanced adoption of technology

Land size devoted to rice

The variable land size devoted to rice (Table 5), is positively and highly significant at 1% level (p>t =0.000), which is the most significant variables found. The implication is that there is a positive relationship between land size devoted to rice and rice yield.

Family size

Family size is highly significant at 1% level (P>t=0.001), which happens to be one of the most significant variables, but negative. Labour input replaces capital input and the majority of family labour is applied to rice, so access to family labour is an important catalyst for increasing yield. Therefore, it eases the labour constraint faced by most rice farmers in Namasagali sub- County. However, the result implies that there is negative relationship between family size and yield of rice produced implying an optimum amount must

be selected for an acre because too many of them impose a negative relation and too little affects the output as well.

Use of ox plough

Using an ox plough by the farmer has a positive relation with the output of rice, and is significant at 5% level (p>t= 0.017). There its use helps to improve on the efficiency other than using the traditional means of Ploughing that are time consuming and inefficient, according to one respondent, it takes 2 days to plough an acre of land using the oxen and it takes a minimum of two weeks for two energetic men to plough an acre of land. Therefore as regards efficiency in rice production use of ox plough is very paramount.

Hiring of labour

This variable has a positive relationship with rice production, and significant at 5% level (p>t=0.045). This implies that as regards rice production efficiency in this area care should be taken when determining the number of labourer's to hire for use. This appears like that that's slightly significant because in this area farm production is highly dependent of family labour as shown by the significance of family size towards rice production.

Motive of growing rice

This is another key variable identified as very significant in determining rice yields in Namasagali sub-county with a positive and significant relationship. This implies that the mindset and aim of a farmer determines very much their levels of action towards ensuring high yields and efficiency in production as a farmer will endeavor to allocate the resources optimally to ensure profitability

Cobb-Douglas production function model results:

The main reason for using Cobb-Douglas production function is to determine the technical efficiency of rice growing of the farmers in Namasagali sub-county. There are a number of variables that are usually known to affect agricultural production for cereals rice in particular. As a result, it is important to use a model that relates production to those variables for a better understanding of the functional relationships. The results indicate that out of six variables used in the Cobb-Douglas, five were significant with one being negatively significant. This implies that there is an input to output relationship.

Elasticity of production

The results indicate that the estimation of the production function resulted in adjusted R- squared of 0.67, indicating that the independent variables included in the model account for about 67% of the variation in rice production in Namasagali (Table 6).

Land size devoted to rice

The result shows that the size of land devoted to rice is an important factor in rice production. With a positive and highly significant elasticity, an increase in one acre of land devoted to rice can result in 31.0% increase in the total yield of rice.

Ox plough use

Cost of hiring the ox plough was used as a proxy for capital. The elasticity coefficient of ox plough is significant but negative, which indicates that the input is paramount but farmers are over-utilising it in the production of rice.

Seeds used per farm

The elasticity of seeds is positive, and also one of the highly inputs significant at 5%. The results indicate a 1% change in the quantity of seeds is associated with a 28.1% change in the total rice yield ceteris paribus.

Labour

The elasticity of labour is significant but negative where a decrease by 1 unit of this variable results in 9% decrease in the rice yields.

Fertiliser used

According to the results in Table 6 a 1% increase in the quantity of fertiliser applied is associated with a 25% increase in the total yield of rice

Pesticides

This variable is negatively related and not significant at all as regards production of rice in this area. It should be noted that few farmers apply pesticides to their rice crops. This is based on the reason that rice is relatively a new cereal crop in this area and therefore the case of pests and diseases infestation is still low and hardly reported by many farmers in this area.

Return to scale

For constant return to scale, the sum of the technical coefficients β and α must be equal to one (K=1), for increasing return to scale, they must also be greater than one (K>1), and for decreasing return to scale they must be less than one (K<1).The regression results indicate that the sum of b`s is less than one (K<1), where K is the sum of the coefficients a and b, thus simply indicating decreasing return to scale. This serves to indicate that the output of rice is priced below the marginal costs of production. It also serves to imply that the factors are over utilised which result in them being technically inefficient in the cultivation of rice.

Discussion

The socioeconomic characteristics displayed in Table 1 favor the production of rice, a labour intensive crop. In line with the country's population structure (35), a youthful family of 6 does present the labour to support rice production. Labour is a critical factor in rice production as observed by several studies (10 & 1).The labour scenario shows situations of disguised un-employment and therefore farmers have to be very keen when determining the number of worker for matters of productivity and profitability. Farmers contend that upland rice yields highest in wetlands and this coupled with the available labour is likely to ensure a continued production of rice in wetlands. This presents a challenge to conservationists to devise proper mechanisms of striking a balance between rice production levels and wetlands conservation.

Access to land is one of the most important variables, explaining the differentiation in output (Tables 5 and 6). This is in line with the findings of many scholars (1, 7 and 10), Land as one of the primary factors of production is very important and because of its limitedness in supply it has always accelerated a number of aspects such as migration from upland areas to low land wetlands.

Use of ox plough in this area is a common practice but many of these farmers fail to cost it and thus end up operating in phase 3 of the neoclassical production function. Therefore this serves to imply that any further increase in the use of this input yields diminishing returns of rice production.

The variable "seed" (Table 6) is sensitive to the total output of rice, meaning that there is an input to output relationship. The species of the seeds used is very important in ensuring productivity of the rice crop since various seed varieties yield differently for example NARIC 1 yields about 3.5-4 t ha^{-1}, NERICA 4 yields about 4-5 t ha^{-1} (33). The use of good seeds in crop production is one way of increasing productivity in terms of quantity and quality (10 and 20).

The variable "fertiliser used" plays a big role in improving productivity and in the intensification of agricultural production as a whole especially where the scarcity of farm land is a big problem (1 and 10). However, the appropriate use of these fertilisers is very important in achieving farm efficiency (13). It should be noted that very few farmers have access to fertilisers and that they are not readily available at affordable prices in this area. Therefore according to the returns to scale, it indicates that the per unit cost of the inputs used in production process of an output of rice exceeds the returns from that output rice. Thus showing inefficiency as they spend more on inputs than they should in the view of the yield, given the fact that their livelihood is majorly dependent on farming. In addition to this they in many cases underestimate the inputs more especially labour, time, land especially where it's freely accessible (12).

Returns to scale

This indicates that per unit cost of the input used in the production of an output of rice exceed the returns from that output of rice. Thus showing inefficiency as they spend more on inputs than they should in the view of the yield, given the fact their livelihood is majorly dependent on farming. In addition to this they in many cases underestimate the inputs more especially labour, time, land especially where its freely accessible. Similar studies in Uganda regarding *matooke* growing indicate the same decreasing returns to scale.

Conclusions

There was a significant difference between the paddy rice yields and NARIC 3 species of the upland varieties. The farmers of paddy rice had slightly higher yields than those of NARIC 3.

On the other hand there were significant differences between the yields of paddy rice and NERICA 1, 10 and 4 where the yields of paddy rice were more than those of NERICA 1 and NERICA 10; however the yields of NERICA 4 were significantly greater than those of paddy rice. This implies rejection of the hypothesis that there is no significant difference between the yields of paddy and upland rice.

The following inputs were found to be key determinants of technical efficiency in rice production and rice output in general: these are land size devoted to rice growing, quantity of seeds used, use of fertilisers, labour, ox plough (cost of hiring); and ox plough and labour were over-utilised, thus if farmers are to improve on production they have to take note of these inputs. The following socio-economic factors were seen as very paramount: family size, farming experience and motive of the rice farmers. It is noteworthy that the returns to scale for the rice farmers are decreasing, suggesting that rice cultivation by farmers in Namasagali is not technically efficient.

Although upland rice is quite promising, the hindrance to its full adoption and therefore a switch out of the wetlands is the use of wetlands during the rather long dry seasons. The performance of upland rice is rather an attractive during the dry season- a reason why farmers grow both paddy and upland rice in the wetlands. Otherwise NERICA 4 is superior to all varieties and therefore a promising variety for integration into the upland crop enterprises.

To realise efficiency and avoid the technical inefficiency portrayed by decreasing returns to scale of rice production, there is need to adopt modern agricultural farming practices such as use of fertilisers, planting of recommended and good rice seeds that are high yielding in companion with improved institutional support, and human resource improvement. This will serve to form bedrock for improving the livelihood and standards of living of the many rural farmers

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Utilization of plant health clinc innovation for sustainable crop production in embu County, eastern Kenya

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Abstract

Plant health clinic (PHC) is a new approach in Kenya that provides a low cost method to provide plant health advisory services to smallholder farmers. The approach is based on field diagnosis on crop health issues which includes plant disease, insect pest, weed and soil health. It aimed to diagnose, manage the crop health issues for increased yield and sustainable livelihood. The plant clinics are run by the extension staff from the Ministry of Agriculture and the Kenya Agricultural Research Institute (KARI). The study revealed that farmers have varying problem and in the three agroecological where the clinics are situated. The crops grown are similar and are affected by similar diseases. However, nitrogen and phosphorous deficiencies were more rampared in the upper midland (UM1) as compared to the UM2 and 3. Since the plant clinic approach is conducted at the farm level it may act as a quick avenue to track any new pest in a area.

Key words: plant health clinic, plant 'doctor' nitrogen, phosphorous.

Introduction

Agriculture is the backbone of the Kenyan economy that contributes to 26% of the GDP annually and another 25% indirectly. The sector provides 70% of the informal employment in the rural areas. It also accounts for 65% of Kenya's total exports. The agricultural sector is not only the driver of Kenya's economy but also the means of livelihood for the majority of Kenyan people (GoK, 2010). Productivity in this sector has been declining due to; inadequate access to production inputs, low crop yields, and unfavourable markets among others. It is in this context that the National Agro forestry Research Project (NAFRP) indicated that the sector should be the main target of concentration in combating poverty (NAFRP, 1999). There are various factors that contributes to low yields that include; low soil fertility, poor crop husbandry, limited use of improved seeds, pests and diseases, monoculture, reduced crop diversity, lack of crop rotation and reduced tillage. It also includes use of herbicides that have boosted yields, though increasing pests and diseases. According to Coakley *et al.,* 1999 the problem of pests and diseases has also been exacerbated by change of climate resulting in high temperatures that favours their survival. Adejumo (2005), Schroth *et al* (2000), Okori *et al (*2004) and Huis (1989) indicated that crop yields productivity has been continuously going down due to diseases and insect pests. Rao (2004), Schroth *et al* (2000) and Allotely and Oweyo (2000) indicated that grain legumes are more susceptible to pests and diseases. According to Oerke *et al* (1994) pests and diseases cause considerable loss of crop yields resulting to 42%,(insects) 15% (pathogens) and 13% (weed) of pre-harvest losses. Due to the climate change the survival of the pathogen that may results to increased inoculums are high which leads to infection of the subsequent crop (Boland, *at al.,* 2004). According to (Bentley, 2009) farmers in the developing countries do not access timely and adequate advice on the issues of crop health. A case of Kenya, the extension services that was initially being rendered by the extension staffs to individual small scale holder was reduced by the Government resulting to a gap in the extension innovations (Davis, 2006). As sighted by (Boa, 2007) farmers demand exceed what can be offered by the extension staff in a more reliable and consistence. Plant health clinic is described as form of health care where farmers' recommendations are based on field diagnosis and available information (Negguse *et al.,*2011). This initiative by the Global Plant Clinic (GPC) alliance led by CABI has responded to the need of small scale farmer through the introduction on plant health clinic for management

of pest and disease. According to Danielsen and Kelly, (2010) the approach provides a low cost method that enable plant health advisory services to smallholder farmers. Plant clinics have been introduced in other areas such as Africa, Latin America as well as Asia (Boa, (2009); Danielsen and Matisko (2010). In Kenya the approach was introduced in 2010 and in 2011 it began in Embu County with an aim of determining the contribution of the plant health clinic in management of pest and disease for sustainable livelihood.

Specific objectives

- Establish if plant nutrients involvement in the plant health clinic and the crop of interest and the gender
- Establish gender involvement in the plant health clinic and the crop of interest
- Establish the crop health challenges in different Agro-ecological zones of Embu County

Methodology

Plant health clinic was initiated in Embu County in September 2010 with the first clinic set at Embu market (coffee dairy land use system) followed by Kibugu (coffee, tea, dairy land use system) and the third one at Kithimu (Marginal coffee and maize land use system). The personnel that carry out the activity (MOA and KARI) were first trained on the approach. Data collected from different clinic sites cover the period between September 2011-Dec 2012. Depending on the site the plant clinics are run on weekly basis at a specified day, place and time. The sites were chosen in areas convenient for majority of the farmers as they visit the market. The publicity of the clinics dates were done through the chiefs' barazas. Farmers carries infected plants material or they may identify the problem through the photo sheet provided at the clinic. Visual diagnosis is done and the recommendation done on a prescription by the staffs. Data was collected in a predefined sheet that included the farmers details (Name of the farmer, location, village, sub-location, email/telephone and district) crop type, crop variety, age of the crop, disease description and diagnosis. Issues brought to the clinic and were difficult to identify were referred to the laboratory for further identification and diagnosis and the farmer given the recommendation once the problem is identified.

Data analysis

The data was cleaned truncated into periods from inception of the clinics to the end, coded and analysed using SPSS software version 17.

Results

The results (Table 1) indicated various problems brought to the plant clinic ranging from diseases, insect pest nematodes and plant nutrients. Among the deficiencies realised were Nitrogen and Phosphorous that rated among the highest challenges. Among the food crops *Fusarium wilt* (Panama disease) of banana was a major challenge followed by maize streak virus in maize (MSV). Coffee berry disease in coffee was a major problem in coffee as commercial crop in the region. This was an indication that although farmers continued with their normal farming routine they are faced with varying challenges that required intervention. The cases reported in the three plant clinic site showed phosphorous and nitrogen as most limiting soil elements.

The results in Figure 1 showed differences on disease, insect pest and plant nutrition across the agroecological zones. Zone three represented by Nembure (UM3) had fewer problems as compared to UM1 (Kibugu) and UM2 (Embu market). UM1 uniquely showed the highest deficiency in Nitrogen.

Figures 2 and 3 shows problems affecting banana and maize which are a major food crops in the region. The *Fusarium wilt,* nematodes and banana weevil are the major challenges for bananas. Maize streak virus, stalk bores and Nitrogen deficiency are the major challenges in maize as the food crops.

Table 1: Diagnosis made in various plant clinics

Problems diagnosed	Frequency	Valid (%)	Cumulative (%)
Panama (*Fusarium wilt*)	131	9.7	31.6
Coffee berry disease	26	2.2	5.8
Bacterial wilt	62	5.1	16.7
Boll worm	26	2.2	18.9
Maize streak virus	56	4.6	23.5
Phosphorus deficiency	58	1.9	25.4
Potassium deficiency	19	1.6	27.0
Banana weevil	33	2.7	29.7
Cigar end rot	9	0.7	30.5
Maize stalk borer	35	2.9	33.4
Coffee borers	28	2.3	37.7
White flies	29	2.4	40.1
Nitrogen deficiency	105	5.8	45.9
Nematodes	73	6.0	52.0
Thrips	38	3.1	55.1
Stem borers	37	3.1	58.2
Leaf rust/minor/spot	43	3.6	61.8
Powdery mildew	18	1.5	63.2
Mango Weevils	42	3.5	66.7
Aphids	69	5.7	72.4
Borers	17	1.4	73.8
Smut	11	0.9	74.8
Others	221	18.3	93.0
Unknown	35	2.9	95.9
missing values	49	4.1	100.0
Total	1,208	100.0	

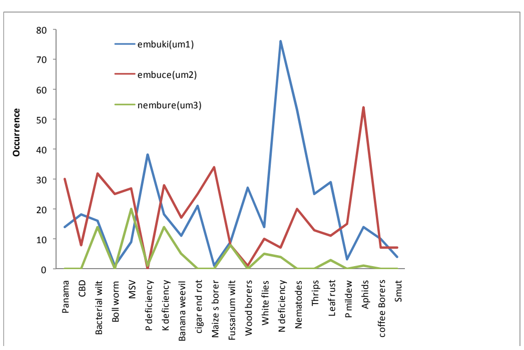

Figure 1: Diseases in different sites

Figure 2: Problems affecting bananas

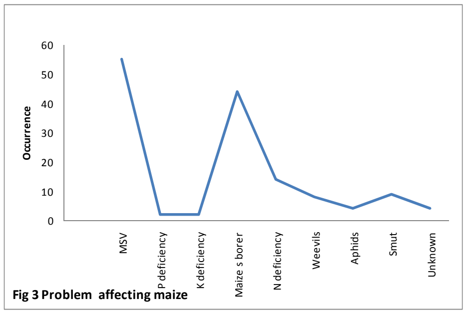

Figure 3: Problems affecting maize

Results in Figure 4 indicated higher percentages of the respondents were from Embuce (UM2 (47%). Embuki UM3 with 42% and Nembure with 11%, respectively

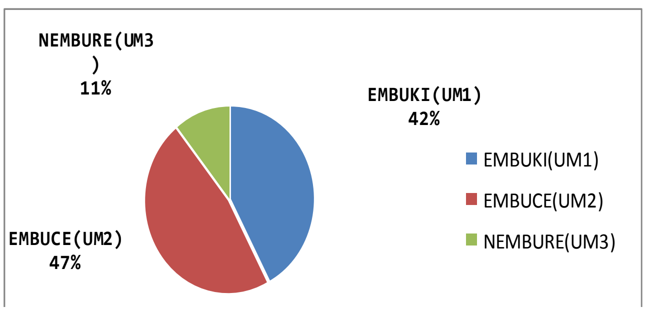

Figure 4: Respondent in different AEZ

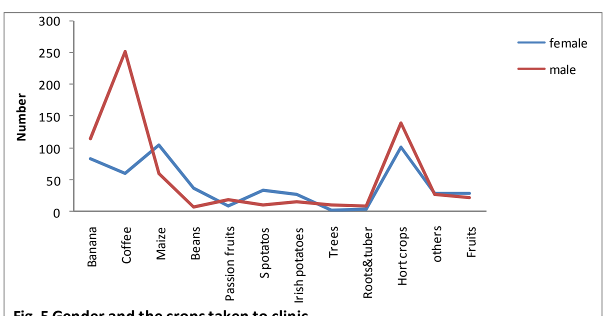

Figure 5: Gender and the crops taken to clinic

Results in Figure 5 showed there were more males who visited the plant clinic but associated with specific crops. Bananas, coffee and horticultural crop attracted more males than women. This may be the reason that more males were attracted to these crops being the decision makers in the families.

Discussions

Bananas and coffee are among the income generating crops in the region. However, they are affected *Fusarium wilt* and coffee berry disease respectively. The disease spread across the three agro-ecological of the study area which agree with Ploetz, (2006) that *Fusarium wilt* is an important disease in many parts of the world. This give a challenge to the researchers that more research study should be emphasized. Maize steak virus also cut across all the maize growing areas in the County in the three agro-ecological zones. This agree with what was reported by Thottappilly *et al*. (1993); Bosque-Perez *et al.,* (1998) and Martin *et al.,* (1999) that the disease cause significant yield loss even in Kenya. Kyetere *et al.,* 1999, Alegbejo,*et al* 2002 have also reported yield loss of 100%. The disease is reported to manifest in wide range of elevation from sea level to 2000 m (Efron *et al*., 1989).

Most of the respondent were from Embu market clinic (Embuce um 2) which may be attributed by the fact that the town is cosmopolitan town having higher population than the rest of the small town. Embu mark*et al*so boarders with Kirinyaga County where there are lot of horticultural farming resulting to more farming challenges. Kibugu (Embuki um1) also had higher number of responded which may be due to its vicinity with Kirinyaga in the upper side of Embu. More males visited the plant clinic than females but the crops associated with them are high value crops in terms of income generation. Men having the affinity of decision making on control and asset of the household may have implied their strong attraction of the PHC to acquire skills that can enhance household income. Secondly men are freer to move than women who are tied down with household core.

The high incidence of phosphorous deficiency in the Kibugu (UM1) may have resulted from the formation of iron and aluminum phosphate minerals that result from the reduced solubility of phosphorous in strongly acidic soil. Phosphorous fixation may also result in acid soils due to continuous cropping without any replenishment as found by Chien *et al*. (1990); Sanchez, (2002). Richard *et al.,* 2013 pointed out that about 80% of the African soils have inadequate amount of phosphorous which is an essential element for crop production. Phosphorus deficiency has also been found to be a production constraints in East Africa as found out by (Zapata *et al*., 2004; and Onwonga *et al*., 2008). Phosphorous deficiency could be brought about by low occurrence of p-containing mineral (Nyandat, 1981; Bunemann, 2003).

Nitrogen deficiency was found to be higher in the upper zone (UM1) than in UM 2 and 3. This can be attributed to various acid management practices done by farmers which may have resulted to decline soil organic matter. As reported by Liu *et al*. (2004) that acid soils limits the growth of microbial growth.

Conclusion

Up-scaling of the technologies through plant health clinic approach is an effective innovation which can be adopted for sustainable pest and disease management due to a wide number of challenges diagnosed. Since the approach is demand driven farmers there is need to introduce the same to other Counties. It consumes little since the farmers may combine the task of going to the market as well. Since the plant clinic approach is at the farm level it act as a quick avenue to track any new pest in a region.

Recommendations

From the data colleted at the clinic sites there are incidences where the officers are not able to identify the problem requiring them to take the sample to the laboratory. The labs need to be equipped to receive the referrals. There is also need to have regular training of the officers to keep in pace with the new challenges as well as good collaboration with the chemical manufacturer in order to know the new chemical in the market. A platform can be crated where the stakeholders meet regularly to review the progress and the benefits of the approach. More research is required on the management of the various challenges brought

to the clinics paricularly on food crops like management of *Fusarium* wilt on bananas, maize sreak virus in maize. Other crop are arrowroots whose not much of the research is done yet the crop is in demand in the current market.

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THEME 5: SOIL BIOLOGY

Abundance and ecological functional categories of soil macrofauna as indicators of soil chemical properties status in oil palm plantations in Bugala island Kalangala District, Uganda

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Abstract

Land use changes have dramatic effect on soil macro fauna communities, yet their activities improve and sustain physical and subsequently chemical soil properties which are necessary for sustainable crop production. A study was conducted to investigate the relationship of soil macro fauna composition with soil chemical properties in oil palm plantations. The macro fauna populations were assessed in soil monoliths of 25 x 25 x 30 cm (Anderson and Ingram, 1993. Significant differences were recorded across fields Ten taxonomic groups macro fauna were observed in the ecosystem with ants *Hymenoptera* followed by termites *Isoptera* constituting the higher numbers of the total organisms The study demonstrated the role of soil invertebrate macro fauna as indicators of soil chemical properties in oil palm plantations Three farms were replicated for each growth stage of three and six years. Abundance, biomass and ecological functional categories of soil macro fauna decreased from 0 - 10 cm to other soil depths. The snails *Gastropoda* contributed the greatest biomass (77.96 g m^{-2}), followed by millipedes *Myriapoda* (23.35g m^{-2}. Soil analysis results indicated very acidic status (pH< 5.2). It was concluded that scientifically soil macro faunal populations in the oil palm plantations can be rejuvenated by applying lime and high quality compost manure to replenish and sustain their food reserves and simultaneously boost nutrition of the crop. The oil palm growers should be trained in user friendly techniques of compost making. The challenge is, the future calls for creation of biophysical tools capable of promoting successful and sustainable biota conservation within oil palm.

Key words: abundance, biomass, diversity, functional categories.

Introduction

Soil biota partially determines the functioning of soil in tropical ecosystems (Lavelle *et al* 1994a and b).Whereas use of inorganic fertilizers is an important part of oil palm management, the potential for manipulating beneficial soil faunal has seldom been considered in designing management practices (Lavelle *et al.*, 1994b). Practices that eliminate beneficial soil faunal communities threaten sustainable production in the long run.

According to ICIPE, (1997) diversity and role of soil fauna have been largely ignored by traditional and conventional agriculturalists due to limited knowledge on their impact on crop yields. The lack of knowledge is particularly crucial given that soil degradation in the tropics is partly related to drastic decline in activity and diversity of soil fauna (Bruyn, 1997).

The soil biota including soil microbial biomass and soil fauna provide the means and regulate the transformation of organically bound nutrients into plant available forms through mineralization (Lavelle *et al.*, 1994b).

As a new venture in Kalangala, oil palm growing automatically caused land use changes from traditional growing of both perennial and annual crops and natural vegetation to oil palm trees monoculture. When natural systems are modified by human activities for agricultural purposes, major changes occur to the soil environment (flora and fauna populations).

This promoted intensive use of inorganic fertilizers which could have induced changes in soil properties particularly in soil macro fauna populations and their ecological functions, subsequently causing continued decline of ecosystems.

Research to identify appropriate means of sustaining tropical soil productivity has intensified during the last two decades and some promising technologies have been proposed. The importance of biological processes for soil fertility conservation is known but there little understands of these processes in tropical cropping systems (Sanginga *et al.*, 1992), hence a need to explore.

The study investigated soil invertebrate macro fauna dynamics within oil palm plantations in Bugala Island Kalangala district, Uganda, specifically the relationship of soil invertebrate macro fauna with different soil chemical properties.

Materials and methods

Description of the study area

The studies were conducted in Bugala Island one of the biggest of a group known as 'Ssese Islands' in Kalangala District. The district is situated between S 010'100', Longitude: 0 ' E03201 and Altitude 1,500 m. The area has mean annual maximum and minimum temperatures of 25 ^{0}C &17.5 ^{0}C respectively, with total annual rainfall ranging between 1125 and 2250 mm. It experiences two distinct rainy seasons: first rains (March to June) and second rains (August to December).

Sample selection and design

Research activities were done during second season in August 2012. Six oil palm fields were purposefully selected in Mugoye Sub County.

Three farms were used as replicates for each growth stage three and six years under a randomized complete block design.

In each field, soils under the canopy of three oil palm trees were sampled. First tree to be sampled was randomly selected, while the rest were marked each on either side at 100 m away from the first tree.

Data collection procedures

Samples were taken using a monolith of 25 x 25 x 30 cm (Anderson and Ingram, 1993) , was sliced into three; 0-10, 10-20 and 20-30 cm depths and sorted depth wise for fauna.

Separated into major taxonomic groups then collected in Mc Cartney bottles using a pooter. Counting and recording of fauna was done in the laboratory upon which number and biomass of different category of organisms expressed per square metre. After counting, the soil fauna were preserved in 75% alcohol for subsequent identification carried out at Maker ere University in Kampala with expertise help.

$$X = \frac{y}{z}$$

X = individual animals per square meter

Y = individual animal counts found in a soil sample

Z = surface area of the monolith which is 25 cm x 25 cm; an equivalent of 0.0625m^2 expressed in terms of square meter.

Soil samples were taken to National Agricultural Research Organization (NARO) National Research Laboratory Institute (NaRLI Kawanda) for determining chemical properties. Due to the physical nature of most soils of Kalangala being of uniformly sandy texture (Kalangala district state of environment report, 2005) only chemical properties were analysed which included: pH, Organic matter and chemical elements like N, P, K, Ca and Mg.

Soil samples were obtained, air dried, ground, sieved through 0.5 mm mesh, analysed, extracted and determined according to procedures described by (Okelabo, *et al.,* 2002). The Soil pH was determined in a water suspension at a 2.5:1:/soil/water ratio.

Data analysis

The statistical analyses were made using SPSS software, and the method used was ANOVA. Soil analysis data on qualitative descriptors Organic matter, N, Ca, K, Mg, P and pH, were subjected to general Analysis of Variance (ANOVA) using GenStat computer statistical package. Means of the parameters were separated and compared using the Turkey`s Significant Difference at $P \leq 0.05$.

Results and discussion

Soil chemical properties across the oil palm plantations

Chemical properties of soil considered during the period of study included: soil nitrogen, phosphorus, potassium, calcium, magnesium and p.H which was below the critical value, indicating very acidic soils (p.H <5.2) Table 1.

These findings are comparable with those of Lavelle (1997) and Nor grove and Hauser(2000), that soil fauna numbers correlate with changes in land management which may lead to disruption or even depletion of soil macro faunal communities.

Table 1: Chemical properties of soils of oil palm plantations

Depth (cm)	p.H(2.5/H_20)	%OM	%N	Ph(ppm)	Ca(me/100g)	Mg(me/100g)	K(ME/100g)
0-10	3.73	9.76	.412	302	1.129	.545	.619
10-20	3.5	8.81	.366	282.8	1.045	.501	.308
20-30	3.48	8.41	.367	322.8	1.612	.682	.563
Critical values	5.2	3.0	0.2	5-15	1.3	0.6	0.4-.0.5

* Sources: Stephen (Quoted by Kizza *et al.*, 2002), Mirro *et al.*, (1lues998) and Okalebo *et al.*, (1993)

Taxonomic groups of soil invertebrate macro fauna within the oil palm plantations

The macro fauna observed during the study period were identified up to order levels. Ten taxonomic orders of soil invertebrate indicated in (Table 2) below were recorded.

Hymenoptera were the most abundant contributing to over 33.6% of the total macro fauna followed by *Isoptera, Coleoptera, Myriapoda, Orthoptera Isopoda*, *Chilopoda*, *Diptera*, *Araneae* and *Gastropoda* (Table 2).

These results were similar to what Ayuke *et al.,* (2009), Taita Kenya under tropical conditions and Mediterranean arid ecosystems Doblas-Miranda *et al.,* (2007). Similar results showing ants and termites dominance in soils under oil palm plantations were obtained by Sarah, 2010, in Malaysia.

Abundance and biomass of the soil invertebrate macro fauna.

The orders: Hymenoptera and Isoptera were the most important component within the ten with frequency of 33.6%, and 23.6% respectively.

However, the trend for biomass for macro fauna was not similar to that of abundance. The snails (*Gastropoda*) contributed the greatest biomass (77.96 g m^{-2}), followed by and millipedes *(Myriapoda*) (23.35g m^{-2}), though were less encountered with counts: 300 and 120 respectively, while *Diptera* flies contributed the least (0.27 g m^{-2}) (Table 4). This was expected because of the normal bigger sizes of both snails *Gastropoda* and millipedes *Myriapoda* compared to the ants *Hymenoptera* or termites *Isoptera* with counts 3190 and 1530, but with low biomass of (6.639g m^{-2} and 8.209g m^{-2}) respectively.

Table 2: Spatial distribution of SMF in soils under Oil palm plantations (n = 10)

Group/Order	Taxonomic units	Frequency
Hymenoptera	Ants	33.6
Isoptera	Termites	23.6
Coleoptera	Beetles	9.1
Myriapoda	Millipedes	4.5
Orthoptera	Cricket	4.5
Isopoda	Wood lice	3.6
Chilopoda	Centipedes	2.7
Diptera	Flies	0.9
Araneae	Spider	0.9
Gastropoda	Snails	0.9.

Table 3: Summary of results from ANOVA comparing soil depth, tree growth stage, root zone activity and soil organisms

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Soil depth	2	394.3	197.1	0.41	0.665
Tree growth stage	.14.277	.14277	.14277	4.53	0.034*
Root zone activity	2	2.443	1.221	0.38	0.683
Soil organisms	19	286.369	15.072	6.17	<.001**

Limited diversity of some (SMF and dominance of a few ants *Hymenoptera* or termites *Isoptera* could be due to intensified use of inorganic fertilizers leading to gradual soil degradation hence reduced (SMF), Nambuya, (2012).

Andersen, (1991) observed that due to their characteristics, ants adapt to a wide range of environmental alterations and hence they are frequently present in high numbers throughout the year.

Table 4: Abundance and biomass of SMF in Oil palm plantations. (n=10)

Type of organisms	Individual counts (m^{-2})	Biomass of organisms (g m^{-2})
Ants	3190	6.63
Termites	1530	8. 20
Beetles	910	17.9
Snails	300	77.96
Spider	130	1.22
Centipedes	130	2.22
Millipedes	120	23.35
Crickets	100	0.94
Flies	100	0.27
Wood lice	100	1.38

Effects of soil depth, root activity and growth stages of oil palm on ecological functional diversity of SMF

Ecological functional diversity was higher close to the oil palm plants in the root zone of inactive with mean of six and five for two zones active and canopy edge (Table 5). This could be attributed to minimal disturbance as compared to active and canopy edge where there has been continued tillage during oil palm management leading to reduced organic matter which is known to be source of nutrition for soil macro

fauna (SMF). Continued tillage could have also led to exposure of organic matter and during heavy rains some of it being swept away by erosion, together with SMF leading to their reduction in numbers and this remains a threat in future as far as their ecological functional diversity benefits are concerned. Organic matter reduction could have also been taken up by oil palm plants leading to its reduction. As organic matter reduces, there is also reduction in soil macro fauna (SMF), hence reduced ecological functional diversity. Use of organic manures such as compost manures would be the best alternative and avoid over dependence on application of inorganic fertilizers alone.

Table 5: Effects of soil depth, root activity and growth stages of oil palm on ecological functional diversity of SMF

Soil depth(cm)	No. of SMF categories	Biomass of SMF	Details of categories encountered
A-0-10	5	0.88*	+Epigeic,++Epigeic/Endogeic,+++Epigeic/Anecic.++++Anecie/Endogeic.
B-10-20	5	0.44*	Epigeic,Epegeic/Anecic,Anecic/Endogeic,
C-20-30	4	0.40*	Endogeic,Epigeic/Endogeic,Endogeic/Anecic,Anecic/Endogeic.
Root activity			
D-Inactive	6	0.70 n.s	Epigeic, Epigeic/Endogeic,Epigeic/Anecic,Anecie/Endogeic.
E-Active	5	0.60 n.s	Epigeic, Epigeic/Endogeic,Epigeic/Anecic,Anecie/Endogeic.
F-Canopy edge	5	0.50*	Epigeic, Epigeic/Endogeic,Epigeic/Anecic,Anecie/Endogeic.
Growth stage			
G-3 years	5	0.78*	Epigeic, Epigeic/Endogeic,Epigeic/Anecic,Anecie/Endogeic,
H-6years	4	0.36*	Epigeic, Epigeic/endogeic,epigeic/Anecic,Anecie/Endogeic,

(+Epigeic–Millipedes, Centipedes, Beetles, Spiders, Snails, Woodlice, ++Epigeic/Endogeic-Beetles, +++Epigeic/Anecic-Ants, +++Anecic/Endogeic-Termites

Means for biomass of organisms in different soil depths, root activity zones, and two growth stages in Oil Palm fields:

Biomass of organisms significantly ($P \geq 0.05$) and negatively correlated with soil depth, ($r = -0.107$). Biomass decreased with increase in soil depth, and was highest in soil depth of (0-10) (8.73 g m^{-2}) and lowest 20-30 cm (3.93 g m^{-2}), respectively (Table 6). This sharp vertical (soil depths) decline could have implied that only tinny organisms like ants *Hymenoptera* and some termites *Isoptera* were able to thrive in deeper soil layers but the heavy bodied macro fauna such as snails, slugs, millipedes, centipedes and earth worms could not.

Biomass of organisms significantly ($P \geq 0.05$) negatively correlated to individual counts. The negative correlation could be due to some bigger, fewer but heavier fauna like snails being more dominant in soil depth (0-10) while numerous but less heavy fauna such as ants and termites in deeper soil depths (20-30 cm).

Inactive region had the highest biomass of organisms at (6.92 gm $^{-2}$) and least in canopy edge (4.76 gm $^{-2}$), while (0-10cm) and three years of oil palm plantations doubled that of depths (10-20) and (20-30 cm) and six years Oil plantations respectively. This could be attributed to more intensified disturbance towards the edge of the canopy compared to close to oil palm trees due to agrochemicals and ring weeding, leading to exposed organic matter hence its reduction especially where there are high chances of soil erosion.

Mean biomass of (SMF) categories found in 0-10cm and three years of oil palm plantations doubled (7.82 gm $^{-2}$) that of other depths (10-20 and 20-30cm) and six years (3.60 gm $^{-2}$) respectively.

This may seem expected, but very important observations from this study, and could be attributed to high organic matter found around newly planted oil palm plants compared to older plants.

Table 6: Means for biomass of organisms in different soil depths, root activity zones, and two growth stages in oil palm fields

Soil Depth (cm)	Biomass of organisms (gm^{-2})
(0-10)	8.73*
(10-20)	4.35*
(20-30)	3.93*
Grand mean	0.594
F-probability	0.074
LSD(5% level)	0.4806
	298.8
Means for biomass of organisms in different root zone activities	
Root zone Activity	Biomass of organism (gm-2)
Inactive	6.92*
Active	5.85*
Up to canopy edge	4.76*
Grand mean	0.594
F-Probability	0.683
LSD(5% level)	0.4881
CV %	300.9
Means for biomass of organisms in different tree growth stages	
Tree growth	Biomass of organisms (gm^{-2})
3years	7.82 *
6years	3.60 *
Grand mean	0.594
F-Probability	0.034
LSD(5% level)	0.3904
CV%	298.7

*Significantly different ($P \geq 0.05$) for each parameter (Soil depth, root activity and tree growth stage

Conclusions and recommendations

The land use changes in Kalangala from smallholder mixed systems to a monoculture of oil palm plantations is associated with decline of macro fauna populations. The effect is largely due to reduction in food reserves both in quantity and quality which seem to be more realised under multiple plant species than now under oil palm monoculture plantations. Moreover, most of the oil palm plant residues are not easily decomposed. Now that people have established oil palm plantations at commercial scale, there is an urgent need to scientifically practice liming of soil and application of well nutrient balanced compost to provide required suitable soil conditions and source of food for rejuvenation of the beneficial soil macro fauna communities.

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Improving shelf life of legume inoculants in East Africa

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Abstract

Adoption of legume inoculation with rhizobia by small-scale farmers in East Africa, and the resultant increase in biological nitrogen fixation requires that quality inoculants meet minimum standards. In the case of BIOFIX, the only commercially-available inoculant in East Africa, that standard is at least 10^9 rhizobia g^{-1}. We examined the effects of carrier material and storage conditions on the populations of two industry standard rhizobia, *Bradyrhizobium* japonicum USDA 110 for soybean (*Glycine max*) and *Rhizobium tropici* CIAT 899 for common bean (*Phaseolus vulgaris*) over 165 days using the drop plate method on Congo Red Yeast Extract Mannitol Agar medium. Viable populations of rhizobia differed significantly between carriers ($P<0.001$) and rhizobia strain ($P<0.05$). *R. tropici* CIAT899 prepared with filter mud carrier achieved a shelf life of 135 days and *B. japonicum* USDA110 contained over 10^9 cells g^{-1} for 105 days. Both inoculants gave results which fell below the stated six month expiry period of BIOFIX. Replacing filter mud carrier with vermiculite resulted in an inferior product however both more thorough sterilization and refrigerated storage after a 14 day curing stage improved it. While BIOFIX meets reasonable standards in terms of its rhizobia, it must not be carried over between seasons. Even under refrigeration, its expiry period should be shortened and opportunity exists to improve its quality.

Key words: BIOFIX, CIAT 899, Kenya, legume inoculant, quality control, USDA 110.

Introduction

Wider use of legume inoculants by African small-scale farmers offers potential to supply a sustainable source of nitrogen and increase nutrient-use efficiency (Dieker *et al*,. 2011), two necessary components to overcome low farm productivity in Sub-Saharan Africa (Batiano *et al*. 2011). These low yields are pronounced in grain legumes and are often associated with declining soil fertility and reduced symbiotic biological nitrogen fixation (BNF) due to biotic and environmental stresses (Giller 2001). Greater availability of legume inoculants offers the potential to better manage BNF (Herridge *et al*. 2008) and substitute for inorganic nitrogen fertilizer (Sofi and Wani 2007; Sanginga and Woomer 2009; Woyessa and Assefa 2011) but the inoculants must be of suitable quality to nodulate legume hosts and offer strong economic returns (FAO 1984).

Nodulation is improved when the number of viable rhizobia inoculated per seed increases, as accomplished by having greater numbers of viable rhizobia in the inoculant or by delivering larger doses (Catroux *et al*. 2001). The key to ensuring high quality legume inoculants is an effective quality control system (Thompson, 1984), whether through internal monitoring or governmental regulation but where producers have little incentive to invest in quality control, some market poor inoculants (Beck *et al*., 1993).Thus, it is important to determine the duration of the bacteria survivability in the respective carrier materials to ensure the desired level of bacterial population remains viable for the inoculants to be effective (Kaljeet *et al*., 2011). Besides that, the carrier materials contained in solid inoculants should have properties that protect rhizobia and permit ease in application to seeds (FAO, 1984). Thus the objective of this experiment was to assess the shelf life of two industry standard rhizobia (*R*.CIAT899 and *B*.USDA110) within a commercially-available BIOFIX inoculant and to assess the means to improve its quality through better carriers, sterilization and storage temperatures

Materials and methods

BIOFIX legume inoculant recovered off the curing shelf from its production facility in Nakuru, Kenya was compared to alternative production approaches in the laboratory. Its carrier is filter mud recovered as sludge from the crushing vat of sugarcane processing. Dried filter mud and commercially-available horticultural vermiculite were ground by a hammer mill, sieved through 2.12 µm and wet to 35% field capacity. The chemical and physical characteristics of filter mud and vermiculite carriers were analyzed by the University of Nairobi Soil Analysis Laboratory and compared to that of a peat from North America (Table 1). Next, 10 g of non-sterile carrier was placed in polythene bags, sealed and autoclaved thrice for three hours at 121°C. *Rhizobium tropici* CIAT899 and *Bradyrhizobium japonicum* USDA110 strains were cultured in yeast extract mannitol broth for seven days on a rotating shaker, resulting in a log-phase broth culture of >10^8 cells ml^{-1}. The volume of inoculants added from broth culture was injected by sterile syringe at 50% of the water holding capacity of the respective carrier materials and then mixed with the carrier. The syringe punctured area was wiped with 70% alcohol and an adhesive seal was applied. These packets were then incubated at room temperature (about 24°C) as is the curing practice at the BIOFIX factory before refrigeration at 4°C and room temperature for 14 days , half of these packets was then refrigerated at 4°C and one other half was stored at room temperature. After 165 days, both experiments were evaluated.

Table 1: Physical and Chemical properties of the carrier used in the experiment and a peat used as carrier in North America

Carrier	Total C %	Total N %	Bulk density kg l^{-1}	Porosity %	Water holding capacity l kg^{-1}	pH
Filtermud	18.4	2.0	0.79	56	155	6.8
Vermiculite	2.1	0.1	0.98	63	152	6.6
Peat	29.1	1.8	0.82	45	200	7.8

A ten-fold serial dilution series to 10^{-7} was prepared from the inoculants after Miles and Misra (1938) and Somasegaran and Hoben (1985) . Three drops of 20 µL from the last three dilutions was plated onto Congo Red Yeast Extract Mannitol Agar with three replicates for each dilution. All plates were incubated at 28°C for 3-7 days. Only the number of colonies that grew in the range of 5 to 55 colonies were counted and colony forming units g^{-1} were back calculated. Occasional presence of fungal contaminants was also recorded. The number of rhizobia and occasional contaminants were counted at six times: 14, 45, 75, 105, 135 and 165 days after injection of broth cultures and compared to commercial BIOFIX. Each treatment was replicated five times in a completely randomized design (Herridge *et al.*, 2002). Effects of rhizobial strain, carrier, storage temperature and time, and their interactions were determined using the General Linear Model procedure of SAS version 9.2 (SAS Institute, 2008). This study was conducted at the Microbial Resource Center of the College of Agriculture and Veterinary Science, University of Nairobi between August 2012 and March 2013.

Results

The chemical and physical characteristics of the two test carriers and a North American peat appear in Table 1. Filter mud closely resembles peat but it has a lower water holding capacity and pH value. Vermiculite is an inorganic material with lower carbon and nitrogen, and greater bulk density but with high porosity. The population dynamics of two rhizobia in different carriers over time appears in Table 2. Four-way ANOVA of these data resulted in significant effects of carrier material ($p<0.001$), storage condition ($p<0.001$), strain ($p=0.01$) and time ($p<0.001$) and many key interactions including carrier x strain ($p=0.02$) and carrier x storage ($p=0.02$) and carrier x time ($p<0.001$) but not strain x storage or strain x day (data not presented). Contamination of inoculants only occurred in the commercial product among 35% of the samples containing fungi, averaging 0.58×10^6 g^{-1} at day 14, presumably through persistent spores (data not presented). Some contamination was also noted among other carriers late in the investigation (day 105 and 135), likely due to repeated sampling of packets.

The BIOFIX carrier represents the commercial product itself while filter mud is essentially a more thoroughly sterilized and carefully prepared alternative within the laboratory. BIOFIX displays a large initial increase followed by steady decline. More careful preparation of filter mud leads to larger populations and greater survival. Vermiculite does not support rhizobia, neither in terms of initial colonization nor longer-term survival. Note that the agreed industry threshold for inoculants in Kenya is a minimum of 1 x 10^9 rhizobia g^{-1}. The population dynamics of the two strains across all carriers and storage conditions is presented in Figure 1. CIAT 899 colonizes carriers better than USDA 110. After a 14 day curing interval, both populations increase to 45 days and then decline. After 105 days both strains exceed industry standards but not thereafter.

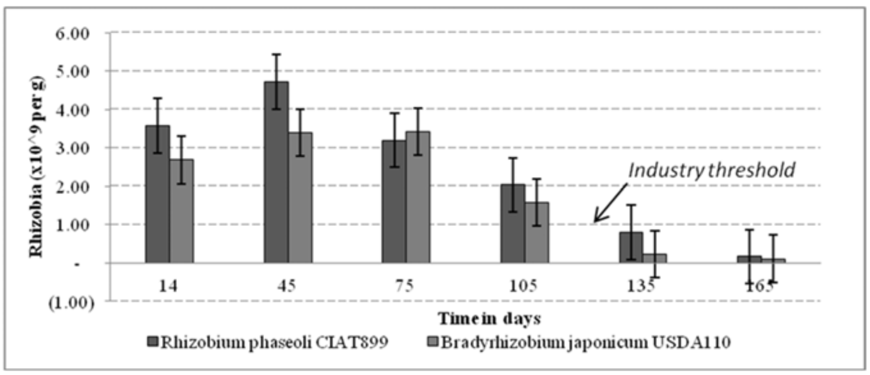

Figure 1: Populations of CIAT 899 and USDA 110 across the two carriers over time

Table 2: Survival of two rhizobia strains in inoculants containing different carriers over time (10^9cell g^{-1})

Carrier	Strain	Time in days[a]					
		14	45	75	105	135	165
		Rhizobia (x 10^9 cells g^{-1})					
BIOFIX	*R. phaseoli* CIAT 899	1.15	6.17	4.06	2.70	0.04	0.03
	B. japonicum USDA 110	1.13	5.60	5.62	1.86	0.21	0.04
Filter mud	*R. phaseoli* CIAT 899	8.79	6.20	5.00	3.14	2.30	0.44
	B. japonicum USDA 110	6.36	3.93	4.13	2.77	0.44	0.25
Vermiculite	*R. phaseoli* CIAT 899	0.78	1.77	0.53	0.27	0.06	0.04
	B. japonicum USDA 110	0.54	0.63	0.54	0.08	0.05	0.02

[a] $LSD_{0.05}$ carrier = 2.78, strain = 4.06 and time = 4.98

The effect of refrigeration on storage of BIOFIX inoculant containing USDA 110 is presented in Figure 2. The x-axis is presented as both days after injection and packing (after a 14 day curing period). Note that lower temperature results in higher populations with time and extends shelf life by 30 days. A similar trend was observed for CIAT 899 and MIRCEN filter mud, but not for vermiculite carrier as it lacked a pronounced population increase following inoculation (Table 1). Shelf lives of different inoculants is presented in Table 3. These values were calculated by interpolating the two values falling above and below 10^9 rhizobia g-1. However, in the case of some vermiculite carriers this could not be performed (Table 1).

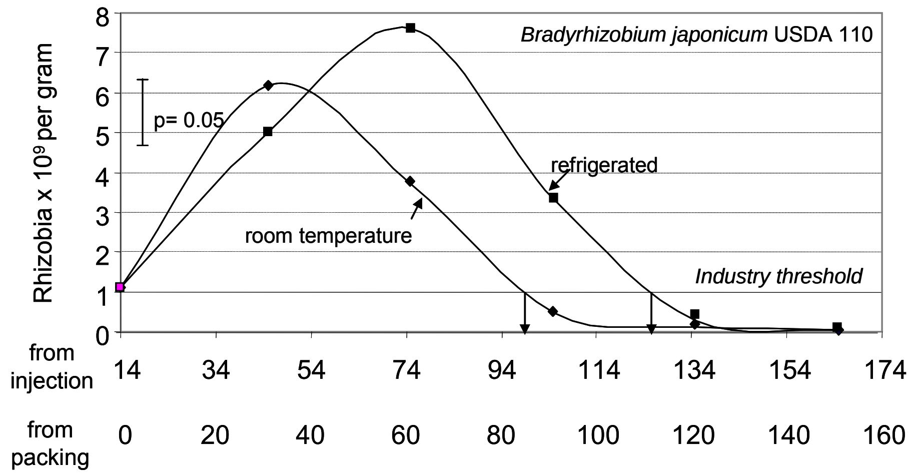

Figure 2: The effect of storage temperature on BIOFIX inoculant containing USDA 110 includes extended shelf life.

Table 3: Shelf life of different inoculant formulations including the 14 day curing period

Carrier	Storage	CIAT 899	USDA 110
		Days since injection	
BIOFIX	Room	131	100
BIOFIX	Refrigerator	132	130
MIRCEN	Room	131	127
MIRCEN	Refrigerator	134	129
Vermiculite	Room	n.a.	41
Vermiculite	Refrigerator	n.a.	43

Discussion

The persistence of two industry standard rhizobia, *B. japonicum* USDA 110 for soybean and *R. tropicii* CIAT 899 for bean in BIOFIX® legume inoculant was examined over time and possible alternatives to improve that inoculant compared. BIOFIX® is the only commercial legume inoculant produced in East Africa, and its improvement stands to benefit large numbers of African farmers. This inoculant is currently produced in Nakuru, Kenya, using a carrier material of sugar cane filter mud from the Muhoroni sugar factory in western Kenya. The factory sterilizes inoculant by autoclave, injects it with rhizobial broth, mixes the broth and carrier, cures the product for 14 days and then packages and ships (Wafulah 2013). The product has a stated shelf life of six months (about 180 days) from the time of injection. Because much of East Africa receives bimodal rainfall, the factory operates year round, and larger orders must be placed in advance, so the product is usually shipped shortly after curing and packaging, and the factory currently does not have refrigerated storage facilities. MEA Fertilizers Ltd., producers of BIOFIX® have adopted a quality standard of at least one billion (1×10^9) live rhizobia g^{-1} inoculant, as in Australia (Herridge *et al*. 2002). BIOFIX® meets this standard over much of its expiry period (Figure 1). However, this study also indicates that the

six-month shelf life may be too long, as both soybean and bean inoculants fell below that expiry interval by 80 and 49 days, respectively (Table 3).

Three approaches were considered to improve the inoculant formulation: altering its carrier material, manner of sterilization and lowering its storage temperature. The filter mud carrier was selected many years ago after careful comparison to other available sources such as coconut fiber, local peat and animal manure (Anyango *et al.* 1985; Kibunja 1985;). Its composition is not similar to pre-package sterilized peat from North America used to produce solid inoculants (Table 1). Filter mud is collected from the bottom of the crushing vat in sugar production. It is largely organic matter but contains some silt, slightly lowering its moisture holding capacity. One problem with this carrier material, however, the heavy contamination of the bulk material by other microbes. The Nakuru factory currently sterilizes the ground, sealed carrier by autoclaving, and over packing has caused problems with contamination in the past. This study found some fungal contamination in BIOFIX® (35% of samples, overall average of 0.58 x 10^6 g^{-1}, data not presented. This is much less than reported in the past and below the target standard of 1 x 10^6 g^{-1}. Nonetheless, when BIOFIX® was replicated at the MIRCEN laboratory, this contamination was eliminated with careful and repeated autoclaving, and we observed significantly higher populations in the inoculant, especially for CIAT 899 (Table 2) and extended shelf life for USDA 110 (Table 3). Attempts to substitute horticultural-grade vermiculite as a carrier were not successful as both rhizobia strains were less able to colonize and persist in this material (Tables 2 and 3).

Attempts to improve inoculant quality through refrigeration offered mixed and somewhat unusual results. Refrigeration of BIOFIX® from the production line immediately after curing resulted in slightly delayed colonization of the carrier material (Figure 2). However, this colonization continued for a longer period and larger populations were later achieved. What was not observed, however, was a greatly extended shelf live (Table 3) in large part because both room temperature and refrigerated inoculants both declined in a linear fashion following colonization of the carrier, but later attenuated (Figure 2). During this steady decline, the die-off of rhizobia is roughly between 90 and 170 million cells $g^{-1}d^{-1}$ (estimated from Table 2) although too few observations between the peak and attenuation reduces the strength of this observation. It was hoped that attenuation of refrigerated inoculant would fall above the industry threshold, but it did not. These findings disagree with Khavazi *et al*. (2007) who reported that the number of rhizobia in carrier was not significantly different after six months of storage. Lupwayi *et al*. (2000) expressed concern that inoculant quality declines quickly if contaminated. Swelim *et al* (2010) also emphasized the importance of complete sterilization of carrier, but even our numerous contamination-free samples displayed linear decline to levels below industry standard. One disadvantage of solid over liquid formulation inoculants is that contaminants may persist in carriers (NifTAL Project 1998; Woomer *et al.* 1999). Our findings also disagree with Boonkerd (1991) who reported differences in inoculant quality due to storage temperatures. However, the temperatures under study were 10°C vs 30°C, the higher temperature somewhat greater than room storage conditions in Nairobi's equatorial highlands.

The excessive die-off observed in this experiment may be attribuTable to the experimental conditions themselves and the need for curing. Dieker *et al*. (2007) reported that rhizobia survive best when changes in moisture status of cells are minimized. Yet at the same time, it is important to cure solid inoculants in a manner that slowly dries them, so that the cells harden and the solid formulation becomes friable rather than caked so it is more easily applied to seed. Curing itself is a two phase process where rhizobia first colonize the carrier, increasing several fold, but then populations decline as surviving rhizobia harden. At the BIOFIX® factory, inoculant is cured in sealed, semi-permeable plastic bags and later packaged into a labeled, airtight outer bag after 14 to 20 days for marketing. In this experiment, inoculants remained in their inner bags throughout the time series, and opened at sampling intervals. Between time, they were stored together in a sealed plastic container with likely different water vapor exchange properties than sealed commercial inoculant. The expediency of repeated sampling rather than preparing samples for individual time points may have altered the results. As no humidity measurements were made, this methodological consideration cannot be tested.

BIOFIX® legume inoculants for soybean and bean were shown to exceed their target industry standard of 1 x 10^9 rhizobia g^{-1} up to 100 and 131 days, respectively, somewhat less than its stated expiry date of six months. This suggests that the inoculant must be used the during the growing season for which it is produced and not carried over to the next, even when stored under refrigeration. More careful preparation of inoculants in the laboratory suggest that there is opportunity of slight improvement along its production line, particularly in better sterilizing the carrier and achieving higher populations several days following injection. Altering the carrier material from organic (filter mud) to mineral (vermiculite) material resulted in an inferior product, but search for a yet better carrier material and production approach, able to support greater than 1 x 10^9 g^{-1} over an extended shelf live should continue.

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Enhancing nitrogen fixation and productivity of dry beans in phosphorus and nitrogen limited in central Kenya through *Rhizobium*, *Azospirillum* rhizobacteria-*Rhizobium* co-inoculation

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Abstract

Bean productivity in the highlands of Kenya is on the decline due to low soil fertility with respect to N and P. The low bean productivity should be addressed by technologies that are based on locally available resources, conserve the environment and are sustainable. Co-inoculation of dry bean with *Azospirillum* and *Rhizobium* has the potential to enhance nitrogen fixation of bean genotypes in N and P limited conditions. The objective of the study was to determine growth and yield response of two bush bean varieties inoculated with *Azospirillum, Rhizobium* and a mixture of *Azospirillum* rhizobacteria and *Rhizobium* under high and low Phosphorus levels at KARI-Embu. The treatments were laid out in a randomized complete block design with a factorial arrangement and replicated four times. Results of four seasons' trials show that P application improved nodulation, grain and biomass production. Inoculation with *Azospirillum* increased the grain yield of bean line Embean 14 in high P soil by 11 kgha^{-1} compared to 97 kg ha^{-1} in low soil P, and bean line Nguaku nguaku in high P soil by 83 kgha^{-1} compared to 335 kg ha^{-1} in low P. Higher yield increases due to *Azospirillum* inoculation were realized in low P soils probably due to improved P uptake. Inoculation with *Rhizobium* increased the grain yield of line Embean 14 by 228 kg ha^{-1} in high P soil compared to 27 kgha^{-1} in low P soil, and line Nguaku nguaku grown in high P soil by 253 kg ha^{-1} compared to 83 kg ha^{-1} when grown in low P soil. *Rhizobium* inoculation resulted higher increase in grain yields in high P soils. Co-inoculation with both *Azospirillum* and *Rhizobium* increased the grain yield of line Embean 14 by 307 kg ha^{-1} in high P soil compared with 146 kgha^{-1} in low P soil. Line Nguaku nguaku increased grain yield by 200 kg ha^{-1} in high P soil and 146 kg ha^{-1} in low P soil. *Rhizobium* CIAT 899 strain was superior in grain yield improvement than the native *Rhizobium* and that that co-inoculation with *Rhizobium* and *Azospirillum* improved grain yields of beans in high and low P soils.

Introduction

In Kenya, bean (*Phaseolus vulgaris* L.) is second to maize in importance as a major grain food crop. The national annual dry bean production is about 380,000 metric tons while the national pulse annual demand is 749,000 t (NDP, 2002-2008). The deficit of 379,000 t is imported from the neighbouring contries of Tanzania, Uganda and Ethiopia.

Dry bean production is predominantly practiced by small-scale farmers and has been on the decline due to various constraints; the major ones being plant diseases, low soil fertility and insect pests (Otsyula and Ajanga, 1995). Small-scale farmers do not apply external inputs such as fertilizers, Rhizobium inoculants, fungicides and pesticides. Production per hectare has declined from 800 kg ha^{-1} in 1990 to less than 500 kg ha^{-1} while the potential yield is over 1,500 kg ha^{-1} (MoA, 2005).

Common bean production in Kenya is mainly in highland and midlands. About 75% of the annual cultivation occurs in three regions namely; Rift valley, Nyanza, and Eastern Province. In terms of output, the rift valley contributes the biggest share, accounting for 33% of the national output followed by Nyanza and Western province accounting for 22% each. Output from Eastern parts of the country and the coast is constrained by adverse climatic conditions. Drought stress in the Eastern Kenya is prominent in impeding bean production.

Although Kenya has two seasons for common bean, a significant number of farmers grow the crop once a year because of adverse climatic conditions. The Rift valley and the Western region which respectively produce 33% and 22% of the national outputs allocates land to common beans once a year, during March-May season (also referred to as long rains) while farmers in the central and Eastern regions grow beans twice a year. Only 70% of the farmers in the Eastern region grow beans during the long rains. Almost all farmers in Central and Eastern regions grow common bean during the short rains (October to December).

The low input production systems of common bean in Kenya is likely to persist and this will continue to favour the spread of small to medium size varieties, particularly, red or red mottled because of the varieties' preference in making the traditional recipe, Githeri (maize and beans cooked together). There is a moderate to high growth potential for Githeri due to increased demand from low-income population in urban areas (Katungi *et al.,* 2009). An experiment was conducted in Embu to determine the influence of inoculants rhizobium, azospirillum rhizobium and azospirillum coinoculation and no inoculants on bean production and performance.

Materials and methods

Field trials were carried out KARI Embu field site on-station for four seasons. Two bean varieties that had been found to be competent in biological nitrogen fixation Embean 14 and Nguaku nguaku were used together with BAT477 NN- a non-nodulating bush bean variety used as a reference crop. The bean varieties were either inoculated with Rhizobium CIAT 899 (100 g package for 15 Kg. seed rate) and Azospirillum brasilense sp.245 (15 ml solution per Kg bean seed) and coinoculated at combined strengths, or not inoculated as appropriate. Triple Superphosphate was applied in the appropriate plots at the rate of 200 kg ha^{-1} and at 0 kg ha^{-1}. The experiment was laid out as a Randomized Complete Block Design with a factorial treatment arrangement experiment with the following treatment combinations as shown below.

Trt. code	Bean variety	Inocula	Phosphorus
A	Embean 14	Azospirillum	+P
B	Embean 14	Azospirillum	0 P
C	Embean 14	Rhizobium	+P
D	Embean 14	Rhizobium	0 P
E	Embean 14	Rhizobium + Azospirillum	+P
F	Embean 14	Rhizobium + Azospirillum	0 P
G	Embean 14	No inoculation	+P
H	Embean 14	No inoculation	0 P
I	Nguaku	Azospirillum	+P
J	Nguaku	Azospirillum	0 P
K	Nguaku	Rhizobium	+P
L	Nguaku	Rhizobium	0 P
M	Nguaku	Rhizobium + Azospirillum	+P
N	Nguaku	Rhizobium + Azospirillum	0 P
O	Nguaku	No inoculation	+P
P	Nguaku	No inoculation	0 P
Q	BAT477 NN	No inoculation	+P
R	BAT477 NN	No inoculation	0 P

Each of these treatment was planted in three-five meter row and the trial was replicated four times. The seeds were planted in moist soils and soil was not allowed to dry as irrigation was arranged.

The data taken included: nodule count from 3 plant per row taken at flowering; nodule dry weight; foliage fresh weight and dry weight; root fresh and dry weight; chlorophyll measurements using A porTable hand-held device developed by the Soil-Plant Analyses Development (SPAD) Unit called the SPAD chlorophyll meter model 502 was used with the measurements taken at three weeks, six weeks and nine weeks after

planting; days to flowering and days to maturity; total dry matter yield and total grain yield were recorded and analysed. Genstat statistical package was used for analysis of variance. Means were separated using least significant difference at 95% significance interval.

Results

Chlorophyll content

Embean 14 had lighter green colour than Nguaku nguaku.

Table 1: Chlorophyll SPAD measurements taken at 42 days after planting showing measurements on both bean varieties at low P and high P combined with different inoculants

Inoculant	Embean 14		Nguaku nguaku	
	+P	0 P	+P	0 P
Azospirillum	34.02	34.24	35.35	35.68
Rhizobium	33.97	33.48	35.88	36.29
Azos + Rhizo	33.67	34.18	35.66	36.25
None	34.59	34.29	36.45	36.07

High P soils recorded lower chlorophyll reading compared to the low P soils.

Azospirillum

Azospirillum inoculation resulted in the lowest chlorophyll measurements in Nguaku nguaku in either low P soil or in high P soil. Azospirillum inoculation on Embean 14 resulted in the highest chlorophyll measurements among the inoculated bean seeds.

Rhizobium

Inoculation of bean seeds with rhizobium resulted in low chlorophyll measurements of Embean 14 and Nguaku nguaku in high P soils and low P soils compared to non inoculated except in Nguaku nguaku in low P soils.

Rhizobium + Azospirillum coinoculation

Similar observations as the rhizobium above.

Table 2: Showing nodulation of bean varieties as affected by inoculation and phosphorus levels

Inoculant	Embean 14		Nguaku nguaku	
	+P	No P	+P	No P
Azospirillum	6	2	7	1
Rhizobium	7	2	7	5
Azos + Rhizo	7	2	6	3
None	9	4	9	3

Application of phosphorus influenced nodulation. Nodulation with the local Rhizobium was influenced by phosphorus application. Inoculants did not seem to influence nodulation.

Table 3: The number of pods per plant of bean varieties as influenced by inoculants and phosphorus levels

Inoculant	Embean 14		Nguaku nguaku	
	+P	No P	+P	No P
Azospirillum	10	10	8	8
Rhizobium	11	9	9	7
Azos + Rhizo	11	10	9	7
None	10	8	8	7
Cv	25	25	25	25
Lsd	3	3	3	3

Embean 14 had more pods per plant than Nguaku nguaku. The number of pods per plant improved marginally with improved P in the soil. Inoculants improved the number of pods per plant of Nguaku nguaku in high P soils and not in low P conditions. Embean 14 had slightly higher response compared to Nguaku nguaku in low and high Phosphorus conditions.

Table 4: The number of seeds of the bean varieties as influenced by inoculants and phosphorus levels

Inoculant	Embean 14		Nguaku nguaku	
	+P	No P	+P	No P
Azospirillum	40	39	28	27
Rhizobium	43	33	29	25
Azos + Rhizo	44	40	30	26
None	38	32	25	23
Cv	28	28	28	28
Lsd	9	9	9	9

Embean 14 resulted in higher number of seeds per plant compared to Nguaku nguaku. The number of seeds per plant was higher in high P soils compared to low P soils.

Azospirillum inoculation resulted in improved seeds per plant in low P soil.

Table 5: The grain yield of bean varieties as influenced by inoculants and phosphorus levels

Inoculant	Embean 14		Nguaku nguaku	
	+P	No P	+P	No P
Azospirillum	2007	1890	1327	1371
Rhizobium	2224	1820	1497	1119
Azos + Rhizo	2303	1939	1444	1182
None	1996	1793	1244	1036
Cv	28	28	28	28
Lsd	678	678	678	678

Embean 14 resulted in higher grain yield than Nguaku nguaku. Embean14 in low P soil resulted in about 1800 kg ha^{-1} compared to Nguaku nguaku with about 1000 kg ha^{-1}. Embean 14 in high P soil resulted in grain yield of 2000 $kgha^{-1}$ compared to Nguaku nguaku with 1250 $kgha^{-1}$

High phosphorus soils improved grain yield by about 200 kg ha-1 in both bush bean varieties.

The contribution of inoculants to yield increase in low P soils and high P soils of each bean variety were as shown in the Table below.

Table 6: The contribution of inoculants and percent increase to grain yield of Embean 14 at low P and high P

	Embean 14			
	+P	Contribution to yield (kg ha^{-1})	0 P	Contribution to yield (kg ha^{-1})
Azospirillum		11 (0.55%)		97 (5.41%)
Rhizobium		228 (11.43%)		27 (1.51%)
Azos + Rhizo		307 (15.38%)		146 (8.14%)
None		0		0

Azospirillum

The contribution of azospirillum to yield increase of Embean 14 in high P soil was minimal- 11 kg ha^{-1} compared with 97 kg ha^{-1} in low P soil. This was 10 times higher in low P over the high P soil.

The contribution of azospirillum to yield increase of Nguaku nguaku in high P soil was little 83 kg ha^{-1} compared with 335 kg ha^{-1} in low P soil. This increase was significant (32.34%). These observations revealed that the influence of azospirillum was higher in low P soils. It also revealed that varietal difference in yield response was evident.

Table 7: Contribution of inoculants and percent increase (kg ha^{-1}) to grain yield of Nguaku nguaku at low P and high P

	Nguaku nguaku			
	+P	Contribution	No P	Contribution
Azospirillum		83 (6.67%)		335 (32.34%)
Rhizobium		253 (20.34%)		83 (8.01%)
Azos + Rhizo		200 (16.08%)		146 (14.09%)
None		0		0

Rhizobium

The contribution of rhizobium to yield increase of Embean 14 in high P soil was 228 kg ha-1 compared with 27 kg ha-1 in low P soil.

The contribution of rhizobium to yield increase of Nguaku nguaku in high P soils was 253 kg ha^{-1} compared with 83 kg ha^{-1} in low P soil.

These observations reveal that the influence of rhizobium was high in high P soil and low in low P soils.

Rhizobium-azospirillum coinoculation

The contribution of rhizobium-azospirillum coinoculation to Embean 14 in high P soil to grain yield was 307 kg ha-1 and 146 kg ha-1 in low P Soil. In both high P and low P soils the yield increments of coinoculations was higher than for individual inoculants.

The contributions of rhizobium-azospirillum coinoculation to Nguaku nguaku in high P soil to grain yield was 200 kg ha^{-1} and 146 kg ha^{-1} in low P soil. Coinoculation resulted in significant yield improvement in both low P and high P soils.

Follow guidelines on caption for Tables and Figures throughout your document

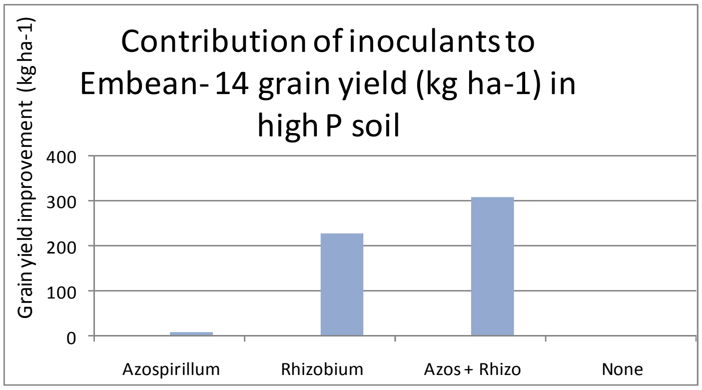

Figure 1: The contribution of inoculants to the grain yield in $kgha^{-1}$ of Embean 14 on high P soil

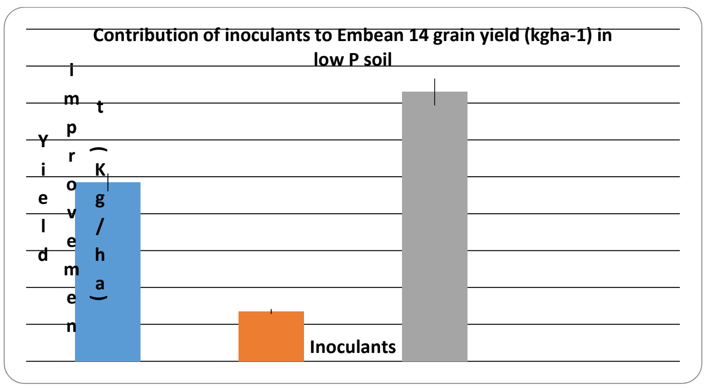

Figure 2: Showing the contribution of inoculants in $kgha^{-1}$ to Embean 14 grain yield in low P soil

Azospirillum

Azospirillum inoculated on Embean 14 in low P soil improved the grain yield by 5.41% compared with yield improvement of 0.55% under high P soil. Similarly, azospirillum inoculated on Nguaku nguaku in low P soil improved the grain yield by 32.34% compared with yield improvement of 6.67% under high P.

The following observations can be made:

- Azospirillum improved the grain yield of Nguaku compared to the increase of Embean 14.
- Azospirillum had higher improvement of grain yield of beans in low P soils compared to the grain yield at high P soil.
- Azospirillum had minimal improvement in grain yield in high P soils

Rhizobium

Rhizobium inoculated on Embean 14 in low P soil had minimal improvement (1,51%) on the grain yield compared with the yield improvement under high P soil (11.43%). Rhizobium inoculated on Nguaku nguaku in low P soil improved grain yield by 8.01% compared to 20.34% in high P soil.

The following observations can be made:

- Inoculation with rhizobium improved the grain yield of Nguaku nguaku more than Embean 14 both at low P and high P soils.
- Though improvement of grain yield of Nguaku nguaku was higher the total grain yield was higher for Embean 14
- Rhizobium had higher grain improvement under high P soils compared to the low P soils.
- Rhizobium had minimal grain improvement in low P soils

Rhizobium +Azospirillum coinoculation

Embean 14 coinoculated with rhizobium and azospirillum in low P improved the grain yield under low P by 8.14% compared with 15.38% improvement under high P. This was higher than any individual inoculant. Coinoculation of Nguaku nguaku resulted in grain yield improvement of 14.09% under low P compared to grain yield improvement of 16.08% under high P.

The following observations can be made:

- Coinoculation improved the grain yield of both bean varieties.
- Coinoculation improved grain yield significantly in low P soils.
- Coinoculation improved grain yields significantly in high P soils

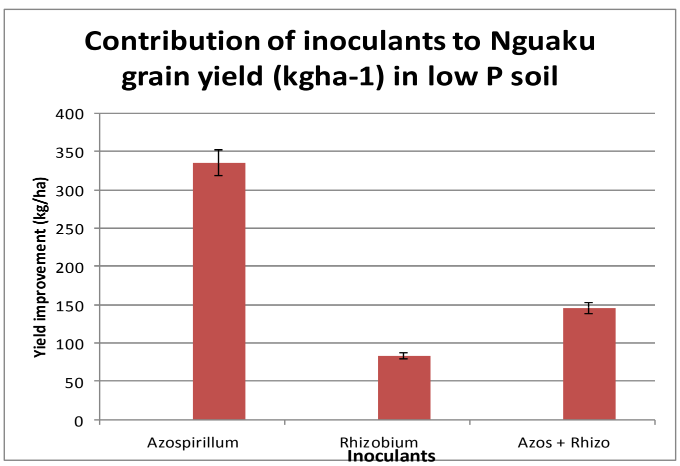

Figure 3: The contribution of inoculants in kgha^{-1} to Nguaku nguaku grain yield in low P soil

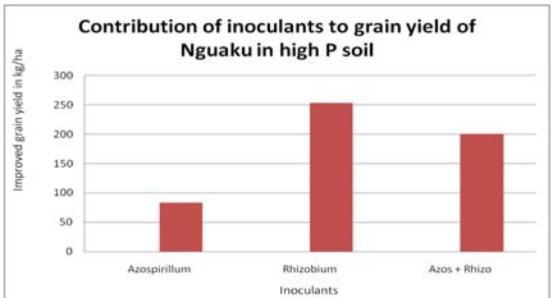

Figure 4: Contribution of inoculants in kgha^{-1} to Nguaku nguaku grain yield in high Phosphorus soil

Table 8: The biomass production of bean varieties as influenced by inoculants and P

Inoculant	Embean 14		Nguaku nguaku	
	+P	No P	+P	No P
Azospirillum	4333	4118	3255	2968
Rhizobium	4860	3942	3343	2484
Azos + Rhizo	4938	4200	3316	2808
None	4435	3706	3192	2759

Phosphorus improved biomass yield in Embean 14 from 3706 kg ha^{-1} to 4435 kg ha^{-1} an increase of 729 kg ha^{-1}. A 20% increased yield. The biomass yield of Nguaku nguaku was increased from 2759 kg ha^{-1} to 3192 kg ha^{-1}, an increase of 433 kg ha^{-1}. A 16% increased yield.

Table 9: Contribution of inoculants to percentage biomass yield (kg ha^{-1}) increase in low P soils and high P soils of Embean 14 variety

	Embean 14			
	+P	Contribution to biomass	No P	Contribution to biomass
Azospirillum		0 (0 %)		412 (11.12%)
Rhizobium		425 (9.58%)		236 (6.37%)
Azos + Rhizo		503 (11.34%)		494 (13.33%)
None		0		0

Higher yield increases were realized in Embean 14 compared to Nguaku nguaku.

Table 10: Contribution of inoculants to percentage biomass yield (kg ha^{-1}) increase in low P soils and high P soils of Nguaku nguaku variety

inoculant	Nguaku nguaku			
	+P	Contribution to biomass	No P	Contribution to biomass
Azospirillum		63 (2.0%)		209 (7.58%)
Rhizobium		151 (4.73%)		0 (0.0 %)
Azos + Rhizo		124 (3.9%)		49 (1.78%)
None		0		0

Azospirillum

Azospirillum had little influence on biomass production in high P soils but had significant increase of biomass in low P soils. Embean 14 resulted in higher biomass yield increases in low P Soil (412 kg ha^{-1}) 11.12% compared to Nguaku nguaku (209 kg ha^{-1}) 7.58%.

Rhizobium

Rhizobium inoculation contributed little to the biomass yield in low phosphorus soils and high influence in high P soils. Embean 14 in low P soil resulted in higher biomass yield increases (236 kg ha-1) than Nguaku nguaku in low P soil (negative).

In high P soils Embean 14 resulted in higher biomass increase (425 kg ha^{-1}) compared to Nguaku nguaku (151 kg ha^{-1}).

Rhizobium + Azospirillum coinoculation

Coinoculation of Rhizobium and Azospirillum improved the biomass yield of beans in both high P and low P soils.

Embean 14 resulted in higher improved biomass yield in both high P soils and low P soils compared to Nguaku nguaku. Embean 14 in high P soils had 503 kg ha^{-1} (11.34 % improved biomas yield) and 494 kg ha^{-1} from low P soils (13.33% improved biomass yield).

Nguaku nguaku resulted in less dramatic yield improvement than Embean 14. In high P soils Nguaku nguaku improved biomass yield improvement of 124 kg ha^{-1} (3.9%) compared to 49 kg ha^{-1} (1.8%) in low P soils.

Discussion

Phosphorus nutrition influenced nodulation of the beans used in this trial. Where high levels of available P were applied there was rise in the nodule population. Nodules are an important sink for Phosphorus since they require high levels of ATP for nitrogenase functioning (Al-Niemi *et al.,* 1998). Nodules contain three times more phosphorus concentrations compared to other tissues. Phosphorus deficient plants exhibit reduced carbohydrate supply to nodules and are usually restricted in nodule initiation, development and growth and in both nitrogenase activity per plant and per unit nodule tissue (Olivera *et al*. 2004). Plants display a variety of adaptations to low phosphorus availability, including root-hair elongation,and proliferation, rhizosphere modification and modification of root architecture to maximize phosphorus acquisition efficiency (Lynch, J.P.and Brown,K.M. 2001; Hinsinger, P. 2001; Ryan, P.R. *et al* 2001)

Measurements of the chlorophyll content of the leaves revealed that a bean variety grown in low P soil recorded higher chlorophyll content compared to the same variety grown in high P soil with no addition of nitrogenous fertilizer. Nguaku nguaku is dark green compared to Embean 14 when grown in the same environmental conditions. The plants under high phosphorus were more vigorous than those growing in low P soil. Though these plants have taken equal amounts of nitrogen from the soil, the growth associated with increased intake of phosphorus redistributed the Nitrogen in the plant to a larger area thereby diluting the N content per unit area. This could explain the low chlorophyll content in high P soil. The low chlorophyll measurement reported in Azospirillum inoculated Nguaku nguaku could be explained in a similar manner. A plant inoculated with azospirillum was able to pick more P from the soil thereby increasing its growth and redistribution of plant nitrogen in a wider area thereby lowering the chlorophyll measurement in the inoculated plants. According to Lambrecht and coworkers (2000) who proposed a model for *Azospirillum*-plant interactions, *Azospirillum* is attracted by plant root exudates and moves towards the rhizosphere. In the rhizosphere bacterial production of IAA triggers proliferation of lateral roots and root hairs and consequently enhances nutrient uptake which contributes to plant growth.

Rhizobium and Azospirillum fall into the category of plant growth promoting rhizobacteria (PGPR). The PGPR exert positive effects on plants by various mechanisms, including secretion of plant growth regulators such as auxins, gibberellins and cytokinins that stimulate metabolic activities in the roots as well

as by supplying biologically fixed nitrogen. The objective of the trial was to investigate the influence of the microbes singly and in combination on growth and performance of bean varieties in low P and high P soils. *Azospirillum* when used on beans in low phosphorus soil was more effective on improving plant growth variables compared to when used on bean plants in high phosphorus soil. *Azospirillum* has been found to improve grain yield of beans grown in low P soil by 5% above the uninoculated beans to 32% depending on bean varieties. Biomass yield in low P soil was also improved by 7.5% to 11%. It was also evident from the trial that *Azospirillum* had little influence on beans grain yield in high P soils where the yield improvement ranged from 0.5 % to 6.6% while the biomass yield ranged from 0-2.0 %. These results reveal that *Azospirillum* is involved with making the limited soil phosphorus available to beans.

Rhizobium, when inoculated on beans planted in low P soil, was less effective on improving plant growth variables compared to when used on bean in high phosphorus soil. *Rhizobium* inoculation in low phosphorus soil marginally improved grain yield of beans. Under nitrogen fixing conditions, low P availability is a major bottleneck to legume performance. Nodules are an important sink for P since they require high levels of ATP for nitrogenase functioning (Al-Niemi *et al.,* 1998,Vadez *et al.,* 1997). Nodules are an important sink for P since they require high levels of ATP for nitrogenase functioning (Al-Niemi *et al.*2004). Phosphorus is needed for plant growth, nodule formation and development, and ATP synthesis, each process being vital for nitrogen fixation (Broughton *et al* 2003).

Coinoculation of Rhizobium+Azospirillum improved grain and biomass yield both at low P and high P soils in both bean genotypes (Embean 14 and Nguaku nguaku) Embean 14 coinoculated with rhizobium and azospirillum in low P improved the grain yield under low P by 8.14% compared with 15.38% improvement under high P. This was higher than any individual inoculant. Coinoculation of Nguaku nguaku resulted in grain yield improvement of 14.09% under low P compared to grain yield improvement of 16.08% under high P. In both cases of coinoculation there was higher yield improvement from low P soils to high P soils. Coinoculation performed best with Embean 14 compared to Nguaku nguaku. Nguaku nguaku under low P soil conditions performed best with single Azospirillum inoculation while under high P soil condition the same variety performed best with single Rhizobium inoculation. Coinoculation of the same variety under both soil conditions improved grain yield significantly.

Similar observations were made with biomass yield under high P soil and low P soil. Embean 14 displayed better performance under coinoculation compared to Nguaku nguaku.

Coinoculation may allow bacteria mixtures to interact synergistically, by providing nutrients, removing some inhibitory products, or stimulating each other through physical or biochemical mechanisms. Coinoculation of *Azospirillum brasilense* sp 245 with *Rhizobium* on bean genotypes across different environmental settings in Cuba demonstrated differential responsiveness (Remans, 2007). Coinoculation of *Azospirillum-Rhizobium* on bean genotype DOR364 increased grain yield by 8% to 29% and the amount of N by 2-43% compared to single rhizobium inoculation. Inoculation with PGPR can stimulate the Rhizobium-bean symbiosis under conditions of low available phosphorus. However, the outcome is strongly dependent on the bean genotype used. Dual inoculation of legumes with *Azospirillum* and *Rhizobium* has been found to increase several plant-growth variables when compared with single inoculation. *Azospirillum* is considered a *Rhizobium* helper by stimulating nodulation, resulting in more nodules being formed (Bashan and Holguin 1997).

Conclusion

The decline in soil fertility in crop production areas need to be addressed if sufficient food production has to be realized. The low nitrogen and phosphorus need huge capital resources to avail these nutrients to the farmers. The farmers have to buy these inputs and therefore this reduces their profit margins Did you get this from your study?If not delete.

Biological nitrogen fixation is a natural process that takes place in legumes and this influences legume production. Inoculation with rhizobium can complement the nitrogenous fertilizer in legume production. Since phosphorus is important in BNF and needs to work together with rhizobium in order to maximize

production, a cheap source of P should be made available for the legume production to have reduced costs. Through these experiments it has been proven that Azospirillum plays a vital role of making the scanty soil phosphorus available to beans.

Acknowledgement

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Conservation Agriculture effects on Earthworm Populations in Western Kenya and Eastern Uganda Soils

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Abstract

High population pressure and poverty levels in Western Kenya and Eastern Uganda have led to continuous cultivation of land aimed at achieving a sTable food supply for the ever growing population resulting in a decline in food crop production and decline in soil quality over the years. Studies have underlined the advantages of Conservation Agriculture towards improving crop production and replenishment of soil fertility; increase in crop yields, increase in soil organic matter content and decrease in runoff and hence aid in controlling soil erosion. However, the mechanisms responsible for these improvements have not been fully explored. Studying soil biodiversity can help in understanding the dynamics of soil structure and the replenishment of nutrients. The population of soil invertebrates and soil pH in relation to Nitrogen application (+N and -N) were therefore studied under maize, beans and mucuna crops: 3 tillage systems; 1) No-Till (NT), 2) Conventional Tilage (CT), 3) Minimum Tillage (MT), and 3 cropping systems; 1) Strip cropping, 2) Intercropping with Mucuna riley, and 3) Maize-Beans intercropping as done by the locals. A total of 20g of soil from a depth of 0-20cm was used at vegetative stage and before harvest, all sampled on a rainy day. From management perspective, tillage systems affected macroorganisms population densities differently with the order of highest to lowest; MT< NT <CT. There was a strong correlation between macrofauna numbers, and the amount and quality of residue returned to the soil as it was evident in the experimental plots with mucuna cover crop. The different Nitrogen fertilization regimes of +N and -N had strongest positive effect on earthworm population and density in a strip cropping system combined with MT, with Mucuna strip and +N recording the highest number of macrofauna (especially termites, earthworms, millipedes, centipedes) followed by beans plots (+N) and maize plots(+N). A negative correlation was realized between soil pH and earthworm population, with the population significantly reducing with soil pH below 5.00 ($P<0.001$). Residue returned to the soil under MT was decomposed by the increased number of soil macrofauna under mucuna cover crop plots and hence resulted to improved soil quality.

Keywords: Soil fertility; Soil structure; Tillage; Cover crop; Soil biodiversity; Soil macrofauna; Nutrients; Soil pH; Soil Quality.

Introduction

Conservation Agriculture Production System (CAPS) have been widely promoted as low-input technologies suiTable for soil fertility replenishment and increasing the yields of legumes and most importantly maize, the staple crop, in smallholder agriculture in Eastern Africa (Sanchez 2002; Mafongoya *et al*. 2006). Tillage systems together with cropping and fertility replenishment regimes have been combined with the aim of improving soil quality besides improving crop yields. Cropping systems that include fast-growing leguminous species that produce large quantities of biomass have been recommended for use towards improved soils and crop production (Mafongoya *et al*. 1998a,b; 2006). Most of the studies on CAPS have concentrated on the effect of legume improved fallows on maize yield, soil moisture retention capacity, as well as changes in chemical properties such as soil organic matter content (Barrios *et al*. 1997), nitrogen mineralization and physical properties (Mafongoya *et al*. 1998a,b; Chirwa *et al*. 2004). Whilst soil invertebrates are the major determinants of soil processes such as organic matter decomposition and

nutrient cycling (Lavelle *et al*. 2003), the potential for manipulating the beneficial soil animals has rarely been studied in Western Kenya and Eastern Uganda. Little attention has been paid to monitoring the effects of legume-cereal related cropping systems on species on the soil biota. Sileshi and Mafongoya (2006) indicated the need for detailed studies on the effect of the quantity and quality of organic inputs produced by agroforestry species on soil biota to develop recommendations on species selection and management.

Literature Review

Cover crops protect the soil from splashing rains where they reduce rain drop impact leading to reduced surface run-offs. Cover crops protect soil from excess solar radiation and reduce surface crusting and high fluctuation in soil temperature and moisture in semi-arid areas. They improve soil physical, chemical, biological and economic properties (Triomphe and Sain, 2004) thus improving the soil structure.

Under conventional tillage soil organic matter is lost easily (Tenywa, 2000; IIRR, 2002). Inversion of the top soil speeds up the breakdown of organic matter (oxidation) resulting in nutrient losses (Jonsson, *et al*., 2000) as well as reduced level of food and good habitat for the soil invertebrates. Conservation tillage reduces soil manipulation, saves on labour requirement and improves soil productivity by minimizing compaction and improves soil moisture storage within the plough layer thus reducing soil and water losses (Kaumbutho, 2000).

While conservation agriculture is not new for large-scale farmers, some of whom have practiced it for the last three decades, small-scale farmers are struggling to change their mindset from intensive to zero tillage. The goal of conservation agriculture is to maintain and improve crop yields and land resilience against drought and other hazards while at the same time protecting and stimulating the biological function of the soil. Conservation agriculture is closely related to conservation tillage. According to Unger *et al*. (1988) conservation tillage embraces crop production systems involving management of surface residue. No tillage, minimum tillage, reduced tillage and mulch tillage are terms synonymous with conservation tillage (Willis and Ameniya 1973; Lal 1973, 1974, 1976; Phillips *et al*. 1980; Greenland 1981; Unger *et al*. 1988, Antapa and Angen 1990; Opara-Nadi 1990; Ahn and Hintze 1990). Conservation agriculture also involves planning crop sequences over several seasons to minimize the build-up of pests or diseases and to optimize plant nutrient use through synergy between crop types and by alternating shallow-rooting with deep-rooting crops. While this is the classical description of conservation, farmers in the study area still hold on to conventional tillage. Generally, conservation agriculture states that soil is a habitat for roots and soil organisms and that any damage to it endangers soil fertility and leads to land degradation. Either a planned cropping system or a permanent soil cover is the only way to protect, feed and regenerate the soil as a habitat. Besides conventional tillage practices, burning of plant residue as a means of land clearing together with incorporation of organic matter or plant residue into the soil, disrupt soil life and structure, removes the soil cover, and destroys humus by enhancing organic matter mineralization.

Materials and Method

A field experiment was conducted from February,2011 to February, 2013 in Bungoma and Kitale located in Bungoma and Trans-Nzoia counties in Western Kenya region respectively, and Kapchorwa and Tororo districts in Eastern Uganda. Bungoma and Tororo sites have two rainy seasons distribution: the long rains in March- August and short rains from September to November. The Tororo and Bungoma sites lie next to each separated by a common Kenya-Uganda border with population densities averaging 129–456 persons per square kilometer (Wortmann and Eledu, 1999), are poorly endowed with natural resources. The region has mostly soils that are sandy, with low soil organic matter levels, highly susceptible to leaching, and consequently low in base saturation and rather acidic. Most of the Tororo district and Bungoma County is flat, lying at an altitude of 1,097 to 1,219 m above sea level and temperatures range between 15.7° to 30.6° C. The region is well known for its highly unproductive sandy ferralsols (Miiro, R. *et al*), with low Carbon (C), Nitrogen (N) and phosphorus (P). Agriculture is the backbone of the economy of the two areas. The adjacent Kapchorwa District and Trans-Nzoia county of Uganda and Kenya lie on the northern slopes of Mt. Elgon with somewhat higher precipitation and better soils than the Tororo and Bungoma. Trans-Nzoia site is located in the Great Rift Valley on coordinates of 0°49'60" N and 35°0'0" E, at an elevation of 1,828

meters above sea level. Kapchorwa site landscape is steeply sloped (% slope size) and divided by many valleys with an average altitude 1466 m above sea level. The soils are derived mainly from volcanic parent material and are typically red clay loam, well drained, highly leached, often acid, but of good nutrient supply. Most of the land is intensively cropped while about 20% is woodland. Rainfall is unimodal, with peaks in April and May but is generally more than 100 mm per month from March to November. The soils are generally highly productive. Maize and beans are the main crops grown in these regions, with beans produced in association with other crops. In every experimental site an experimental block each measuring 32M by 32M was laid. The test crops were maize (Zea mays) and beans (Phaseolus vulgaris) and mucuna (Mucunapruriens).

Field Methods

Experimental Treatments

The experiment involved three tillage and three cropping systems as factors. Tillage systems studied were traditional/local farmer practices, No-Till (NT) using herbicides to control weeds, and Minimum Till (MT) using shallow tillage to control weeds. Strip cropping and riley cropping system that utilize cover crops and, traditional/local cropping system were studied.

The experiment was laid down in a split-split plot arrangement with tillage systems (Zero tillage, Minimum tillage and conventional tillage which is termed farmer practice) as main plot, cropping system (strip mono-cropping and relay cropping systems that utilize cover crops and, conventional cropping system) as sub-plots and N application (+N and -N) as sub-sub plots. Conventional intercropping systems were built up from the current system in use locally in each site. The order of the three tillage practice main plots was randomized within each block, with each tillage practice occuring across the whole block. However, cropping system and N fertilizer subplots were completely randomized within each tillage practice main plot. The treatments were then replicated in four blocks in a Randomized Complete Block Design (RCBD).

Initial land preparation and planting

Land preparation was done by hand digging using a hoe at a depth of 15cm for conventional/current tillage practice according to the local practice of that particular site as recommended by advisory group. For minimum tillage, limited manipulation of soil cover by scratching to reduce or eliminate weeds was done. Zero or No-till was done by use of eco-friendly chemicals before planting. Seeding in the minimum and zero tillage was done using a sharp stick. The main plots measured 10m by 10m. Maize (Zea mays) and beans (Phaseolus vulgaris) were the test crops while Mucuna (Mucuna pruriens) was used as a cover crop with the aim of organic matter building up. Certified seed was for each crop. The current cropping practice plus two alternative cropping systems that incorporate soil-building cover crops were studied. The current cropping system was Maize-Beans intercropping. One cropping system refered to as Rotation 1 (One) (ROT 1) was built from a current cropping system and it involved intercroppingg Maize-Beans with Mucuna cover crop relay after second weeding in maize and after bean harvest.. Alternative cropping system Rotation 2 (Two) (ROT 2) involved strip cropping having six rows of maize, six of beans and six of annual cover crop Mucuna pruriens. Nitrogen fertilizer application will serve as a split-split, with one side of the half of the sub-plot receiving the nitrogen fertilizer. Certified hybrid maize seed H502 H505 were used in Bungoma and Tororo site s respectively, while H6210 was planted in both Kitale and Kapchorwa. Certified bean seeds was acquired from Kenya seed company. Normal land management practices e.g. weeding, pest control was carried out on the experimental plots at appropriate stages of plant growth in the respective treatments. Bullock pesticide was used to control weeds in the Zero tillage (ZT) system, scratching was done to control weeds in the Minimum Tillage (MT) practice. Harvesting was done when the maize and beans attained physiological maturity for maize and pod yellowing for beans, and yield data obtained. Maize and beans from each experimental plot were shelled, representative samples air dried for laboratory analysis.

Soil fertility replenishment

Phosphorus and nitrogen will be added as DiammoniumPhosphate (DAP) as a starterfertilizer to each plot. Maize monocrop will receive 60kg P_2O_5/Ha and 30kg N/Ha, with beans monocrop receiving 40kg P/Ha (FURP, 1994). Additional N will receive 30kg P/Ha as a split-plot treatment (+(plus)N and –(minus)N imposed on each plot) at vegetative stage of the crop, thus an area of 5m by 10m will receive the N while the other 5m by 10m will not. No fertilizer was added to Mucuna pruriens crop during planting as this was only meant for soil biomass build up studies.

Fertilizers were applied at the time of sowing by banding close to the seed row in order to enhance contact between the fertilizer and the roots early in the growing season for enhanced nutrient uptake by plants. Crop residue from previous cropping season was incorporated back in their respective plots as a means to recycle nutrients.

Crop harvesting procedures

A simple random sampling method was adopted. Sample size of Ten (10) selected plants for both maize and beans were collected for the yield data for each of the treatments in a marked central area in the experimental plots. To eliminate the "edge effects" a central area of 8m by 7m was used to get the representative sample of ten plants (both maize and beans). However for Rotation 2 where we had minus N and plus N split put across the rows, only one border row and sampling the central plants (both beans and maize), while for mucuna a 1m x 1m quadrat area was harvested for biomass measurement done in two spots in each experimental unit. The rest of mucuna crop in rotation 2, rotation 1 and in current practice plots was incorporated back in the soil for both organic matter content and nutrient recycling. The plant population was taken for the central area marked for collecting biometric observations both for maize and beans in all rotations. For yield data the several yield parameters were measured. For maize:- total plant population, number of cobs, cobs weight (kg), weight of 10 cobs, total maize stover yield (kg) in the harvest area; Beans:- weight of plants harvested in a plot, weight of 15 plants randomly sampled from the total crop from the harvest area, Number of pods/plant for the 15 plants, fresh and dry weight of the 15 plants, dry weight of the grains from the 15 plants, 100 grains test weight, grain yield; while for Mucuna:- biomass production per unit area (2 sites are taken using a 1 m^2 quadrat, but only for rotation 2).

The yield component method is based on the premise that one can estimate grain yield from estimates of the yield components that constitute grain yield. These yield components include number of ears per area, number of kernel rows per ear, number of kernels per row, and weight per kernel. Final weight per kernel is measured at harvest moisture and at oven drying for realistic results. The above data was used in yield estimation using equation 1:

Yield (g) = {(Total Fresh Weight x 10,000)/ Effective area} x Dry matter factor………………..1

Crop residue from the prevoious cropping season was incorporated back in their respective plots, and left to rot. This was then incorporated in the soil during land preparation in CT plots, while for the other treatments it was used to form mulch for the other planted crops.

Soil sampling and analysis

Initial soil sampling was done prior to the onset of the experiment across all the four sites, at the following depths;

0-10 cm

10-30cm

30-60cm

60-100cm

A 'W' shape was used in every plot to mark four sampling spots, each randomly picked on the four arms of the 'W'. Soil sampling of the soil down the profile were used for better assessment of nutrient status down the profile. Soil samples were collected in well labeled plastic polythene bags. Sampling errors were

reduced by making composite sample (using buckets) at each depth in every plot. Soil samples were collected in plastic bags and properly labeled both on the outside and a written label inside. Soil samples for microbial, mineral nitrogen and moisture analysis was transported to the laboratory under reduced temperature conditions in a cooler box and analyzed upon arrival in the laboratory. Soil samples for chemical analysis were air dried and prepared by sieving through a 2mm sieve to remove large clods and organic matter, after which 250 g was obtained for laboratory analysis. Soil chemical analysis including percent organic carbon, soil pH, particle size analysis, total Nitrogen and phosphorus, soil organic carbon, mineral Nitrogen, available Phosphorus (Olsen Method) and exchangeable acidity were analyzed and determined according to the procedures as outlined by Okalebo *et al.,* (2002). Soil macrofauna were analyzed from a 50g freshly sampled soil sample using the standard method of the Tropical Soil Biology and Fertility Programme (TSBF) Handbook of methods (Anderson and Ingram, 1993), in which the various groups representing the soil macrofauna (Table 3) are hand-sorted. This method has been successfully employed worldwide by a large number of researchers of the Macrofauna Network (Lavelle and Fragoso, 2000) and, despite its limitations (smaller, more rapid or more difficult to see organisms are frequently missed in handsorting, much labor is required, and social insects are often underestimated), has been shown to be fairly robust, rapid and do not require sophisticated materials. Soil macrobial population analyses were determined twice in every cropping season both at the vegetative and end of cropping season just before harvesting. Only the 0-10cm depth was sampled.

Experimental Design and Layout

The experiment was laid down in a split-plot design having three main effects of tillage systems (Zero tillage, Minimum tillage and conventional tillage termed farmer practice) and sub-plots representing four cropping systems (strip cropping, intercropping system and intercrop with mucuna relay). Intercropping system with mucuna rilley was built up from the current intercropping system in use locally. The sub sub-plots were represented by nitrogen application at vegetative stage that is +N and –N. The test crops were maize, beans and mucuna as a cover crop. Four study areas (Kenya-Bungoma and Trans Nzoia), and Uganda (Tororo and Kapchorwa) each having four experimental blocks measuring 32m by 32m. Each block had 9 experimental plots measuring 10m by 10m. The main plot, sub-plot and sub sub-plots were randomly distributed in these plots in a Randomized Complete Block Design (RCBD).

Data collection and analysis

Soil sampling was done at vegetative and at harvest of the crop for both soil microbial and chemical analysis. The test crops were harvested by hand at physical maturity. Dry matter production and grain yield for both the maize and the legumes was measured. The test crops were harvested from the experimental plots excluding the outer rows for grain yield assessment at 15 % moisture content. Dry matter production was measured by cutting and weighing all the stover and trash. From the harvested crop, grain yield will be determined and for the soils, soil samples will be taken from each plot for nutrient/chemical analysis, mainly pH, N, P, and soil organic carbon.

Data obtained from the experimental variables was subjected statistical analysis using General Linear Model (GLM). Means were separated by Duncan Multiple Range Tests (DMRT). Relationships between crop yields and the treatments were drawn. Changes in the microbial biomass over time under different tillage and intercropping systems were also determined.

Results and Discussions

Seasonal rainfall in LR2011, SR2011, LR2012 and SR2012 cropping seasons for the four sites.

Rainfall at all the four sites- Bungoma, Tororo, Trans-Nzoia and Kapchorwa- was measured daily using rain gauge installed on every experimental farm. Rainfall intensities varied in the rain days within the season (Figure 1).

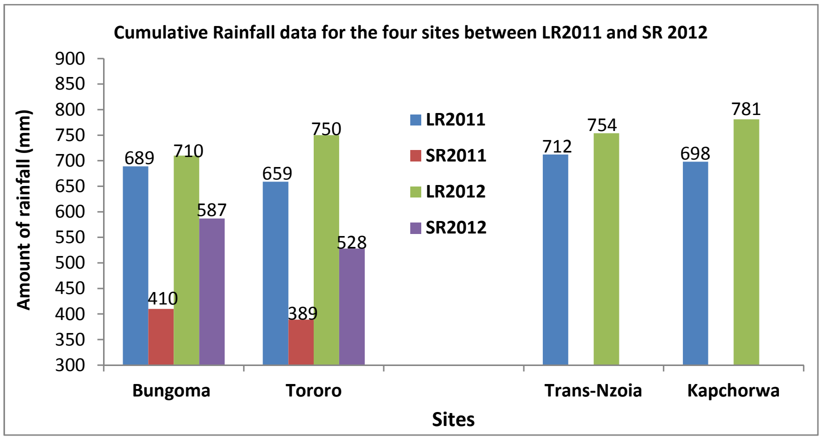

Figure 1: Cumulative Rainfall data for the four sites between LR2011 and SR 2012

Rainfall intensities varied in the rain days within the cropping seasons. This varied between the sites and cropping seasons (Figure 2).

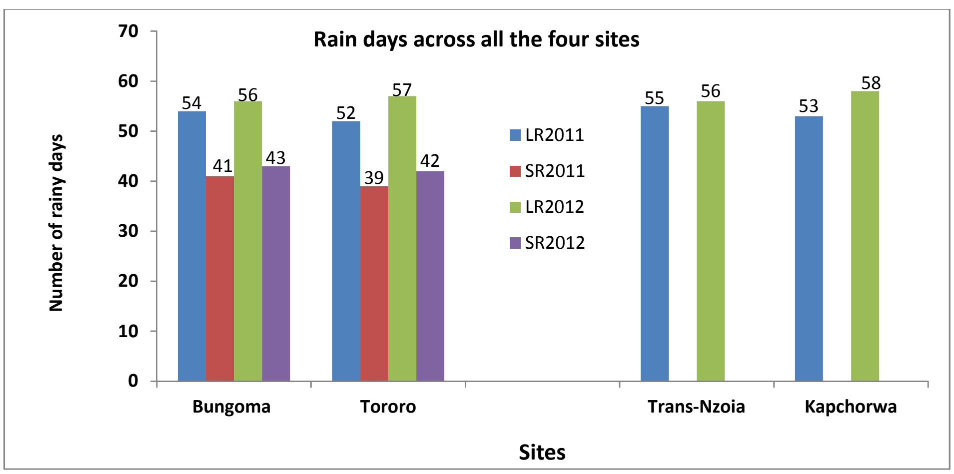

Figure 2: Rain days across all the four sites

The initial soil analysis data shows the depleted status of the soils across all the four sites (Table 1). The levels of phosphorus were below the required adequate levels for crop production, with the lowest levels recorded in Kapchorwa. The soils across the four sites indicate acidic soils with the soil pH ranging between 4.61–5.37. The percent organic carbon levels of the soils across the sites were low ranging between 1.09-1.40.

Table 1: Initial soil chemical analysis data for the four sites

		Kenya		Uganda	
	Recommended Levels	Bungoma	Trans-Nzoia	Tororo	Kapchorwa
Soil pH (1:2.5H2O)	5.5 - 6.0	4.54	5.01	4.49	4.41
Av. P mg Kg-1	13 - 15	6.457	8.453	6.045	5.435
% O. C	1.5 - 3.0	1.48	1.32	1.43	1.40
% N	0.2 - 0.3	0.168	0.131	0.185	0.143

Effects of Tillage, Cropping Systems and Nitrogen application on earthworm population

The interaction of Tillage by Nitrogen application had a high significant effect on the earthworm population count in Bungoma , in LR2011 ($P \leq 0.815$) and LR2012 ($P \leq 0.893$) cropping seasons. The population of the earthworms doubled in the subsequent seasons generally, with LR2012 recording the highest population of 3 earthworms from the sample of 50g of the soil.

Table 14: Table of means of earthworm's population; Bungoma and Trans-Nzoia

Treatments		Bungoma				Trans-Nzoia	
		LR2011	SR2011	LR2012	SR2012	LR2011	LR2012
Tillage	CT	1.08a	1.00a	2.33c	1.00b	1.00a	2.18c
	MT	1.10a	1.10a	3.85a	1.10a	1.10a	3.98a
	NT	1.03a	1.10a	3.35b	1.00b	1.10a	3.13b
Cropping Systems	CP	1.00a	1.00a	2.04b	1.00a	1.00a	2.08c
	ROT1	1.04a	1.00a	2.21b	1.00a	1.00a	2.33b
	ROT2	1.10a	1.11a	3.88a	1.06a	1.11a	3.68a
Nitrogen Application	+N	1.07a	1.13a	3.40a	1.07a	1.13a	3.35a
	-N	1.07a	1.00a	2.95b	1.00b	1.00b	2.83b
Grand Mean		1.07	1.07	3.18	1.03	1.07	3.09
SE		0.26	0.23	0.58	0.16	0.23	0.48
% CV		24.39	21.76	18.16	15.88	21.76	15.52

Tillage systems; CT- Conventional Tillage, MT-Minimum Tillage, NT-No-Tillage: Cropping systems; CP-Current Practice, ROT1-Rotation 1, ROT2-Rotation 2: Nitrogen Application; +N-Nitrogen applied, -N-No Nitrogen applied. Means within particular treatments followed by different letters are significantly different

LR2011 cropping season in Bungoma realized a significant effect on earthworm population count under the treatments; Tillage ($P \leq 0.581$), Nitrogen application ($P \leq 0.733$) which was highly significant, Tillage by Nitrogen Application interaction ($P \leq 0.815$), Tillage by Cropping Systems interaction ($P \leq 0.886$), Nitrogen Application by Cropping Systems interaction ($P \leq 0.665$), and Tillage by Cropping Systems by Nitrogen Application interaction ($P \leq 0.711$) (appendix 1.e.i). ANOVA for other treatments in the subsequent cropping seasons of SR2011, LR2012 and SR 2011 revealed that even though there was an effect of the three treatments on earthworms population count, the differences were not significant.

There was no significant effect on earthworm population counts in LR2011 and LR2012 cropping seasons of Trans-Nzoia site by the three treatments- Tillage, Cropping systems and Nitrogen application.

Table 2: Table of means for Earthworm population count in soils of Tororo and Kapchorwa

Treatments		Tororo				Kapchorwa	
		LR2011	SR2011	LR2012	SR2012	LR2011	LR2012
Tillage	CT	1.00a	1.00a	2.15b	1.00a	1.03a	2.20c
	MT	1.03a	1.10a	3.50a	1.05a	1.10a	4.10a
	NT	1.08a	1.08a	2.33b	1.03a	1.10a	2.20b
Cropping Systems	CP	1.00a	1.00a	2.00b	1.00a	1.00a	2.11c
	ROT1	1.00a	1.00a	2.05b	1.00a	1.00a	2.55b
	ROT2	1.06a	1.10a	3.08a	1.04a	1.13a	3.81a
Nitrogen Application	+N	1.07a	1.12a	2.83a	1.05a	1.15a	3.88a
	-N	1.00b	1.00b	2.48b	1.00a	1.00b	3.03b
Grand Mean		1.03	1.06	2.66	1.03	1.08	3.21
SE		0.18	0.22	0.47	0.16	0.25	0.54
%CV		17.12	21.00	17.58	15.68	23.33	16.69

Tillage systems; CT- Conventional Tillage, MT-Minimum Tillage, NT-No-Tillage: Cropping systems; CP-Current Practice, ROT1-Rotation 1, ROT2-Rotation 2: Nitrogen Application; +N-Nitrogen applied, -N-No Nitrogen applied. Means within particular treatments followed by different letters are significantly different

The interaction between Tillage and Nitrogen application significantly affected earthworm population across all cropping systems-LR2011, SR2011, LR2012 and SR2012- in Tororo site (Table 2). In LR2012 however, the interaction the significance effect was so high (P≤0.900) above all the rest. Also, in this cropping season the number of earthworms counted doubled as compared to the previous cropping seasons. Tillage systems also had a significant effect on the earthworm's population across all cropping seasons apart from LR2012. MT recorded the highest earthworm population mean of 3.50 in LR2012 cropping season, significantly different from NT and CT. There was however no significant difference between NT and CT. Nitrogen application significantly increased the number of earthworms across all cropping seasons from LR2011 to SR2012, with the highest grand mean being recorded in LR2012.

In Kapchorwa, Tillage had a significant (P≤0.770) effect on earthworm population in LR2011 cropping season as compared to other treatments. In the same cropping season in Kapchorwa, Tillage by Cropping system, Tillage by Nitrogen Application, and Tillage by Cropping system by Nitrogen Application interactions had significant effect (P≤0.810; P≤0.762; P≤0.812 respectively) on the earthworm population count. In the subsequent cropping season of LR2012, there was an effect of the treatments on the population of the earthworms but only the Cropping system by Nitrogen Application interaction recorded a significant difference (P≤0.665). The difference in means showed an increase in the population of earthworms in the successive cropping seasons in Kapchorwa.

Generally, tillage systems significantly affected the number of earthworms counted in Bungoma and Trans-Nzoia. MT recorded the highest earthworm population as compared to MT, with CP recording the least (Table 1). A similar trend was realized with cropping systems in Bungoma and Trans-Nzoia, where ROT 2 recorded the highest earthworm mean population followed by ROT 1 and CP in that order. Nitrogen application significantly increased earthworm's population in Bungoma, Trans-Nzoia, Tororo and Kapchorwa (Table 1 and 2). MT tillage systems recorded highest mean of earthworms counted above NT and CT in Tororo and Kapchorwa (Table 2). ROT 2 significantly increased the number of earthworms counted in both Tororo and Kapchorwa.

Generally, there was a general increase in several nutrients tested. MT recorded the highest levels of soil pH, available phosphorus, earthworms and SOC, with NT and CT following suit in that order (Figure 3).

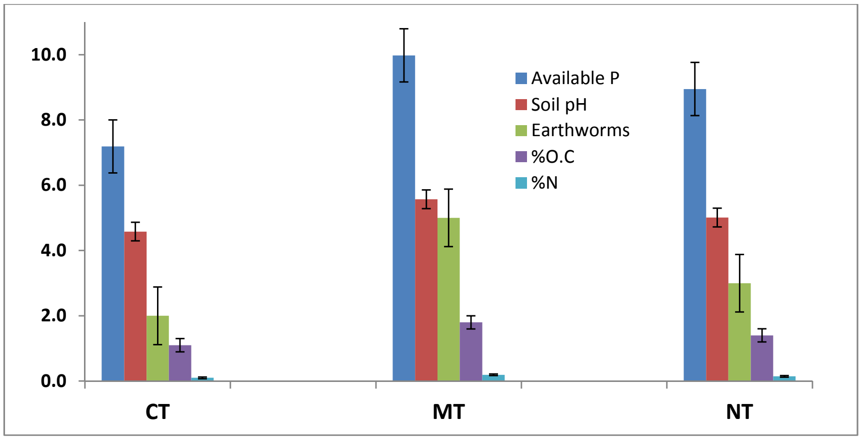

Figure 3: The nutrient status of the soil and earthworm population count under different tillage systems

The test crops contributed to the improvement of the soil fertility status differently. There was more contribution of the soil nutrients- SOC, P, soil pH – as well as earthworms population count in the plots with mucuna as compared to maize and beans plots (Figure 4).

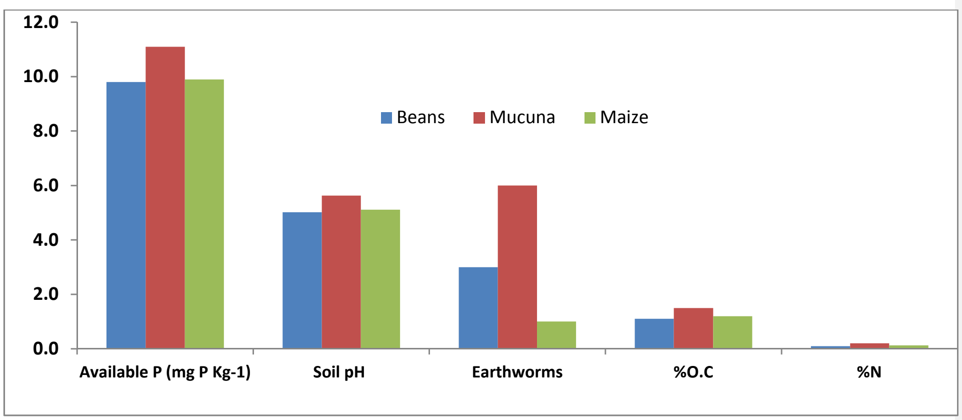

Figure 4: The nutrient status of the soil and earthworm population count under different test crops

Mucuna pruriens improved SOC as well as percent nitrogen in the soil above maize and beans. There was a high earthworm population in plots under MT having mucuna cover crop.

Effects of Tillage, Cropping Systems and Nitrogen application on soil pH.

Soil pH ranged from 4.61 to 4.84in Bungoma, Trans-Nzoia and Kapchorwa sites in the first Long Rains season of 2011 (LR2011) (Tables 3 and 4). Conventional Tillage (CT) had significantly low soil pH as compared to Minimum Tillage (MT) and No-Till (NT) across the three sites (Table 3).

An interaction involving all the three significantly improved soil pH in Bungoma from 4.61 initially to 5.01 (soil pH; 1:2.5 H2O). The interaction between cropping systems and N-application significantly affected soil pH highly ($P \leq 0.920$) in LR2012 cropping season in Bungoma. Soil pH was significantly influenced by N-Application ($P \leq 0.946$, $P \leq 0.954$) in LR2011 and LR2012 cropping seasons in Trans-Nzoia. Tillage by cropping systems by N-Application interaction also influenced soil pH significantly ($P \leq 0.813$, $P \leq 0.808$ in LR2011 and LR2012 cropping seasons respectively) in Trans-Nzoia site. This led to an increase in soil pH mean from 4.76 in LR2011 to 5.15 in LR2012 cropping season (Table 3).

CT recorded the lowest soil pH means as compared MT and NT across all cropping seasons in both Bungoma and Trans-Nzoia (Table 3). There was significance difference between CT and the group of NT and MT. However, the soil pH was highest in the plots under MT treatments. Soil depth significantly affected soil pH, reducing with depths in both Bungoma and Trans-Nzoia (Table 3).

Table 3: Table of means of Soil pH under different tillage, cropping systems and nitrogen application in Bungoma and Trans-Nzoia

Treatments		Bungoma				Trans-Nzoia	
		LR2011	SR2011	LR2012	SR2012	LR2011	LR2012
	CT	4.52b	4.68b	4.87b	4.90b	4.67b	5.06b
Tillage	MT	4.67a	4.87a	5.05a	5.08a	4.79a	5.18a
	NT	4.64a	4.83a	5.02a	5.06a	4.82a	5.21a
Cropping Systems	CP	4.62a	4.81a	4.99a	5.02a	4.71a	5.10a
	ROT1	4.59a	4.79a	4.98a	5.02a	4.82a	5.21a
	ROT2	4.61a	4.79a	4.98a	5.01a	4.76a	5.15a
Nitrogen Application	+N	4.60a	4.79a	4.97a	5.01a	4.76a	5.16a
	-N	4.61a	4.80a	4.98a	5.01a	4.77a	5.14a
Depth	0-10cm	4.78a	4.83a	5.16a	5.05a	4.80a	5.18a
	10-30cm	4.43b	4.76b	4.79b	4.97b	4.73a	5.10b
Grand Mean		4.61	4.80	4.98	5.01	4.76	5.15
SE		0.28	0.30	0.31	0.30	0.32	0.32
% CV		6.07	6.26	6.13	6.05	6.66	6.17

Tillage systems; CT- Conventional Tillage, MT-Minimum Tillage, NT-No-Tillage: Cropping systems; CP-Current Practice, ROT1-Rotation 1, ROT2-Rotation 2: Nitrogen Application; +N-Nitrogen applied, -N-No Nitrogen applied. Means in row followed by different letters are significantly different

The three treatments of Tillage, Cropping systems and N-Application individually affected soil pH significantly at both the beginning and at the end of the study (i.e. LR2011 and SR2012) in Tororo. Tillage significantly affected soil pH in Tororo from LR2011 to SR2012. Tillage highly influenced soil pH in SR2011 (significant at $P \leq 0.986$), and significantly influenced in combination with other treatments, a change from soil pH of 4.84 to 5.09 across the four cropping seasons. Also, an interaction involving cropping systems and Nitrogen application positively and significantly influenced soil pH across all the cropping seasons. The Tillage, Cropping systems and N-Application treatments resulted in to an improved soil pH, raising it from 4.84 to above pH 5.00. In Kapchorwa, N-Application significantly influenced a rise in the soil pH in

all cropping seasons. The same was experienced with the interactions of all the three treatments, plus CS by NA that highly affected the soil pH significantly ($P \leq 0.888$; $P \leq 0.914$) in LR2011 and LR2012 respectively in Kapchorwa.

Table 7: Table of means of Soil pH under different tillage, cropping systems and nitrogen application in Tororo and Kapchorwa

Treatments		Tororo				Kapchorwa	
		LR2011	SR2011	LR2012	SR2012	LR2011	LR2012
Tillage	CT	4.89a	4.85a	5.27a	5.14a	4.47b	4.86b
	MT	4.76b	4.75b	5.14b	5.01b	4.53b	4.89b
	NT	4.87a	4.86a	5.26a	5.13a	4.76a	5.15a
Cropping Systems	CP	4.83a	4.86a	5.22a	5.15a	4.56ab	4.95a
	ROT1	4.89a	4.84a	5.27a	5.09a	4.48b	4.83b
	ROT2	4.83a	4.80a	5.21a	5.08a	4.62a	5.01a
Nitrogen Application	+N	4.83a	4.83a	5.21a	5.08a	4.60a	4.97a
	-N	4.85a	4.82a	5.24a	5.11a	4.57a	4.96a
Depth	0-10cm	4.86a	4.85a	5.24a	5.12a	4.62a	4.99a
	10-30cm	4.82a	4.80a	5.21a	5.07a	4.55a	4.94a
Grand Mean		4.84	4.82	5.22	5.09	4.59	4.97
SE		0.35	0.31	0.35	0.35	0.28	0.30
% CV		7.11	6.51	6.66	6.83	6.17	5.96

Tillage systems; CT- Conventional Tillage, MT-Minimum Tillage, NT-No-Tillage: Cropping systems; CP-Current Practice, ROT1-Rotation 1, ROT2-Rotation 2: Nitrogen Application; +N-Nitrogen applied, -N-No Nitrogen applied. Means in row followed by different letters are significantly different

MT recorded the highest means of soil pH, significantly standing out from the other Tillage systems in both Tororo and Kapchorwa. Generally, there was an improvement in the soil pH across all the sites as influenced by Tillage, Cropping Systems and Nitrogen Application interactions except Tororo that realized an improvement in soil pH due to CS by NA interaction.

Discussion

Initial soil characterization

The initial soil analysis data shows the depleted status of the soils across all the four sites (Table 5) with the measured parameters indicating lower levels of the measured nutrients. This is below the critical level for crop production of 10 mg Kg-1 of soil as per Okalebo *et al*., (2002). The acidic nature of the soils in these sites meant that the fertility status of the soils in question was inadequate to ensure good crop production.

Effects of Tillage, Cropping Systems and Nitrogen application on earthworm population

Tillage had a significant effect on the earthworms population count in Bungoma, Tororo and Kapchorwa. However, whenever there was no significance difference between means of the earthworm population as affected by the tillage systems, the number of earthworms counted doubled as it is evident in the LR2012 cropping seasons in Tororo and Kapchorwa (Table 2). Tillage by Nitrogen application interaction on the other hand significantly affected the earthworm's population in all cropping seasons in Tororo.

Earthworm's population was improved in the conservation agriculture tillage systems of MT followed closely by NT.

As the number and intensity of tillage operations increase, so does the physical destruction of burrows, cocoons, and the earthworm bodies themselves. This is attributed to the mixing of the soil between layers during land preparation by tillage to the extent of destroying the habitat of the earthworms. In the event, some are killed while reproduction is hampered caused by the adverse conditions. In this study, less intensive tillage systems that leave residues on the surface after cropping season prior to the subsequent one which are MT and Rotation 2 treatments respectively, improved the environment for earthworm's habitat. The residue provides food, insulates earthworms from weather conditions, and provides cover to protect them from predators. Although a single tillage event will not drastically reduce earthworm populations, repeated tillage over time will cause a decline in earthworm populations as it is evident with the reduced number of earthworms under CT. Similar results have been recorded by researchers in different parts of the world. Edwards and Bohlen, (1996) records that No-till and other methods of conservation tillage such as Minimum Tillage and ridge tillage, can increase populations of both types of earthworms. According to their study, earthworms were reduced by 70% compared to previously undisturbed sod after five years of plowing (Edwards and Bohlen, 1996). After 25 years of conventional tillage crop production earthworm populations were only 11-16% of what existed in the original grass field (Edwards and Bohlen, 1996). Edwards *et al*. (1995) reported up to 30 times more earthworms in conservation agriculture tillage systems compared to plowed fields. Tillage affects decomposition and availability of surface residue, while choice of crop determines the quantity and quality of the residue as a food source for earthworms. Earthworm populations decreased to low numbers under an exhaustive cropping system of conventional tillage, crop residue removal, and no additions of nitrogen fertilizer as it was evident under CP cropping system under CT under no Nitrogen Application (-N) in which least population means were recorded (Table 2). Earthworms seem to multiply in legumes under a crop rotation system as their population under the legume crops in the crop rotation of Maize-bean-mucuna (Rotation2) was double as compared to the Rotation1 and current practice (CP). Researchers from the Agricultural Research Service National Soil Tilth Laboratory (Ames, Iowa) also found more earthworms in Thompson's fields compared to an adjacent neighbor's conventionally tilled field in corn-soybean rotation (Ernst, 1995). The larger earthworm populations were attributed to more food from legume crops beans and mucuna, as well as reduced tillage under MT. Using cover crops helps to increase earthworm populations by increasing their food supply (organic residue) and by giving them a longer season to eat and reproduce. The extra food and ground cover provided by cover crops are especially important where earthworms are removing a high percentage of crop residues, as it was evident in a study in the University of Wisconsin that reported residue cover being reduced from 30% to 15% by earthworms at planting time in no-till fields (Ernst, 1995). Nitrogen application use of inorganic fertilizers resulted in to increased populations of earthworms and was of great benefit to the earthworms. This is probably an indirect effect of the increased crop biomass production and consequent increases in organic residues. Edwards and Bohlen, (1996), Edwards *et al.,* (1995), and Hendrix *et al*. (1992) in different studies also reported that earthworm numbers in meadows receiving inorganic fertilizer averaged nearly twice the earthworms in unfertilized meadows on the Georgia piedmont. Although ammonia and ammonia-based fertilizers can selectively, but not always, adversely affect earthworm numbers. This is probably due to the effect these fertilizers have on lowering soil pH. However, in his study, Ernst (1995) reports that farmers realize increased numbers in the long run due to higher yields and more food for earthworms to feed upon.

Generally, fertilizers increase earthworm numbers by increasing crop residues, especially when pH is maintained near neutral. Earthworms benefit soil quality by shredding residues stimulating microbial decomposition, thus improving soil fertility as it was evident with the improved measured soil chemical parameters. Producing food through crop residues and cover crops and leaving them on the soil surface through the use of conservation tillage practices provides food to increase earthworm numbers.

Effects of Tillage, Cropping Systems and Nitrogen application on soil pH

The soil pH in Bungoma, Trans-Nzoia, Kapchorwa and Tororo generally improved under conservation tillage treatment of NT and MT, together with strip cropping system under Rotation 2 (Tables 7 and 8), with Kapchorwa realizing a minimal improvement as compared to the other sites. Soil pH in the LR2011 was not significantly affected in Bungoma. This is attributed to the fact that the tillage and cropping systems treatments tested had not established well yet to have an effect on soil pH. Lack of soil mixing in NT and minimal disturbance of the soil as associated with MT is often associated with pH stratification (Garcia *et al.*, 2007) and accumulation of salts associated with fertilizer application on soil surface as compared to tilled soils (Veenstra *et al.*, 2006). The observed increase in acidity under NT and MT (Tables 3 and 4) is consistent with results of De Villiers *et al.*, (2005) and could be attributed to the decomposition of high volumes of organic matter associated with conservation agriculture tillage systems relative to CT. Similarly, high acid release with decomposition of high quantities of plant biomass under mucuna, maize and beans rotational cropping enhanced soil acidity under Rotation 2 and Rotation 1 rotations relative to Current Practice across all the sites (Tables 3 and 4). The Minimal changes in pH observed over the study period could be attributed to application of Calcium Ammonium Nitrate (CAN) as N top-dress to maize and beans crop resulting in pH stabilization under both tillage practices. Furthermore, there was a well establishment of mucuna cover crop and this in combination with Nitrogen application as a top dress realized an increase in levels of plant biomass leading to increased decomposition activity. It is recorded that conservation tillage leads to accumulation of decomposing organic matter on the surface soil layer (Juo and Kang, 1989). The increased soil organic matter acts as a soil buffer, reducing the free H+ ions and stabilizing pH levels of the soil. The extent of acidification is however controlled by choice of cropping systems together with soil and residue management. This resulted in to a minimal positive change in soil pH in Kapchorwa. However, according to USDA/NIFA, 2011 and Nkhalamba *et al.*, 2003, it is worth noting that as the clay and organic matter content increases, the ratio of reserve to active acidity also increases. The authors however note that the relationship between active and reserve acidity is not constant across soils, and is depended on the type and amount of clay and organic matter content of the soil. Application of ammonium N fertilizers has also been reported to counter the increase in acidity arising from nitrification of such N sources (Malhi *et al.*, 1998). Salts are recycled through plant biomass and decomposition of high crop residue inputs under NT and MT thus enhancing salts release to the soil compared to CT and Rotation 2 in across all the sites. Soil pH improved from acidic to lesser acidic levels in the Rotation 2 and Rotation 1 combined with conservation agriculture tillage systems of MT and NT, as compared to intercropping under the current practice combined with conventional tillage. Under the Rotation 2 and Rotation 1, there was a continuous buildup of organic matter on the surface soil and the compounded effect of not disturbing the soil surface layer. Hynes and Mokolobate (2001) reported in their study that an initial soil pH was realized after addition of organic materials, and that this was only sTable for the first 1-2 months after which a decline in the same was realized. The magnitude of the initial soil pH rise was dependent on the type of residue, application rate and biomass content (Hynes and Mokolobate, 2001). Also, the change in soil pH is influenced by time as it was evident with a slight increase in soil ph after the two cropping seasons in Kapchorwa as compared to the increment seen in Bungoma and Tororo which both have four cropping seasons each.

Effects of Tillage, Cropping Systems and Nitrogen application on maize and beans yield

The low yield obtained under Conservation Agriculture treatments in the first cropping season (data not shown) across all the four sites was due to the weeds proliferation especially in the NT and MT plots in that order. Gradual increase in the yield of maize and beans in the succeeding cropping seasons under MT and NT is attributed to the recycling of the nutrients through incorporation of the crop residues from the previous season. Increase of soil available phosphorus from deficient levels across all the sites could have resulted in to improved crop yields maize and beans. Also, this could have been as a result of suppression of weeds by the crop residues from the previous season. Reduced yields of maize and beans under CT plots could be attributed to the residue being inverted during tillage thus resulting in the C:N ratio of residue (above 24) and subsequent available soil N being consumed by microbes leading to a reduction in plant available nitrogen (Patra *et al.*, 2010). Crop residue return in to the soil has been observed under

conservation agriculture tillage and cropping systems in Brazil (Govaerts *et al*., 2005). Long term benefits of conservation agriculture production systems of reduced costs of production overrides those obtained under conventional tillage (Govaerts *et al*., 2005). Research has demonstrated that conservation production systems moderate soil surface conditions (Govaerts *et al*., 2009; Blanco-Canqui *et al*., 2010). This results in to improved crop production (Bescansa *et al*., 2006) thus increasing the net farm benefits due to reduced production costs (Chikoye *et al*., 2006; Sanchez-Giron *et al*., 2007). With MT, diurnal soil temperature is dampened, surface runoff controlled, soil moisture maintained, crop rooting enhanced and hence improved maize-beans production.

Crop rotations results in to distribution of the soils nutrients in the soil from season to season, making them available to the growing crops. Crop residues from previous cropping seasons ensures that there is recycling of soil nutrients enabling the maize and beans in the succeeding cropping season uptake these nutrients for their better growth and development.

The application of nitrogen improved the soil cation exchange capacity (CEC) making more macronutrients available for better crop growth and development resulting in to higher yields.

Conclussions

The results of this study suggest that factors responsible for organic carbon accumulation also influence soil total N and pH changes. The effects of tillage on pH in the four sites were not consistent. Minimum tillage and no till increased total N and pH compared to conventional tillage across all the sites. Tillage systems, Cropping systems and Nitrogen Application either singularly or in combination of any of the three influence soil pH at different levels dependent on the soil type. Conservation of phosphorus may be a potential benefit of conservation tillage, improving phosphorus availability. Improvements in SOC and N levels under CA tillage and cropping systems impacted positively on soil structural stability, biotic activity and plant nutrient availability, thus improving soil quality generally. In agreement with other long-term tillage studies, there was higher soil extracTable phosphorus, SOC, total nitrogen as well as increased soil pH to the required minimum for crop maize and beans production (soil pH 5.0-6.0) under minimum tillage followed by no-till as compared to conventional tillage in both sites. Minimum Tillage and crop rotations involving two legumes and a cereal crop as was in ROT 2 are essential components of conservation agriculture and both practices had a positive impact on maize and beans yield, as well as plant nutrient availability in this short-term study. Generally, the differences associated with tillage and crop rotations on soil chemical and crop growth parameters take long to emerge and further long-term studies may be needed to complement these findings. Minimum tillage systems that leave residues on the surface throughout the year improve the environment for earthworms. Crop rotation of maize-beans-mucuna (ROT 2) and the use of inorganic fertilizers also have a positive impact on earthworm population. This is probably an indirect effect of the increased crop biomass production and consequent increases in organic residues resulting in to increased SOC levels. The residues provide food, insulate earthworms from weather conditions, provide cover to protect them from birds and other surface predators, and protect their burrows. The increased earthworm populations are attributed to increased food supply from legume crops beans and mucuna, as well as reduced tillage under MT that ensures them a longer season to eat and reproduce/multiply. The study highlights that crop rotation, minimum tillage and crop residue incorporation practices have a potential to improve maize and beans yield throughout the year. The two optimizes soil pH, extracTable soil phosphorus, soil organic carbon, soil total nitrogen as well as earthworm's population which all reflect in to an improved soil nutrient status, and soil quality in general.

Recommendations

The study recommends the use of a less intensive tillage system of minimum tillage in combination with crop rotation involving maize-beans-mucuna with nitrogen application in the study areas. This will realize both improved maize and beans production, and better soil nutrient status and overall soil quality replenishment. M. pruriens however could be the most preferred management candidate for the following reasons: In addition to all the benefits accrued from inclusion of legumes in cropping systems towards

improving soil quality in general, M. pruriens provides excellent hay for livestock, and its seeds are used as protein rich feed supplement to livestock and as a beverage by some farmers in Trans-Nzoia but after processing through roasting. More importantly, M. pruriens is used for food in some African countries (Rachie and Roberts, 1974).

However, earthworm's population studies should be undertaken for a longer period of time and on a wider scope in order to be able to study specific earthworm species associated with any particular treatments of tillage, cropping systems and nitrogen fertilizer application.

The N contribution from legume cover crops could improve the performance of subsequent cereal crop. However, legumes contribute less to soil C accumulation compared to cereal cover crops. There is need to investigate whether mixed cereal/legume cover crops could improve both soil C and N for sustainable crop production in low organic C soils.

The difference in soil C accumulation among crop rotations in this study was attributed to relative differences in residue decomposition rates as influenced by their biochemical composition. A laboratory incubation study on rate of decomposition of rotational cover crops is recommended to substantiate this possibility.

Tororo had low soil P concentration compared to other sites at the initiation of this study in 2011 which was maintained till the end of the study. There is need to investigate P management strategies for optimizing maize yields in Tororo which is dominated by Ultisols soils.

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Tillage effects on biological nitrogen fixation and soybean grain yields in western Kenya

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Abstract

Low soil fertility has become a major impediment to crop production in most parts of sub-Saharan Africa. Over the years, technologies have been generated to combat this problem and the most used is application of organic and inorganic fertilizers. However, inorganic fertilizers are not always available to most small holder farmers due to their high costs and poor accessibility. Although use of legumes is a viable option, biological nitrogen fixation is influenced by soil moisture availability which is in turn influenced by the type of tillage used. The objective of this study was to determine the effect of tillage methods on biological nitrogen fixation and grain yields of three soybean varieties. The study was conducted in four sites representing four agro-ecological zones of Western Kenya. The treatments were laid in a randomized complete block design in a split plot arrangement. Tillage methods (No tillage and conventional tillage) were main plots and soybean varieties (Nyala, SB19 and SB20) were subplots. Determination of N fixed was conducted using ^{15}N abundance method. The results showed that Nyala fixed higher amount of nitrogen under no till at Alupe (28.7 kg ha^{-1}) and Bungoma (11.3 kg ha^{-1}). At Ugunja and Rarieda the interactions between variety and tillage were not significant. Overall amounts of N fixed in no till plots were higher than till plots for all the sites combined. Soybean grain yield between the tillage methods was not different in all the sites and also between varieties. Alupe site had the highest grain yield (1543.0 kg ha^{-1}) and Nyala fixed higher nitrogen amounts across the four sites. No till has potential to increase biological nitrogen fixation in some agroecological zones which may translate to higher grain yields over time.

Key words: till, no till, soil moisture content, biomass, N_2-fixation.

Introduction

Poor soil fertility has been acknowledged as a major hindrance to high crop yield (Hilhorst *et al.,* 2000). Researchers have devised some ways of alleviating this problem including application of organic and inorganic fertilizers. However, use of inorganic fertilizers by small holder farmers in sub-Saharan Africa is inadequate (Bationo *et al.,* 2006) due to high costs, unavailability and sometimes lack of knowledge on usage. Materials for organic fertilizers are also difficult to acquire; farmers prefer supplying livestock with stovers rather than leaving them in the field to decay and consequently release nutrients. These challenges have led to exploitation of other economical ways of supplying nutrients to the crops and one of these ways is biological nitrogen fixation.

Biological nitrogen fixation (BNF) in legumes has for a longtime been a component of many farming systems throughout the world. Soybean for example is a legume which has the capacity to obtain its full nitrogen requirements through symbiotic nitrogen fixation and can contribute surplus N to the soil reserves for successive crops (Salvagiotti *et al.,* 2008). Sanginga *et al.,* 2003 reports that some soybean varieties can biologically fix 44 to 103 kg N ha^{-1} annually. However, this biological nitrogen fixation (BNF) process is affected by several factors: soil moisture content, temperature, mineral nitrogen content, native rhizobia population and soil pH among others (Hungria and Vargas, 2000). Soil moisture influences several biochemical and physiological functions of a crop including biological nitrogen fixation (Sinclair *et al.,* 2007) hence its deficit is detrimental to crop growth and yield. Several methods have been put forward in order to increase soil moisture content and consequently increase nitrogen absorption (Dijkstra and Cheng, 2008); examples are irrigation, mulching, cover cropping, ridge planting and conservation tillage among others.

However, some of these methods are either expensive to small scale farmers who are the majority in Sub-Saharan Africa (Kipkoech *et al.,* 2007) or lack of skills to implement them therefore, tillage which is a common practice among almost all farmers would be the best approach to increase soil moisture. Although tillage is also only viable if an appropriate tillage method that conserves soil moisture is used.

The method of tillage applied in crop production influences soil biophysical and chemical properties. Conservation tillage for example has been found to increase soil quality including soil moisture retention and reduce operation costs (Singh *et al.,* 2008). Conventional tillage has also been found to enhance residue decomposition, expose harmful soil pests and allow extensive root growth. In Western Kenya where unreliable rainfall distribution and amounts prevails research to identify appropriate methods of tillage is warranted to conserve soil moisture and subsequently improve biological nitrogen fixation by legumes. Therefore the main objective of this study was to determine the effect of different methods of tillage on biological nitrogen fixation and yield of different soybean in different agro-ecological zones of Western Kenya.

Materials and methods

Experimental sites

A two season experiment starting in long rains of March to August, 2011 and short rains of September to December, 2011 were conducted in four sites representing four agro-ecological zones of Western Kenya. The sites were: Kanduyi - Bungoma county (0˚ 35´ N, 34˚ 35´ E) lies on agro-ecological LM 1 – Lower midland sugarcane zone. The area receives annual rainfall of 1600-1800 mm, average temperature of 21-22 ˚C and the soils are well drained, deep to very deep, red to dark brown and friable sandy clay (classified as Ferralo-orthic acrisols). Ugunja-Siaya county (0˚ 09´ N, 34˚ 18´ E) receives annual rainfall of 1450-1600 mm, average temperature of 21-22 ˚C and lies on agro-ecological zone LM 2-marginal sugarcane zone. The soils are well drained, deep, dark red (classified as Orthic-rhodic ferralisols). Kari – Alupe (0˚ 28´ N, 34˚ 07´ E) which receives 1100-1450 mm, rainfall p.a., average temperature of 22 – 22 ˚C and the soils are well drained, deep and of low fertility (classified as Ferralo-orthic acrisols). It lies on agro-ecological zone LM 3 - Lower midland marginal cotton zone. Asembo-Rarieda (0˚ 08´ N, 34˚ 23´ E) lies on agro-ecological zone LM 4 – Lower midland cotton zone, receives annual rainfall amount of 900-1100 mm, average temperature of 22-22˚ C and the soils are well drained, very deep and dark red (classified as Orthic feralisols) (Jaetzold *et al.,* 2005).

Experimental procedures

The experiment was laid in a complete randomized design in a split plot arrangement with three replicates. Tillage methods were: no tillage and conventional tillage being the main plots and three soybean varieties (Nyala, SB19 and SB20) were the sub plots. The main experimental plots measured 13 m by 11 m while the sub-plots measured 4m by 3m.

Conventional tillage was conducted using hoes of 20 cm length and 15 cm width while no tillage was done using glyphosate at 1.5 litres in 100 litres of water per hectare two weeks before planting. A basal rate of fertilizer was applied in the form of Triple Superphosphate (TSP) at a rate of 30 kg P ha^{-1} and potassium in form of Muriate of Potash (MOP) at a rate of 30 kg K ha^{-1} applied to all treatments in furrows of 5 cm depth and 3 cm away from the planting lines and covered with soil. All soybean seeds were inoculated using biofix inoculants strain USD 110 from Mea Limited – Kenya at 10g kg^{-1} of seeds and planted at a spacing of 50 by 5 cm. Maize stovers with 60% moisture content were chopped at 10 – 15 cm length and applied at a rate of 4 t ha^{-1} between the rows after emergence in both till and no till. Rust control was done using armistar Xtra from Syngenta at a rate of 1l/ha three times after flowering (this is the stage when the plants are highly susceptible) at an interval of two weeks. Weeding in no till was done by hand pulling depending on the appearance of the weeds while in conventional tillage it was done using hoes after every two to three weeks.

Soil characterization and data collection

Soil samples were taken for analysis of organic carbon content, total nitrogen, available phosphorus and potassium, pH, particle size according to standard procedures outlined by Okalebo *et al.,* (2002).

Plants for biomass and N accumulation and assessment were randomly sampled in an area of 0.1 m^2 within the net plot at 50% flowering stage. These plant were cut at the first node from the ground using a kitchen knife, packed in a well labeled polythene bag (17 by 29 cm by 30 microns) of known weight followed by determination of field weight using an electronic balance (2000 g). At this stage, weeds from weedy fallow strips were samples in triplicates and brought to the lab for drying. The below ground part of the plant was excavated from the soil using a sharp spade and the soils were carefully removed and roots and nodules recovered. The roots with nodule intake were packed in the polythene bag (17cm by 29 cm by 30 microns) and kept in a cooler box ready for transfer to the laboratory. In the laboratory the plant samples were oven dried at 65 ^oC to a constant weight (between 24 to 48 hours) and their dry weights determined. The roots were detached of nodules, nodule counted and the roots and nodules oven dried to determine their dry weights. Nodule colors were assessed as either good (>75 % nodules per root system; pink in color), moderate (25% – 75% nodules per root system; pink in color) and poor (<25% nodules per root system; pink or white in color or >25% nodules but white in color) (Alemayehu, 2009). The dry plant samples (including the weeds) were ground in an electric grinder (model – Retsch SM 100 comfort) to pass through 1 mm sieve prior to laboratory analysis.

Grain yield data was collected at physiological maturity within the net plot. The total plant within the net plot was counted, uprooted and the roots cut away from the whole plant using a kitchen knife. Pods subsamples were taken and threshed, the fresh weights of the seeds were recorded. The seeds were dried at 65 ^oC in an oven (model – Memmert UNB 500) for a period of 24 – 48 hours and their dry weights taken then calculated to kg ha^{-1}.

Determination of N_2-fixation

The ground plants samples were used to determine the amount of nitrogen fixed using ^{15}N natural abundance method (Unkovich *et al.,* 2008). Non N_2 fixing reference plants were three weed plants sampled from the fallow plots. The weeds were *Brassica napus*, *Sorghum sudanense* and *Oxalis corniculata*. The ^{15}N natural abundance method applies the principle that if N_2 – fixing plant is grown in a medium free of combined N (mineral N and or organic N) and is completely reliant upon symbiotic N_2 fixation for growth then the isotopic composition of the legume would be expected to be similar to that of atmospheric N_2 (δ ^{15}N %). On the contrary, if non N_2 fixing plant is grown in a soil containing mineral N, its $\delta^{15}N$ value should be equal to that of soil mineral N taken up by the plant from the soil. Determination of N fixed using ^{15}N abundance was conducted at Wageningen University – Netherlands. The amount of nitrogen fixed was calculated using the formulas shown below:

$$\delta\ ^{15}N = \left(\frac{\text{Sample atom}\ \%\ 15_N - 0.3663}{0}.3663\right) \times 1000$$ …………………..equation 4.1

$$\%\ Ndfa = \frac{\delta\ 15_N \text{of reference plant} - \delta\ 15_N \text{ of } N^2 \text{ fixing legume}}{\delta\ 15_N \text{ of reference plant} - \delta 15_N \text{ of } N^2} \times \frac{100}{1}$$ ……equation 4.2

$$\text{Total N accumulated by legume crop} = \frac{\%\ \text{legume total N} \times \text{Shoot biomass} \left(\frac{kg}{ha}\right)}{100}$$ ……equation 4.3

$$\text{N-fixed (kg ha}^{-1}) = \frac{\%\ Ndfa \times \text{Total N accummulated by the legume crop}}{100}$$ ………..equation 4.4

Where: %Ndfa is percentage of N derived from the atmosphere through biological fixation

Statistical analysis

Data collected was subjected to analysis of variance (ANOVA) at 5% level of significance and the means were separated using Duncan's Multiple Range Test (DMRT) on SAS software version 9.00 (SAS, 2002).

Results

Effect tillage on biological nitrogen fixation

Nodule dry weight was different at Bungoma and Alupe sites between the tillage methods. However, percent active nodules were not significant between the tillage methods in all the sites (Table 1). Nodule dry weight was not different among the soybean varieties except at Alupe site while percent active nodules were significant among the soybean varieties at Bungoma and Alupe (Table 2). Nitrogen fixed biologically differed significantly between tillage methods at Alupe and Bungoma sites (Table 3). At Ugunja and Rarieda there were no differences in nitrogen fixed between the tillage methods (Table 3).

Table 1: Effect of tillage on soybean nodule dry weight and percent active nodules at different sites

Tillage methods	Nodules	
	Nodule dry weight (kg ha^{-1})	Percent active nodules
Bungoma		
Till	6.6^{b}	76.7^{a}
No till	9.8^{a}	77.3^{a}
Ugunja		
Till	5.3^{a}	79.0^{a}
No till	5.5^{a}	86.5^{a}
Alupe		
Till	4.2^{b}	70.3^{a}
No till	7.4^{a}	76.8^{a}
Rarieda		
Till	4.2^{a}	79.1^{a}
No till	4.3^{a}	81.1^{a}

Means with different letters are significantly different at p<0.05 the within a column of a given site. The words in bold are the sites

There were differences in nitrogen fixed among the soybean varieties at each site (Table 3). At Alupe, Nyala variety fixed the highest amount of nitrogen, at Bungoma it was SB20, at Rarieda it was Nyala and at Ugunja it was SB19 (Table 3).

There were interactions of tillage method × soybean variety in all the sites (Table 3). At Bungoma the interaction of no till × SB20 fixed the highest nitrogen while till × Nyala interaction fixed the lowest. At Ugunja No till × SB19, at Alupe No till × Nyala and at Rarieda No till × Nyala (Table 3) interactions had highest N fixed.

Table 2: Nodule dry weight and percent active nodules of different soybean varieties at Bungoma, Ugunja, Alupe and Rarieda

Soybean varieties	Nodules	
	Nodule dry weight (kg ha^{-1})	Percent active nodules
Bungoma		
Nyala	6.7^{a}	72.3^{b}
SB19	8.1^{a}	74.9^{ab}
SB20	7.0^{a}	86.5^{a}
Ugunja		
Nyala	5.3^{a}	85.2^{a}
SB19	4.3^{a}	84.9^{a}
SB20	6.5^{a}	79.1^{a}
Alupe		
Nyala	6.3^{ab}	85.7^{a}
SB19	3.9^{b}	71.3^{b}
SB20	7.2^{a}	72.0^{ab}
Rarieda		
Nyala	3.6^{a}	80.8^{a}
SB19	4.0^{a}	80.5^{a}
SB20	4.9^{a}	79.1^{a}

Means with different letters are significantly different at p<0.05 the within a column of a given site. The words in bold are the sites.

Table 3: Effect of soybean varieties, tillage methods and their interactions on amount of nitrogen fixed (kg ha^{-1}) in different sites

Source	Nitrogen fixed (kg ha^{-1})			
	Bungoma	Ugunja	Alupe	Rarieda
Soybean variety				
Nyala	6.5^{b}	13.5^{ab}	19.3^{a}	16.6^{a}
SB19	7.9^{b}	16.9^{a}	6.0^{b}	13.7^{ab}
SB20	14.0^{a}	6.4^{b}	7.0^{b}	5.4^{b}
Tillage method				
Till	6.5^{b}	5.7^{a}	8.1^{b}	5.8^{a}
No till	12.4^{a}	6.8^{a}	13.8^{a}	6.4^{a}
Interactions				
Till × Nyala	3.8^{c}	6.3^{b}	10.0^{b}	7.9^{a}
No till × Nyala	11.3^{ba}	7.4^{ab}	28.7^{a}	8.8^{a}
Till × SB19	7.0^{bc}	7.7^{a}	6.2^{b}	6.5^{b}
No till × SB19	8.8^{b}	8.9^{a}	5.8^{b}	7.3^{ab}
Till × SB20	10.7^{ba}	3.2^{c}	5.7^{b}	2.1^{c}
No till × SB20	17.2^{a}	3.5^{c}	7.0^{b}	3.4^{c}

Means with different letters are significantly different at p<0.05 within the column of a given source.

Effect of tillage methods on growth and grain yield of soybean

There were significant differences of root biomass, shoot biomass and dry grain yield among the sites (Table 5). Root biomass, shoot biomass and grain yield were not different between the tillage methods (Table 5). Differences were there among the soybean varieties on root and shoot biomasses (Table 5) where soybean variety SB20 had the highest root and shoot biomasses (Table 5). No till × SB20 and Till × SB20 had the

highest root and shoot biomasses while, Till × SB19 gave the highest dry grain yield. No till × Nyala had lowest root and shoot biomasses (Table 5).

Table 4: Top soil (0-20 cm) chemical and physical characteristics of the experimental sites

Site	pH	Olsen P	C.E.C.	K	Ca	Mg	Na	clay	sand	silt	Soil texture	Total N	Total C
		mg kg^{-1}		Cmol kg^{-1}					%				%
BGM	5.3	12	8.39	0.27	3.66	0.94	0.05	24.8	69.6	5.6	sandy clay loam	0.08	1.04
Ugunja	4.8	13	6.90	0.29	1.60	0.87	0.14	28.9	55.5	15.6	Sandy clay loam	0.11	1.29
Rarieda	6.0	20	3.31	0.31	1.74	0.47	0.06	10.9	85.5	3.6	Loamy sand	0.04	0.40
Alupe	5.7	20	4.70	0.16	2.11	0.92	0.05	36.8	57.6	5.6	Sandy clay	0.12	1.12

Table 5: Effect of experimental sites, tillage methods and the interaction of tillage methods and varieties on root biomass (kg ha^{-1}), shoot biomass (kg ha^{-1}) and dry grain yield (kg ha^{-1}) of soybean

Source	Root biomass	Shoot biomass	Dry grain yield
Sites			
Bungoma	60.0^{b}	306.6^{a}	921.8^{b}
Ugunja	67.8^{ab}	248.7^{b}	661.5^{c}
Alupe	81.0^{a}	342.5^{a}	1543.0^{a}
Rarieda	36.2^{c}	148.7^{c}	703.7b^{c}
Tillage method			
Till	63.1a	265.6a	1063.3a
No till	62.6a	273.2a	935.0a
Soybean varieties			
Nyala	48.5^{b}	174.9^{c}	923.4^{a}
SB19	58.6^{b}	249.9^{b}	1115.0^{a}
SB20	78.9^{a}	359.5^{a}	943.7^{a}
Interactions			
Till × Nyala	54.4bc	195.1bc	883.8b
Till × SB19	57.4bc	231.7b	1222.2a
Till × SB20	72.6ab	339.4a	925.5b
No till × Nyala	42.1c	151.8c	753.1b
No till × SB19	55.1bc	246.3b	919.3b
No till × SB20	79.9a	350.6a	943.1b

Means with different letters are significantly different at p<0.05 within the within the column of a given source.

Discussion

At Bungoma and Alupe, the high amount of nitrogen fixed in no till could be attributed to lack of disturbance on the rhizobial population through tilling leading to increased activity in no till plots. Zhang *et al*. (2012) confirms that in no till plots there are higher rhizobial population than till plots. Ferreira *et al*. (2000) states that rhizobia isolate from no till plots fixes higher atmospheric nitrogen than till. Van Kessel and Hartley (2000) stated that no till lead to stimulation of nitrogen fixation. These results is supported by higher the dry nodule weight in no till plots (Table 1). The insignificant difference in nitrogen fixed at Ugunja and Rarieda could have been due to low pH and high sodium content (Table 4) that affected the rhizobia activity at Ugunja and low soil nitrogen content at Rarieda that reduced take off of nitrogen fixation.

The difference in nitrogen fixed among soybean varieties could have been due to differences in soil moisture within their plots which could have enhanced the activity of the rhizobia at different sites. In Van Kessel and Hartley (2000) review they reported that increased soil moisture increases the potential of biological nitrogen fixation. This difference among the varieties could be due to genetic potential of nitrogen fixation from different varieties. This with the increase in soil moisture under individual plots could have increased the nitrogen fixed by a given soybean variety.

High nitrogen fixation in no till × SB20 interaction at Bungoma could have been due to high percentage of active nodules on SB20 roots (Table 2) compared to the other varieties. The high nitrogen fixed by the interactions at Ugunja, Alupe and Rarieda was probably due to higher soil moisture content presented by the no till method and the fact that no till usually have rhizobia isolates which fixes higher atmospheric nitrogen than till according to Ferreira *et al*. (2000).

Root biomass that was high at Alupe could have been due to sufficient soil nutrients such as total nitrogen and phosphorus (Table 4) that are known to boost root growth. The high root biomass at Alupe could have been the reason for high shoot biomass and consequently high dry grain yield. Expansive shoot biomass leads to increased photosynthesis and translocation of assimilates to the sinks (grains) if the soil especially soil moisture and climatic conditions are favorable.

The insignificant difference in root biomass, shoot biomass and grain yield between the tillage methods, during long and short rains could be attributed to the argument that growth and yield differences in no till and till methods always become evident after several years of cropping (Malhi *et al.*, 2006). This high root biomass on soybean variety SB20 could explain its high shoot biomass since it could absorb more moisture and nutrients from the soil to enable faster and expansive growth.

High root and shoot biomasses in no till × SB20 and Till × SB20 could have been due to presences of SB20 variety. This is because on analysis of individual factors the tillage methods show insignificance while SB20 gives high root and shoot biomasses among the soybean varieties tested. No till × Nyala performs dismally probably due to the genetic composition of the variety. Since Nyala is an early maturing variety, its shoot is compact and the roots are not expansive. This paired with the insignificance of the tillage methods could have led to low root and shoot biomasses.

Conclusion

The amount of N fixed was higher in no till plots than till plots at Bungoma and Alupe, hence the need to encourage farmers to practice no till to increase their soil fertility. Grain yield between the tillage methods and varieties was not different in all the sites. Tillage methods differences are visible over a long period of cropping therefore, if this experiment could have gone beyond two seasons it could have discerned the best tillage methods for each site for yield increment the different varieties.

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Effectiveness of promising commercial bio-fertilizers on soybean production in Bungoma county, western Kenya

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Abstract

The study was conducted to compare the performance of promising commercial bio-fertilizers that have been evaluated under the green-house conditions at TSBF-CIAT, in farmers' conditions through the use of promiscuous soybean variety (SB19). The trials were laid out on small scale farms in Bungoma County, situated in Western Kenya. The experiment was established in March 2010 during the long rains (LR) and repeated during the short rains (SR) of 2010; laid out in multi-locational and used individual farmer field as areplicate. Treatments were not replicated within each field. During LR 2010, 50 farms were researched on and 100 farms in the second season (SR 2010). A promiscuous medium-maturity soybean variety TGx1740-2E (SB 19) was inoculated with Legumefix (Rhizobia) or/and Rhizatech (mycorrhizae) inoculants. The mycorrhizae inoculum was applied to the soil in the seed furrows at the recommended rate of 30 kg ha^{-1}. Nodulation was examined at mid-podding (50% podding) by carefully uprooting all plants with their entire root system from a 1 m^2 section in each plot. Nodules were counted and weighed; the root and shoot parts separated, and fresh and dry weights assessed. Analysis of variance was conducted to determine the effects of (and interactions between) the two inoculants on plant parameters using a mixed linear model (MIXED procedure, SAS). Rhizobial inoculation resulted in significantly ($p<0.001$) higher nodule biomass (0.93 g per plant) compared to the control (0.27 g per plant) across many farms. Mycorrhizal inoculation had no significant effect on nodulation when applied solely (0.38 g per plant), but co-inoculation of Rhizobia and mycorrhizae increased nodule biomass further by 0.09 g per plant There was a significant difference ($p<0.001$) in terms of biomass yield between treatments. Rhizobial inoculated plants had the highest biomass production of 2086 kg/ha. Rhizobial inoculation resulted in higher grain yields of 1116 kg/ha above the control. Soybean inoculation increased both nitrogen and phosphorus uptake in the biomass. Rhizobial inoculant had the highest soybean N uptake of 48.6 N kg/ha which was significantly different ($p<0.05$) from control and sole application of mycorrhizae. Statistical analysis showed that soil factors (pH, P, C, N) significantly ($p<0.001$) affected soybean grain yields during both seasons. It is concluded from this study that rhizobial inoculants have a high potential as commercial bio-fertilizers. However, there is need to target these inputs to the most responsive fields. Further studies are needed to elucidate the conditions under which synergism between both inoculants may occur, with specific focus towards soil P availability and management of P inputs.

Key words: soybean, Rhizobia, Mycorrhizae, Inoculant.

Introduction

Soybean [*Glycine max* (L.) Merrill] is an annual legume that belongs to the legume family *Fabaceae*. It is a strictly self-pollinating legume. World demand for soybean has been able to absorb ever-increasing production at prices that are profiTable to producers. Since 1970, world consumption of soybean has grown at an annual rate of 4.8% on average and since the 1990s it showed an annual increase of 5.4% on the average (Okalebo *et al.,* 2005).

In Western Province, mixed cropping, with minimal nutrient inputs are the norm and crop rotation is secondary to continuous maize cropping. Few farmers recognize the benefit of improved soil fertility through nutrient recycling. Leguminous intercrops and improved short fallows contribute nitrogen (N) to the soils through litter falls and biological nitrogen fixation, but this process is not widely recognized as beneficial by farmers. On the other hand, mineral fertilizers and livestock manure are considered important inputs, but are usually in short supply (Chianu, 2009).

The high cost of chemical fertilizers and other inputs has not favored increased food production. One way of increasing food production without degrading the environment is through bio – intensive farming (Chianu, 2009). An indirect benefit of growing soybean is the change they introduce in crop rotations, by acting as break-crops to slow down the build-up of cereal pests, diseases and weeds thus reducing the need for pesticides in subsequent cereal crops (Mahasi *et al*, 2009). Due to lack of alternative crops, most farmers practice continuous cropping (mostly maize, cassava, sweet potatoes and cotton).

Soybeans that nodulate effectively with diverse indigenous Rhizobia are considered as promiscuous (Kuneman *et al*, 1984). Hence, promiscuous genotypes of soybean form symbiotic association with available *Rhizobium* strains in the soil and thus fix atmospheric nitrogen whilst non-promiscuous genotypes need specific rhizobial strains to fix nitrogen from the air.

In the late 1970s, breeders at IITA observed that most high yielding soybean cultivars from USA have specific requirements for *Bradyrhizobium japonicum* (Pulver *et al.,* 1982) and inoculation of these varieties was found to be essential when growing them under tropical conditions of low soil nitrogen. In the early 1980s, it was assumed that most tropical countries did not have the facilities and personnel required for inoculum production, storage, and distribution and were dependent upon importation of the final product. The non abundance of commercial *Bradyrhizobium japonicum* inoculants and nitrogenous fertilizers led to the option of breeding promiscuous cultivars in IITA since soybean genotypes that do form symbiotic association with indigenous cowpea-type Rhizobia were identified. Generally, soybean varieties developed for promiscuous nodulation with the indigenous Rhizobia were considered to increase production of soybean in tropical Africa with minimum cost affordable to small-scale farmers (Giller & Wilson, 1991).

Materials and methods

Experimental site

The trials were laid out on small farms in Bungoma County, situated in Western Kenya. The district lies between latitude $00^0 34'$ N and longitude $34^0 34'$E. Bungoma County falls under two major agro-ecological zones: the transitional upper midland zone UM4 (referred to as the maize-sunflower zone) and the Lower Midland zones which cover a greater proportion of the district (LM1-LM3).

The district has a bimodal rainfall pattern, with the first growing season (long rains) extending from March to August, and the second (short rains) from October to January. The district has generally well-distributed annual average rainfall of 1000-1800 mm, depending on the location (TSBF, 2009). The temperature in the district ranges from about 20-22°C in the southern part of Bungoma to about 15-18°C on the slopes of Mount Elgon in the northern part of the district.

Field layout and design

Performance of soybean was tested with rhizobial and myccorhizal bio-inoculants. The experiment was established during the long rains (LR) and repeated during the short rains (SR) of 2010 laid out in a multi-locational one farmer field one replicate design. Since one of the objective was to assess the correlation between selected soils chemical properties on bio-fertilizers performance within a large geographical area in terms of soybean grain yields, treatments were not replicated within each field or farm: instead, farms and seasons were considered as replicates (Pypers, 2010), with 50 farms in the LR 2010 and 100 farms in the second season (SR 2010). Treatments were allocated in new farms each season to avoid contamination and residual effects of the inoculants. Soil characterization was done on each farm so as to determine the soil types and properties in each farm.

Land preparation

Land preparation was done in February 2010 for long rains and September 2010 for short rains using hand hoes. Fine-seedbed preparation was also done by hand prior to demarcation of plots. All the initial land preparations for the two cropping seasons were done by farmers themselves to facilitate the adoption of technologies through their participation in the experimentation.

Soil sampling

Plots of 10 x 10 m area were demarcated and zigzag method used to sample the soils giving a total of 9 sub-samples per plot. The top 0-2 cm soil layer was removed to avoid sampling excess debris and samples taken up to 15 cm depth with a soil auger. The sub-samples were thoroughly mixed and 500 g composites were packed in polythene bags for laboratory analysis. The samples were analyzed for pH, organic carbon (C), total N and available P, according to Okalebo *et al*., (2002). Other routine analyses on cations, micronutrients were not performed due laboratory limitations.

Planting

The treatments were administered into plot sizes of 10 m by 10 m. A promiscuous medium-maturity soybean variety TGx1740-2E (SB 19) that was recommended across locations in Western Kenya by Mahasi *et al*., (2009) was inoculated with either or both inoculants and planted at 50 cm between rows and 7.5 cm between plants in the rows to give a soybean population of 266,667 per hectare. Each experimental plot had nine rows. Rhizobial inoculation (Legumefix, Legume Technologies, UK, containing 532c strain of *Bradyrhizobium japonicum)* was done by thoroughly mixing 125 g of damp seed with 2 g of inoculum (1 x 10^{-9} CFU g^{-1}) as per the manufacture's recommendation. The mycorrhizal inoculum (Rhizatech, Dudutech Ltd., Kenya, containing spores and mycelial fragments of *Glomus intraradices* (50 propagules/cm^3)) was applied to the soil in the seed furrows at the recommended rate of 30 kg ha^{-1} by the manufacture. The germination and emergence were uniform in all the treatments and there was no visual observation on detrimental effects from the treatments. Apart from the technical operations such as treatment application and data collection; all the other operations were managed by the individual farmers.

Plant sampling for biomass and tissue N analysis

Nodulation was examined at mid-podding (50% podding) by carefully uprooting all plants with their entire root system from a 1 m^2 section in each plot. Nodules were washed, counted, put in zip lock bags and weighed. The root and shoot parts were separated, and fresh and dry weights assessed. Pods were also separated from the shoots, fresh and dry weights assessed.

Harvesting

Soybean was harvested at physiological maturity when the pods were dry but not yet shattered in August 2010 for the first crop and second crop was harvested in January 2011. All the plants in the entire plot were harvested and grain yields measured by weighing the dry soybean grain yields produced from each plot.

Statistical analysis

Analysis of variance was conducted to determine the effects of the inoculants and their interactions on plant parameters using a mixed linear model (MIXED procedure, SAS Institute Inc., 2003). The effects of different treatments were compared by computing least square means and standard error of difference (SED): significance of difference was evaluated at $p<0.05$ level of probability. In the mixed model analysis, farmer group nested within site and season were considered as random factors (Pypers, 2010) while the treatment effects (biofertilizers) were evaluated as fixed factors as shown in the SAS model below.

$$Y = X\beta + Z\gamma + \varepsilon$$

Where: Y = Yield (observation), β = treatment (biofertilizer) effect with known design matrix X, γ = denotes the farmer group within site and season which are considered as a random - effects parameters with known design matrix Z, and ε is an unknown random error vector whose elements are no longer required to be independent and homogeneous (MIXED procedure, SAS Institute Inc., 2003). Pearson correlation analysis was done to determine the effect of selected soil chemical properties on soybean grain yields.

Results

Initial soil characterization

The major soil type in the experimental sites was Haplic Ferralsols. These soils are characterized by deep yellowish or reddish colour, highly weathered, high permeability and sTable micro-structure, with very low CEC. They are also chemically poor, with low pH and nutrient reserves, high P fixation, easily depleted by agricultural practices (TSBF, 2009), thus the pH of the soils in surface (0 - 15 cm) ranged from 4.4 to 7.8 in the 44 farms with a mean of 5.46 during Long rains of 2010 and a pH of 5.39 in 63 farms in second rains of 2010. Available phosphorus in surface soils (0-15 cm) by the Olsen *et al*., (1954) sodium bicarbonate extraction, ranged from 1.31-34.64 mg Pkg^{-1} during LR 2010 and from 1.1 to 40 mg Pkg^{-1} during SR 2010. The total N content in soils was low to moderate (0.05 to 0.25 %N) as per Okalebo *et al*., (2002) in Bungoma farms during both seasons. The carbon (or organic matter) contents of soils were low to moderate (0.5-2 %C) according to Okalebo *et al*., (2002) with a mean of 1.32%C during LR and 1.42%C during SR seasons of 2010.

Treatments effect on soybean biomass yield at 50% podding

Biomass yield is an important measure of plant vigor and health. There was a significant difference ($p<0.001$) in terms of biomass yield between treatments in this study. Bradyrhizobium inoculant treated plants had the highest biomass production at 2086 kg/ha. Therefore, the N biofertilizer (Legumefix) can be used as an alternate or as a supplement to N fertilizer to increase agricultural production with less input capital and energy. There was no significant difference ($p>0.05$) between sole rhizobial inoculation and co-inoculation at 2048 kg/ha biomass yield but there was a significant difference ($p<0.001$) between rhizobial and control yielding 1572 kg/ha and/or mycorrhizal inoculation at 1673 kg/ha. Rhizobium inoculant produced higher quantities of biomass, and likely made highest contributions from N fixation.

Treatment effects on soybean grain yield

Rhizobial inoculation resulted in higher grain yields than control. There was no significant difference between sole application of rhizobial (1116 kg/ha) and the co-inoculation (1027 kg/ha) at ($p>0.05$). Low yield in mycorrhizal treatment could be due to the mycorrhizal strain rather than the conditions of the soil and can be attributed to the quality of the strain that might be inferior. Low soybean grain yields in Bungoma even after inoculation (less than 2 t/ha) could be attributed to high soil acidity within the farms (4.5-5.9). Soybeans are very sensitive to soil acidity and prefer a soil pH between 5.8 and 7.8. Rhizobial inoculation also increased the average grain yield by 21% over control treatment. This is because N fixed due to inoculation resulted into high biomass yield. The high biomass implies increase in the rate of photosynthesis due to high leaf number and leaf area. The photosynthates are transported via phloem and used in grain yield production (Majengo *et al*., 2011). Control plots gave poor results, as well as the mycorrhizal product, though that was not expected, given the good performances observed under greenhouse conditions.

Accumulation of plant N and P by soybean biomass and grains

Rhizobial inoculation increased both N and P uptake in the biomass and grains. Rhizobial inoculant contributed to the highest soybean N accumulation of 48.6 N kg/ha and was significantly different ($p<0.05$) from control treatment and sole application of Mycorrhizae. This is because the rhizobial inoculum contains the strains of *Bradyrhizobium japonicum* which are able to fix N through the BNF process hence high N accumulation.

Correlations between selected soil parameters and soybean grain yields

The initial soil pH was positively but weakly correlated ($p<0.05$, $r = 0.19$) with grain yields during LR 2010 season (Table 4.6). This could be attributed to low soil pH that induced deficiency in some essential nutrients, for example P and Mo, thereby leading to a reduction in the number of nodules and BNF (Marschner, 1995 Insert reference in list). There was significant correlation ($p<0.001$, $r=0.42$) between soil organic carbon and soybean grain yields. Since the quantity of humus in soil is influenced by the quantity of carbon compounds added, the availabilities of N, S and P compounds is increased in soils with high organic C. At moderate level of carbon, the soil is able to supply the plant with essential plant nutrients

hence a high significant correlation with grain yields (p<0.001) found in this study. Highly significant correlation (p<0.001) between soil available P and soybean grain yields could be attributed to the fact that P bioavailability is a major factor limiting N fixation.

Conclusions, recommendations and further studies

Bradyrhizobium inoculants have a high potential as commercial biofertilizers and can partially substitute the need for mineral N fertilizer in legume farming systems. However, there is need to target these inputs to the most responsive fields. Legumefix inoculant (Bradyrhizobium) was more effective compared to Rhizatech inoculant (mycorrhizae) under local field conditions in Bungoma at moderate soil N and P. Co-inoculation of Bradyrhizobium with mycorrhizae did not result in increased nodulation or soybean yield compared to sole rhizobia inoculation. Selected soil chemical properties (pH, Olsen P, N and C) and nodule weights had significant effect on soybean yields during both seasons. 5.2 Further studies Further studies are suggested to elucidate the conditions under which synergism between both inoculants may occur, with specific focus towards soil P availability and management of P possible inputs in the low P soils and also to determine the contribution of environment and plant interactions in soybean production, especially as soybean yields are still disappointingly low in most Kenyan conditions. Screening of other cultivars is also suggested.

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Effect of Rhizobia inoculation, and three Phosphorus fertiliser levels on nodulation and yield of soybean in central highlands of Kenya

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Abstract

A field study was conducted in central highlands of Kenya to investigate the response of soybean (*Glycine Max*. L. Merril.) to *Bradyrhizobium japonicum* inoculation and Triple Super Phosphate during the 2012 short rains. Three fertiliser rates (0, 30, and 60 kg P ha^{-1}) were evaluated with rhizobia inoculation and non-inoculation. The experimental design was a randomised complete block design (RCBD) with 12 replicates. Number of nodules and activity, plant wet/dry and root wet/dry weights, total biomass and grain yield were determined. Rhizobia inoculation significantly increased nodule numbers of soybean and affected the presence of leghaemoglobin in nodules. It also significantly increased plant total biomass yield and grain yield. Phosphorus significantly increased root dry weight of soybean, plant biomass and grain yield. Phosporusd rate, however, did not significantly affect the nodule numbers of soybean neither did it affect leghaemoglobin in nodules since non-inoculated plots had minimal nodulation than inoculated plots. Nitrogen fixation was evident in all inoculated and nodulated plants due to the presence of leghaemoglobin. Nodulation was negatively affected by soil acidity with more acidic soils (pH 4.8-5.3) recording low nodulation despite inoculation. Phosphorus rate affected soybean yield during the long rains with higher yield in the higher rate application of 60 kg ha^{-1}. The highest agronomic efficiency was, however, realised in the 30 kg P ha^{-1}.

Key words: triple super phosphate, *Bradyrhizobium japonicum*, leghaemoglobin, soybean, nodulation.

Introduction

Biological nitrogen fixation (BNF) of grain legumes is a strategy to ease the burden that commercial fertilisers exert on poor farmers in sub-Sahara Africa (SSA). The gross annual nitrogen (N) mining in SSA averages 22 kg N ha^{-1} with some as high as 100 kg N ha^{-1}. (Stoorvogel *et al.,* 1993). In Kenya, soybean production has gained momentum due to demand for protein and biodiesel with small-scale farmers becoming more interested in the crop. It is also possible to improve soil fertility in Kenya amongst smallholder farmers through introduction of promiscuous soybean varieties (varieties that do not require inoculation with a specific *Rhizobium*) (Kihara *et al.,* 2011) or inoculation with suiTable Rhizobia strains to non-promiscous varieties.

Amount of N fixed by grain legumes such as soybean is affected by the degree of colonisation by rhizobia from the soil (Kihara *et al.,* 2011) or inoculated, by their interaction with other biological, physical, and chemical properties of the soil and by weather. Apart from weather, other factors are influenced by management practices and input applications both in quantity and type. Legumes such as soybean transport N fixed from roots to shoots in the form of ureides (allantoin and allantoic acid) and hence susceptible to water stress (Kihara *et al.,* 2011). Efforts that aim to increase water absorption through the root system and scavenging for water through increased root biomass would contribute positively towards greater soybean yield. Fertilisers may affect nodulation, plant water and nutrient uptake and yield. Soybean crop may fix atmospheric N to meet its requirements and those of subsequent crops (Aulak *et al.,* 2003).

Studies show that low native soil phosphorus availability and poor utilisation of added P is a major constraint limiting the productivity of soybean. However, the use of P is limited by its high cost, while organic inputs do not provide sufficient P for optimal crop growth due to their low P concentration (Aulakh *et al*., 2003).

Therefore, the optimal use of phosphorus fertilisers leading to increased P use efficiency should be encouraged. Information on recommended P rates for smallholder farmers in central highlands of Kenya is unavailable hence the need to investigate the most efficient rate and effect of combination with enhanced biological N fixation methods.

The objective of this study was to evaluate the effect of different rates of P on soybean growth and yield and assess the effect of rhizobia inoculation on soybean nodulation and yields.

Materials and methods

Site description

Field studies were carried out during the short rains (Season 1) within selected farmers in Embu and Meru counties (00°06'19.4" S37°54'49.7" E) between October 2012 and January 2013. According to agroecological conditions (based on temperature and moisture supply), the areas lies in the upper midland zone 3 (UM3) (Jaetzold *et al.,* 2006) on the eastern slopes of Mount Kenya at of 1150-1600 m. The annual mean temperature is about 18.7-22° C and a total annual rainfall of 1300 mm. The soils are mainly humic Nitisols which are extremely deep dusky red to dark reddish brown, friable clay well weathered (Jaetzold *et al.,* 2006).

Design of experiments

The study was conducted in 12 farmers fields. The trials were set in a randomised complete block design (RCBD), each as a replicate. Phosphorus levels of 0, 30, and 60 kg ha^{-1} were applied with inoculation and without inoculation. Phosporus was applied at planting as Triple Super Phosphate (TSP) 46% P_2O_5 using banding method. Each experimental plot measured 4 × 4.5 m. Two soybean seeds per hill were sown manually at a depth of 5 cm and a spacing of 15 × 45 cm in three non inoculated units and two *Brandyrhizobium japonicum* inoculated seeds sown in three inoculated units. The inoculums was prepared by mixing 100 g of *B. japonicum* (carrier material included) with 300 ml Lukewarm water and adding 5 g of gum Arabic sticker in a plastic bucket. Fifteen kilogrammes of seeds were then thoroughly mixed in the bucket to have a uniform cover. The inoculated seed were kept under shade during the planting. The treatment combination were:

- *B. japonicum* (USDA 110 Strain) inoculated + 60 kg P ha^{-1}
- *B. japonicum* (USDA 110 Strain) inoculated + 30 kg P ha^{-1}
- *B. japonicum* (USDA 110 Strain) inoculated + 0 kg P ha^{-1}
- 60 kg P ha^{-1}
- 30 kg P ha^{-1}
- Control.

Plots were kept weed-free throughout the growing season.

Measurement of nodule numbers and activity

This was determined at vegetative 50% flowering equivalent to 40 days after emergence (DAE). Soybean plants were randomly uprooted from four hills of the inner rows per experimental plot after loosening the soil with a hand hoe and immersing in water to loosen the soil around the roots. The number of nodules per plant was recorded and the presence or absence of leghaemoglobin determined by puncture method and recorded.

Measurement of crop biomass and grain yield

Above- and below-ground biomass was determined at 50% flowering, 40 DAE and at harvest maturity, 100 DAE. The biomass was from plants uprooted from four hills randomly selected from interior rows of the

experimental units. Biomass at harvest maturity was determined from an area of 1.5 m^2 of the innermost rows. The harvested plants were oven dried at 65° C for 48 h and weighed to obtain the biomass. Grain yield was determined from the same plants used for biomass at harvest maturity. Pods were separated from the plants, weighed and threshed to determine grain yield.

Statistical analysis

The Genstat 14th edition statistical package was used to analyse the data. Analysis of variance (ANOVA) was used to assess the effect P and inoculation on wet and dry weight, biomass and grain yield. Poisson was used for nodule number count data and binomial regression was used to test the nodule activity due to only two possible outcomes. Significant (P<0.05) differences among the treatment means were recorded.

Results and discussion

The variation in wet weight was significant (p<0.001) among farms, inoculation and P level and the interaction between inoculation and P level was not significant (p=0.12) (Table 1).

Table 3: ANOVA for wet weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P_level	2	4236.6	2118.3	12.85	<.001
Inoc_status	1	6754.6	6754.6	40.98	<.001
Replicate	10	27206.9	2720.7	16.51	<.001
P_level.Inoc_status	2	730	365	2.21	0.12
Residual	50	8241.7	164.8		
Total	65	47169.8			

Multiple mean comparison shows that plant wet weight was not significantly different between 30 and 60 levels of P

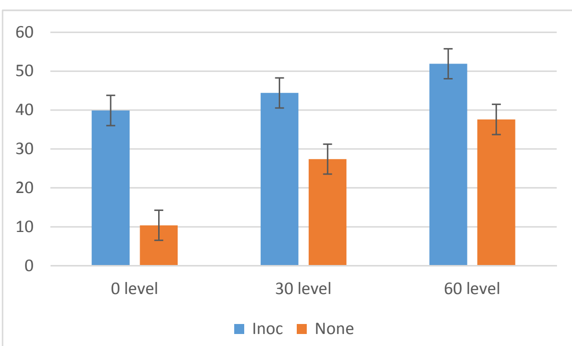

Figure 1: Plant wet weight

Table 4: Multiple mean comparison for plant wet weight

	Mean	
60	44.75	a
30	35.91	a
0	25.16	b

There was statistical significance in the mean obtained from P at 60, 0, 30 and0 kg ha^{-1} on the plant wet weight. Variation in root wet weight was significant among P levels, inoculation and different farms ($p<0.001$) (Table 3).

Table 5: ANOVA for Root wet weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P_level	2	44.809	22.405	13.6	<.001
Inoc_status	1	112.876	112.876	68.52	<.001
Replicate	10	160.951	16.095	9.77	<.001
P_level.Inoc_status	2	2.69	1.345	0.82	0.448
Residual	50	82.368	1.647		
Total	65	403.693			

Mean separation reveals that there was no significant difference in root wet weight between P levels at 60 and 30 kg ha^{-1} (Table 4).

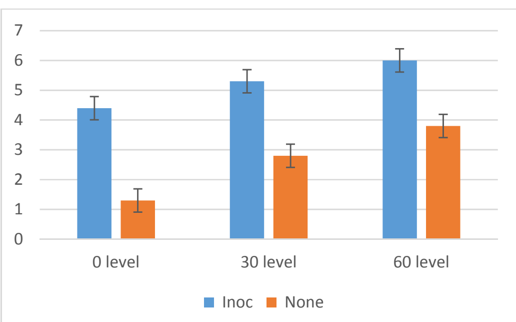

Figure 17: Root wet weight

Table 6: Bonferroni Mean separation for root wet weight

	Mean	
60	4.866	a
30	4.034	a
0	2.858	b

There was a significant (p<0.001) variation in plant dry weight among phosphorus levels, inoculation and different farms. The interaction between phosphorus levels and inoculation was also significant (p=0.018).

Mean separation revealed that all the three P levels had a significantly different plant dry weight from each other.

Mean root dry weight varied significantly (p<0.001) among the P levels, inoculation, and farms (Table 7).

Table 7: ANOVA for dry plant weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P_level	2	723.67	361.83	18.53	<.001
Inoc_status	1	824.98	824.98	42.24	<.001
Replicate	10	3824.26	382.43	19.58	<.001
P_level.Inoc_status	2	171.05	85.52	4.38	0.018
Residual	50	976.45	19.53		
Total	65	6520.41			

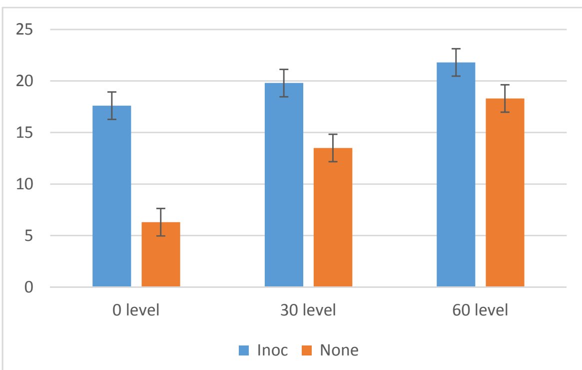

Figure 18: Plant dry weight

Table 8: Mean separation for dry weight

	Mean	
60	20.05	a
30	16.61	b
0	11.97	c

Table 9: ANOVA for root dry weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P_level	2	15.0729	7.5364	15.66	<.001
Inoc_status	1	22.8626	22.8626	47.5	<.001
Replicate	10	60.3211	6.0321	12.53	<.001
P_level.Inoc_status	2	1.618	0.809	1.68	0.197
Residual	50	24.0655	0.4813		
Total	65	123.9402			

All the P levels differed significantly among each other in the root dry weight (Table 8).

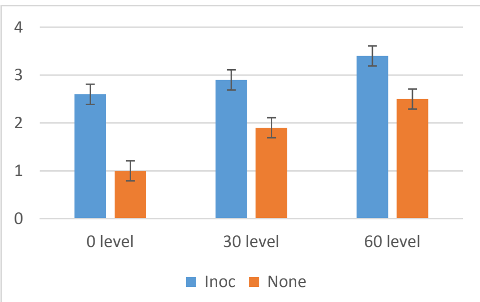

Figure 19: Root dry weight

Table 10: Root dry weight mean separation

	Mean	
60	2.987	a
30	2.406	b
0	1.816	c

Plant total biomass differed significantly (p<0.001) among P levels, inoculation, and farms. However the interaction between P levels and inoculation status was not significant (p=0.093).

Table 11: ANOVA for biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P_level	2	1366412	683206	19.95	<.001
Inoc_status	1	1476014	1476014	43.1	<.001
Replicate	10	5595776	559578	16.34	<.001
P_level.Inoc_status	2	170873	85436	2.5	0.093
Residual	50	1712152	34243		
Total	65	10321226			

Multiple mean comparison revealed that at each level of P was significantly different from the others (Table 10).

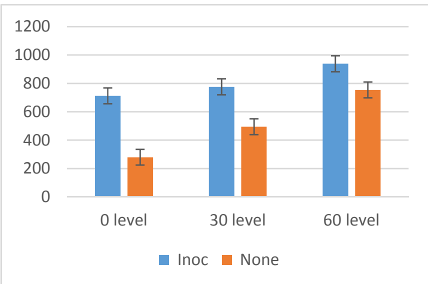

Figure 20 : Soybean biomass

Table 12: Benferroni mean separation for biomass

	Mean	
60	845.9	a
30	635	b
0	495.9	c

Yields were significantly ($p<0.001$) different among P levels, inoculation and farms (Table 11).

Table : ANOVA for yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P_level	2	15834930	7917465	15.33	<.001
Inoc_status	1	27996514	27996514	54.2	<.001
Replicate	10	64200928	6420093	12.43	<.001
P_level.Inoc_status	2	865835	432917	0.84	0.439
Residual	50	25826450	516529		
Total	65	1.35E+08			

Multiple mean comparison shows that there was no significant difference in yield for P at 30 level and where none was applied. However, where P was applied at 60 there a significantly higher yield (Table 12).

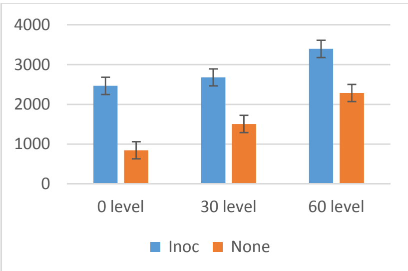

Figure 6: Soybean grain yield

Table 13: Mean separation for yield

	Mean	
60	2841	a
30	2092	b
0	1655	b

From the poisson regression analysis there was a significant ($p<0.001$) difference in number of nodules among the farms, inoculation status and interaction between P levels and inoculation status. Number of nodules were not significantly ($p=0.6739$) different among phosphorus levels (Table 13).

Table 13: Poisson analysis for number of nodules

			Resid. Df	Resid. Dev	Pr(>Chi)
NULL	Df	Deviance	575	10603.5	
Farmers	1	109.9	574	10493.7	< 2.2e-16 ***
Inoculation status	1	7989.1	573	2504.6	< 2.2e-16 ***
P level	1	0.2	572	2504.4	0.6739
Innoculation P level	1	56.8	571	2447.6	4.863e-14 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

There was significance ($p=0.00833$) variation in nodule activity among different farms, inoculation status ($p< 0.001$) and the interaction between inoculation status and P level ($p<0.001$) (Table 14).

Table 14: Binomial analysis for activity

		Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	Df	575	781.75		
Farmer	1	6.96	574	774.79	0.00833 **
Innoculation	1	423.49	573	351.3	< 2.2e-16 ***
P.level	1	0.03	572	351.27	0.86577
Innoculation: P level	1	23.97	571	327.3	9.78e-07 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

There was a significant correlation between moisture content and plant wet and dry weight, biomass, nodule formation and yield. Soil pH using both KCl ($p=0.1883$) and water ($p=0.2096$) did not have a

significant correlation with nodule formation. There was also no significant correlation between altitude and nodule formation (p=0.8925). Soil pH using both methods had a correlation with plant wet weight ($p<0.001$), root wet weight ($p<0.001$), plant dry weight and total biomass (($p<0.001$).

Table 15: Two sided correlation analysis for various variables

MC_corrected	1	-										
pH_KCl	2	<0.001	-									
pH_water	3	0.0042	<0.001	-								
Alt_MASL	4	0.0029	0.2157	0.9834	-							
Plant_wet_Wt_g	5	<0.001	<0.001	<0.001	0.5374	-						
Root_Wet_wt_g	6	<0.001	<0.001	0.0046	0.3894	<0.001	-					
Root_dry_wt_g	7	<0.001	<0.001	<0.001	0.8802	<0.001	<0.001	-				
Plant_dry_wt_g	8	<0.001	<0.001	<0.001	0.7587	<0.001	<0.001	<0.001	-			
Total_Biomass_g	9	<0.001	<0.001	0.0027	<0.001	<0.001	<0.001	<0.001	<0.001	-		
Nodule_numbers	10	<0.001	0.1883	0.2096	0.8925	<0.001	<0.001	<0.001	<0.001	<0.001	-	
Kg_Ha	11	<0.001	<0.001	0.0042	0.0029	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
		1	2	3	4	5	6	7	8	9	10	11

Table 16: Variables: Correlation coefficient of various variables

MC_corrected	1	-										
pH_KCl	2	0.4974	-									
pH_water	3	0.348	0.8406	-								
Alt_MASL	4	0.3605	0.1544	0.0026	-							
Plant_wet_Wt_g	5	0.8055	0.5812	0.4562	0.0773	-						
Root_Wet_wt_g	6	0.8207	0.4457	0.3446	0.1077	0.9446	-					
Root_dry_wt_g	7	0.7463	0.5045	0.4205	0.0189	0.9542	0.9595	-				
Plant_dry_wt_g	8	0.7503	0.5612	0.4505	-0.0385	0.974	0.9204	0.9604	-			
Total_Biomass_g	9	0.9785	0.502	0.3633	0.4235	0.7823	0.7763	0.7105	0.7305	-		
Nodule_numbers	10	0.6146	0.164	0.1565	0.017	0.5292	0.6845	0.5699	0.5158	0.545	-	
Kg_Ha	11	1	0.4974	0.348	0.3605	0.8055	0.8207	0.7463	0.7503	0.9785	0.6146	-
		1	2	3	4	5	6	7	8	9	10	11

Bolded values have a significant correlation

Discussion

Grain yield results in the study show no statistical significance difference between 0 and 30 kg ha^{-1} P levels but a higher significant yield difference is obtained at P 60 kg ha^{-1}.

Among the variables that are significantly correlated plant biomass and moisture content are among the highest in correlation coefficient (97.85%). Yield and plant biomass also have a very high correlation coefficient (97.85%). Plant wet weight and dry weight had a strong correlation (r=0.974). Root dry weight and plant dry weight had a very strong correlation (r=0.9604). Nodule numbers and biomass yield had a moderate correlation (r=0.545). The pH and grain and biomass yield were not very strongly correlated. There was a strong correlation between root wet weight and plant wet weight (94.5%), root dry weight and plant wet weight (95.4%), plant dry weight and plant wet weight (97.4%) and plant wet weight and yield

(82%). Root dry weight was strongly correlated with root wet weight (96%) and plant dry weight was also strongly correlated with root wet weight (92%). Yields were also strongly correlated with root wet weight (82%), while plant dry weight was also strongly correlated with root dry weight at 96% and total biomass was strongly correlated to grain yield at 97.85% (Table 16).

Conclusion

The results from this study show that:

- 60 kg ha^{-1} of fertiliser could contribute to higher grain yield compared to 30 kg ha^{-1} in the study area
- A combination of P and inoculation does not affect the grain yield significantly
- pH does not seem to significantly affect biomass and grain yield in the study area
- Different farms had different levels of nodule activity and nodule numbers varied across the farms
- P levels do not affect number of nodules but interaction between P and inoculation does
- inoculation status affect number of nodules

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Bacterial diversity in Lake Nakuru and their potential utilization in agriculture and environment management

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Abstract

Albeit their known importance in decomposition which is an important function in environmental health and soil's nutrient replenishment, bacteria have been largely omitted from ecosystem studies of saline lakes. An inventory was taken in Lake Nakuru to determine the biodiversity of bacteria of the alkaline waters and potential utilization of microorganism in agriculture and environment restoration through decomposition. Samples were collected in three different depths at five points of the lake selected based on their locations, proximity to fresh water inlets and depth of the lake. The samples were collected once a month for six months in the year 2011. Bacterial were cultured and pure cultures were isolated, identified and introduced to different pollutants and materials to elucidate their decomposition potential. Decomposition potentials of the isolated bacteria were observed for various materials including plastic cup and polythene papers. The experimental set up was put in a shaker set at seventy revolutions per minute and at room temperature for 90 days, after which the final weight was determined. Twenty one different types of bacteria were identified. Some bacteria were found to be effective in decomposition of materials and hence important in agriculture and environment waste handling. Some of the bacteria that were identified as having high potential in utilization in agriculture and environment management include Sphingomonas paucimobilis, Streptococcus pyogenes, Tatumela ptyseas, Bacillus anthracoides, Chryseobacterium indologenes, Chryseobacterium meningosepticum, Pseudomonas cepacia, proteus penneri, Morganella morganii, Moraxela sp., Alcaligene sp., Providencia stuarti, and Providencia rettgeri.

Introduction

Bacteria are one of the most abundant and species rich groups of organisms that mediate many critical ecosystem processes (Claire *et al.,* 2003). Bacteria are economically important as they are used in industrial microbiology, as biological pest control, in vitamin synthesis and in remediation of the environment (Liese *et al.,* 1999). It is important to understand patterns of bacterial biodiversity because they mediate many of the environmental processes that sustain life on the earth and their diversity is greatly applied in bioremediation and in search for novel bio-chemicals for use in medicine, agriculture and industry (Claire *et al.,* 2003).

Saline lakes have significant economic, ecological, biodiversity and cultural value. They are an important source of minerals, water, fish, biochemical products and food stuffs or aquaculture. Many have a high aesthetic value and cultural significance (Hammer, 1986). Halophiles which are found in these halophilic lakes are used in bioremediation, biodegradation and in oil recovery (Dubey *et al.,* 2003).

Bioremediation is any process that uses microorganisms, fungi, green plants or their enzymes to return the environment altered by contaminants to its original conditions (Shristi *et al.,* 2006). It is a process caused by biological activity which leads to the change of the chemical structure of a material to naturally occurring metabolic products (Yutaka *et al.,* 2009) Naturally-occurring bioremediation and phytoremediation technologies have been used in desalination of agricultural land by phytoextraction. Bioremediation technologies can be generally classified as *in situ* or *ex situ*. *In situ* bioremediation involves treating the contaminated material at the site while *ex situ* involves the removal of the contaminated material to be treated elsewhere. Some examples of bioremediation technologies are bioventing, landfarming, bioreactor, composting, bioaugmentation, rhizofiltration, and biostimulation (Mandri and Lin, 2007). Bioremediation

has a number of advantages such as broad applicability, low cost and low risk of exposure to hazardous chemicals during cleanup (Hoff, 1993).

The elimination of a wide range of pollutants and wastes from the environment is a requirement to promote a sustainable development of the society with low negative environmental impact. Biological processes play a major role in the removal of contaminants due to catabolic versatility of microorganisms to degrade or convert such compounds (Diaz, 2008). Plastics which are non-biodegradable waste have been widely used due to their light weight, inertness and low cost. Their disposal especially those used for packaging have become a major environmental concern due to poor waste management practices. Their accumulation especially in urban areas is a challenge worldwide. Some plastics collect water and become the breeding places of mosquitoes worsening the problem. In addition, they block drainage systems. Moreover, plastics have also been recently recognized as a major threat to marine life. They sometimes cause blockage in fish intestine, birds and marine mammals. There is considerable research interest in the microbial degradation of plastics waste material since microbes are able to degrade most organic and inorganic materials (Shristi *et al.*, 2006). Plastics are high molecular weight polymers that are at some stage in their existence capable of flow but may also be brought into a non-fluid form in which they have sufficient toughness and strength to be useful in self supporting applications (Brysdon, 2010).

A plastic is a broad name given to different polymers with high molecular weight which can be degraded by various processes (Iwata *et al.*, 1998). Polymers are a broad class of material which are made of repeating units of smaller molecules called monomers. A plastic material is called biodegradable if all its organic compounds undergo a complete biodegradation process (Iwata *et al.*, 1998). It is also said to be biodegradable if the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae and ultimately the material is converted to water, carbon dioxide and/or methane and a new cell biomass (Suyama *et al.*, 1998). Environmental factors have a crucial influence on the polymer to be degraded, on the microbial population and on the activity of the different microorganisms themselves (Gu *et al.*, 2000). Parameters such as humidity, temperature, pH, salinity, presence or absence of oxygen and the supply of different nutrients have an important effect on the microbial degradation of the polymers. Presence of molecular oxygen is a prerequisite for the degradation of polymers **(**Doi, 1990). Biodegradation of plastics is a heterogeneous process which involves biotic and abiotic processes (Tokiwa, 1994). The major mechanisms involved in the biotic degradation of plastic are; the adherence of the microorganism on the surface of the plastic followed by colonization of the exposed surface. Due to properties and the size of the polymer molecules, microbes are unable to transport the polymeric material directly into the cells where most biochemical processes take place. They first excrete extracellular enzymes which depolymerize the polymers outside the cells. This yields smaller molecules of short chains, for example oligomers, dimers, and monomers that are able to pass semi-permeable outer bacterial membrane and be utilised as carbon and energy sources (Frazer, 1994). Consequently if the molar mass of the polymers can be sufficiently reduced to generate water soluble intermediates, these are transported into the microorganism and fed into the appropriate metabolic pathways. As a result the end products of these metabolic processes include water, carbon dioxide and methane in case of anaerobic degradation. This degradation process is called mineralization (Barzal *et al.*, 1989).

Biodiversity and occurrence of plastic degrading microbes vary depending on the environment such as soil, sea, compost and activated sludge (Yutaka *et al.*, 2009). A number of aerobic and anaerobic microorganisms that degrade plastics particularly fungi and bacteria have been isolated from various environments (Lee, 1996).

Materials and methods

Study area

The study site was Lake Nakuru, located in the Rift Valley Province, Nakuru County, Kenya, at an altitude of 1,759 m. It consists of a shallow pan of water lying on salt impregnated clay which retains coarser polar sediments. Its surface area is 40-60 km^2 but is subject to marked fluctuations because lake level is constantly

rising and falling. The average depth is 1 m (Kairu, 1991). The length of shoreline is 27 km. The water level is unregulated. It has a catchments area of 1,800 km^2 (Vareshi, 1982).

Sampling locations

Five sites were selected and geo-referenced using Geographical Positioning System (GPS): Middle lake or Jetty mid (latitude -0.354781, longitude 36.093118) hippo point (latitude -0.319546, longitude 36.), Nderit (latitude -0.386313, longitude 36.110497) Makalia (latitude -0.391499, longitude 36.083254l) and Njoro ((latitude -0.331833, longitude 36.092667). These sampling points reflected different catchments areas.

Serial dilution was carried out by using a sterile pipette and transferring 1ml of the sample water to 9ml of sterile water to make a dilution of up to 10^6. 1ml of the diluted sample water was inoculated on sterile Nutrient agar media using spread plate method. The media was sterilized by autoclaving at 121^{o}C for 15 minutes. The inoculated plates were incubated upside down at 35°C for 24 hours. This was done to prevent condensation droplets from falling onto the surface of the agar. The petri dishes were sealed using adhesive tape to prevent contamination. Sub-culturing was done by streaking method.

Single colonies were picked using a sterile wire loop and streaked on sterile media to obtain pure cultures.

The bacteria isolated were identified based on physical characterization and biochemical tests as outlined in Bergey's manual of determinative bacteriology (Holt, 1994). Morphological characteristics such as shape and size were observed under light microscope. Gram stain was conducted. In this procedure, a thin film of each isolate was smeared on the surface of the slide and heated gently over fire to fix it. The smear was first stained with crystal violet, left to stand for a few seconds and then rinsed with a stream of water. It was then treated with a mordant (iodine). The slide smear was then washed with a decolorizing agent (acetone) and counterstained with safrinin. The smear slide was then observed under oil immersion using a light microscope.

Motility test was determined by microscopically observing the bacteria in a wet mount. An inoculum from a freshly prepared culture was used to prepare the wet mount. The inoculum was transferred to a drop of water on a microscope slide, mixed and covered using a cover slip. The slide was observed under light microscope. The bacteria that were observed to swim randomly against the current of water streaming across the slide surface were positive for this test.

Lactose test was conducted in order to determine whether the bacteria fermented this carbohydrate as a carbon source. An inoculum from a pure culture was transferred aseptically to a sterile tube of phenol red lactose broth. The inoculated tube was incubated at 35° C for 24 hours. A positive test indicated colour change from red to yellow.

Hydrogen sulfide gas production test was carried out to determine whether the bacteria were able to reduce sulfur containing compounds to sulfides during metabolism process. An inoculum from a pure culture was transferred aseptically to a sterile triple sugar ion agar slant. The inoculated tube was incubated at 35° C for 24 hours. A black colour in the agar slant media indicated a positive test.

Citrate test was carried out to determine the ability of the bacteria to utilize sodium citrate as the only source of carbon. A sterile wire loop was used to inoculate 3ml of sterile Koser citrate medium with a broth culture of bacteria. The inoculated broth was incubated at 35° C for three days. A change of colour from green to blue indicated a positive result.

Serotyping using Analytical Profile Index (API) kits was carried out. API kits used were enteric (API 20E) non-enteric (API 20NE) and streptococcus kits (API 20strep.) manufactured by Biomerieux Inc. USA.

Degradation of plastics disks

Degradation of plastic disks was determined by percentage weight loss of the materials, as described by Kathiresan, (2003). The experiment was set up in four replicates and carried out for a period of 90 days. Disks of 0.6 cm diameter were prepared from clear polythene bags and white disposable plastic cups. Ten mg of each type of disk was put in a conical flask, 150 ml of distilled water and inorganic nutrients

composed of 0.01M ammonium phosphate, 0.002M magnesium sulfate, 0.012M potassium phosphate and 0.144 M non-iodinated sodium chloride were added to the conical flasks, sealed using alluminium foil and sterilized by autoclaving at 121° C for 20 minutes. The contents in the conical flasks were inoculated with different bacterial species separately after cooling to 25° C. The conical flasks were covered with parafilm to provide aeration, avoid contamination and evaporation.

The negative control contained ten mg of sterile disks measuring 0.6 cm in diameter, 150 ml of distilled water, and the inorganic nutrients as stated above. A positive control contained 150 ml of distilled water, 5 g of soil from mangrove forest collected at Mtwapa, Kenya, and the inorganic nutrients. This soil was collected at a depth of 5 cm, placed in sterile polythene bags and taken to the laboratory for the purpose of the culturing, isolation and identification of the bacteria present. The soil was autoclaved after bacteria isolation and later inoculated with these bacteria. These were put in conical flasks which were covered using parafilm.

The experimental set up was put in a shaker set at seventy revolutions per minute and at room temperature for 90 days. After 90 days of shaking, the plastic and polythene disks were washed thoroughly using distilled water, shade dried and then weighed for the final weight. From the data collected, the average weight loss caused by each bacterium was computed for both plastic and polythene bags. The degradation was then determined as percentage weight loss and calculated as

$$\text{Degradation} = \frac{\text{Initial weight - Final weight} \times 100}{\text{Initial weight}}$$

Results

Biodiversity and Identification of Bacteria

The waters of Lake Nakuru were found to have diverse bacteria. Various types of bacteria grew on nutrient agar forming colonies of different sizes and colours. Twenty one species were isolated and identified from the waters of Lake Nakuru (Table 1). The bacteria were classified according to their different morphological characteristics. There were seventeen bacilli, one coccus, one coccobacillus, one vibrio and one filamentous. There were nineteen Gram negative and two Gram positive bacteria. They were further identified using other biochemical tests and API kits. There were twelve enteric and nine non enteric bacteria. Fifteen bacteria were motile while six were non motile. The bacteria isolated and identified from mangrove soil were *Bacillus sp.*, *Micrococcus sp.*, *Staphylococcus sp.*, and *Streptococcus* sp.

Table 1: Bacteria species isolated from Lake Nakuru, classified according to shape, gram staining and biochemical tests

Bacteria species	Gram stain	Citrate test	H_2S production	fermentation	Motility test	Enteric/non enteric	Shape
Bacillus anthracoides	+	-	-	+	+	Non enteric	Rods
Streptococcus pyogenes	+	-	-	-	-	Non enteric	spherical
Erwinia mallotivora	-	-	-	-	+	Enteric	Rods
Erwinia amylovora	-	-	+	+	+	Enteric	Rods
Sphingomonas paucimobilis	-	-	-	-	+	Non enteric	Rods
Morganella morganii	-	-	+	+	_	Enteric	Rods
Enterobacter or Pantonea agglomerans	-	-	-	+	_	Enteric	Rods
Yersinia pseudotuberculosis	-	-	-	+	_	Enteric	Rods
Chryseobacterium meningosepticum	-	-	-	-	_	Non enteric	Rods
Providencia stuarti	-	+	-	-	+	Enteric	Rods
Vibrio vulnificus	-	-	-	+	+	Non enteric	Comma
Pseudomonas cepacia	-	-	-	-	+	Enteric	Rods
Proteus penneri	-	-	-	-	+	Enteric	Rods
Erwinia nigrifluence	-	-	-	+	_	Enteric	Rods
Agrobacterium radiobacter	-	-	-	+	+	Non enteric	Rods
Providencia rettgeri	-	+	-	+	+	Non enteric	Rods
Alcaligen sp.	-	-	-	+	+	Enteric	Rods
Tatumella ptyseas	-	-	-	+	+	Enteric	Rods
Moraxella sp.	-	-	-	+	+	Non enteric	Spherical and rods
Chryseobacterium indologenes	-	-	-	-	_	Non enteric	Filamentous
Acinetobacter sp.	-	-	-	-	_	Enteric	Rods

Biodegradation of plastics cups by selected ***bacteria isolates from Lake Nakuru***

The percentage weight loss of white disposable plastic cups that was caused by the bacteria was calculated as the percentage weight loss that was obtained after subtracting the amount of weight lost by the plastic in the negative control. Table 2 shows the percentage degradation of plastics that had taken place after ninety days of degradation. The initial weight of plastic that was put in each experimental set up was 10 mg. The bacteria from mangrove soil had the highest percentage of plastic degradation with the plastic discs loosing 27.5% of the original weight (Table 2).

These bacteria which were isolated from the mangrove soil included *Bacillus sp., Micrococcus sp., Staphylococcus sp.,* and *Streptococcus sp*. The microorganism that caused the highest percentage of plastic degradation from Lake Nakuru was *Sphingomonas paucimobilis* with a percentage of (17.5%). *Erwinia nigrifluence* was also effective in degradation of plastic with weight loss of 12.5% of the original weight of plastics. Other bacteria that were observed to degrade plastic were *Streptococcus pyogenes (11.5%) Tatumella ptyseas (11%) Pseudomonas cepacia*, (9.5), *Chryseobacterium meningosepticum (8%), Erwinia Amylovora (7%) Moraxella sp., (6.5%) Bacillus anthracoides (6%), Providencia rettgeri (5.0%) Proteus penneri (4.50%), Chryseobacterium indologenes (3%), Morganella morganii (2%) Providencia stuarti (1.5%)* and *Alcaligen sp. (0.5%). Providencia stuarti* and *Alcaligen sp.* were slow degraders. *Yersinia pseudotuberculosis* and *Acinetobacter* species were unable to degrade plastics.

Biodegradation of polythene bags

The results in Table 3 show that the bacteria from the mangrove soil presented the highest percentage (50.5%) of degradation of polythene. These bacteria were *Bacillus* sp., *Micrococcus* sp., *Staphylococcus* sp. and *Streptococcus* sp. Among the bacteria isolated from Lake Nakuru, *Sphingomonas paucimobilis* presented the highest percentage of polythene degradation (37.5%). *Pseudomonas cepacia* caused 35.5% polythene degradation. *Streptococcus pyogenes* and *Alcaligen sp*. had the same percentage of degradation (27.0%). *Tatumella ptyseas* degraded polythene by 21.5%. *Chryseobacterium meningosepticum* reduced the polythene weight by 19.5 % while *Proteus penneri* reduced the weight of polythene by 18%. Other bacteria from Lake Nakuru that were able to degrade polythene were *Providencia rettgeri (13.5%), Erwinia nigrifluence (11.5%), Providencia stuarti (5.50)* and *Chryseobacterium indologenes* (7.5%). *Erwinia amylovora* and *Acinetobacter sp.* were slow degraders as they had only degraded (1%) of plastics in 90 days. *Yersinia pseudotuberculosis* and *Morganella morganii* were unable to degrade polythene (0%).

Most bacteria were able to degrade polythene at a higher percentage than plastics (Figure 1). *Morganella morganii* degraded plastics though to a smaller degree but was unable to degrade polythene. *Yersinia pseudotuberculosis* was unable to degrade both plastics and polythene. *Sphingomonas paucimobilis*, *Erwinia nigrifluence, Tatumella ptyseas* and *Streptococcus pyogenes* showed high rates of degradation of both plastics and polythene. *Acinetobacter sp*. was able to degrade polythene but unable to degrade plastics. *Alcaligen sp*. indicated a high percentage of degradation of polythene but low percentage of degradation of plastics.

Table 1: Mean weight (mg) and percentage weight loss of plastics after treatment with different species of bacteria isolated from lake Nakuru. Initial weight of plastic put in each experimental set up was 10 mg

Name of bacteria species	Mean wt (mg)±SE after 90 days of degradation	Wt loss (mg) after 90 days	Wt loss (%)	Wt loss due to bacteria (%)
Bacillus anthracoides	5.750 ± 0.0005	4.25	42.5	6.00
Yersinia pseudotuberculosis	6.350 ± 0.0005	3.65	36.5	0.00
Providencia rettgeri	5.850 ± 0.0005	4.15	41.5	5.00
Positive control	3.600 ± 0.0090	6.40	64.0	27.5
Providencia stuarti	6.200 ± 0.0040	3.80	38.0	1.50
Morganella morganii	6.150 ± 0.0015	3.85	38.5	2.00
Sphingomonas paucimobilis	4.600 ± 0.0060	5.40	54.0	17.5
Acinetobacter sp.	6.350 ± 0.0015	3.65	36.5	0.00
Moraxella sp.	5.700 ± 0.0030	4.30	43.0	6.50
Erwinia amylovora	5.650 ± 0.0025	4.35	43.5	7.00
Negative control	6.350 ± 0.0005	3.65	36.5	0.00
Alcaligen spp.	6.300 ± 0.0100	3.70	37.0	0.50
Proteus penneri	5.900 ± 0.0090	4.10	41.0	4.50
Chryseobacterium meningosepticum	5.550 ± 0.0005	4.45	44.5	8.00
Pseudomonas cepacia	5.400 ± 0.0020	4.60	46.0	9.50
Erwinia nigrifluens	5.100 ± 0.0000	4.90	49.0	12.5
Tatumella ptyseas	5.250 ± 0.0015	4.75	47.5	11.0
Chryseobacterium indologenes	6.050 ± 0.0035	3.95	39.5	3.00
Streptococcus pyogenes	5.200 ± 0.0010	4.80	48.0	11.5

Weight loss was calculated by subtracting the mean weight from the original weight (10mg) put in the set up. Weight loss attributed to bacteria was calculated by subtracting the weight lost by the negative control from the weight lost in each bacterium set up

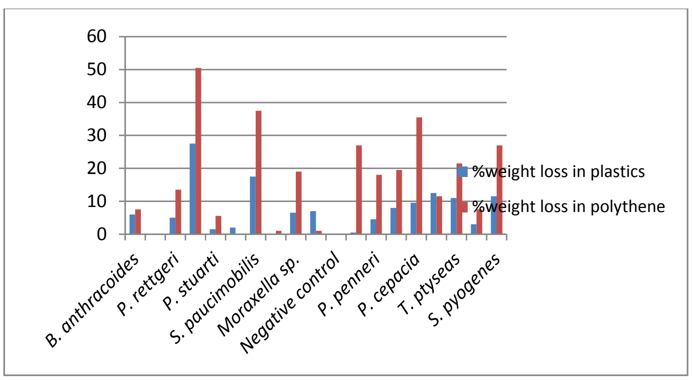

Figure 1 : Comparison of the percentage weight loss in plastic cups and polythene bags by each bacterium species isolated from lake Nakuru

Table 2: Mean weight (mg) and percentage weight loss of polythene after 90 days of treatment with different species of bacteria isolated from lake Nakuru. Initial weight of polythene put in each experimental set up was 10 mg

Name of bacteria species	Mean wt (mg)±SE of degradation	Wt loss (mg)	Weight loss (%)	Wt loss due to bacteria (%)
Baccilus anthracoides	8.40 ± 0.0010	1.60	16.0	7.50
Yersinia pseudotuberculosis	9.15 ± 0.0005	0.85	8.50	0.00
Providencia rettgeri	7.80 ± 0.0110	2.20	22.0	13.50
Positive control	4.10 ± 0.0030	5.90	59.0	50.50
Providencia stuarti	8.60 ± 0.0050	1.40	14.0	5.50
Morganella morganii	9.15 ± 0.0005	0.85	8.50	0.00
Sphingomanas paucimobilis	5.40 ± 0.0020	4.60	46.0	37.50
Acinetobacter sp.	9.05 ± 0.0005	0.95	9.50	1.00
Moraxella sp.	7.25 ± 0.0105	2.75	27.5	19.00
Erwinia amylovora	9.05 ± 0.0005	0.95	9.50	1.00
Negative control	9.15 ± 0.0005	0.85	8.50	0.00
Alcaligen spp.	6.45 ± 0.0045	3.55	35.5	27.00
Proteus penneri	7.35 ± 0.0005	2.65	26.5	18.00
Chryseobacterium meningosepticum	7.20 ± 0.0010	2.80	28.0	19.50
Pseudomonas cepacia	5.60 ± 0.0010	4.40	44.0	35.50
Erwinia nigrifluens	8.00 ± 0.0040	2.00	20.0	11.50
Tatumella ptyseas	7.00 ± 0.0150	3.00	30.0	21.50
Chryseobacterium indologenes	8.40 ± 0.0100	1.60	16.0	7.50
Streptococcus pyogenes	6.45 ± 0.0045	3.55	35.5	27.00

Weight loss was calculated by subtracting the mean weight from the original weight (10mg) put in the set up. Weight loss attributed to bacteria was calculated by subtracting the weight lost by the negative control from the weight lost in each bacterium set up

Discussion

Diversity of Bacteria in Lake Nakuru

The results from this study show that lake Nakuru has a rich diversity of bacteria. This may be due to diverse ecological niche of the lake. Twenty one species of bacteria were identified. They had different morphological and biochemical characteristics. There were bacillus, coccus, coccobacillus, vibrio and filamentous bacteria. Some of the bacteria were inhabitants of the Lake as they are known to be found in various habitats including salty waters for example *Vibrio vulnicus*. Other bacteria were likely to be in the Lake as a result of pollution for example *Streptococcus pyogenes*. Vareshi, (1982) had reported that the ecosystem in the lake may have changed due to pollution.

Degradation of Plastics and Polythene

The study revealed that the waters of lake Nakuru are a good source of bacteria capable of degrading plastics and polythene. There were visible changes in the plastic and polythene materials such as rough surface and dull colour. In the control, there was no observable change. Ikada, (1999) reported that parameters of visual changes can be used as a first indication of any microbial attack. According to katheserian, (2003) *Streptococcus sp, Pseudomonas sp*, and *Moraxella sp*. were able to degrade polythene and plastics. *Bacillus sp* was able to degrade polythene but unable to degrade plastics. In this study these bacteria, including *Bacillus sp*. were able to degrade both plastic and polythene.

Sphingomonas paucimobilis caused the highest percentage weight loss which is attributed to degradation for both plastics (17.5%) and polythene (37.5%). This bacterium can be used in bioremediation and

biodegradation. *S. paucimobilis* occurs in various enviroments hence easy to isolate and culture for remediation purpose. *S. paucimobilis* is metabolically versatile, which means it can utilize a wide range of naturally occurring compounds as well as some types of environmental contaminants. Burd, discovered that *Sphingomonas* can degrade over 40% of the weight of polythene in less than three months (http://www.mnn.com/green-tech/research-innovations). Studies have been held to further explore its metabolic mechanisms for application in biotechnology, in addition to its current utilization in bioremediation and in the food technology. *Sphingomonas paucimobilis* is able to degrade lignin-related biphenyl chemical compounds (Nilgiriwala, 2008). According to Ni'matuzahroh *et al.* (1999) *Sphingomonads* have been utilised for a wide range of biotechnological applications, from bioremediation of environmental contaminants to production of extracellular polymers such as sphingans e.g. gellan, wellan, and rhamsan which are used extensively in the food and other industries due to their biodegradative and biosynthetic capabilities. One strain, *Sphingomonas* sp. 2MPII, can degrade 2-methylphenanthrene.

Streptococcus pyogenes was able to degrade both plastics (11.5%) and polythene (27.0%). According to Kathiresan, (2003) *Streptococcus sp.* was able to degrade polythene at 2.19% and 1.07% of plastics per month. It can be used for the elimination of these two pollutants. It is also applied in biotechnology whereby many of its proteins are known to have unique properties, which have been harnessed to produce a highly specific "superglue" (Zakeri, 2012) and a route to enhance the effectiveness of antibody therapy (Baruah, 2012).

Alcaligen sp. was able to degrade polythene at a high percentage (27%) and plastics at low percentage (0.5%). This may be due to the molecular weight of plastic which is higher than that of the polythene. This bacterium was able to degrade polythene at a higher percentage which could be attributed to its low molecular weight. The surface area of the plastic exposed to this bacterium was smaller compared to the surface area of polythene that was exposed to it. The surface area of the material being degraded that is exposed to the bacteria affects the percentage of degradation. The more the surface area exposed to the bacteria, the higher the rate of degradation (Goldberg, 1995). *Alcaligen sp*. is known to be used in remediation of environmental pollutants. According to Anderson, (2003) *A. faecalis* converts the most toxic form of arsenic, arsenite (AsO_2^-) to its less dangerous form, arsenate (AsO_4^-). *Alcaligenes* has been used for the industrial production of non standard amino acids. *Alcaligen eutrophus* also produces the biopolymer polyhydroxybutyrate (PHB). Species of *Alcaligenes* generate energy in a number of ways, including arsenite oxidation. This species can be used to clean up environments contaminated with polythene.

Acinetobater sp. was able to degrade polythene (1%) but unable to degrade plastics. This may be attributed to the thickness of plastics that was higher than that of the polythene and also to the surface area of polythene exposed to the bacteria compared to the plastics. This species is metabolically versatile and hence can be exploited in various biotechnological applications including biodegradation and bioremediation (Gutnik, 2008). Gerischer (2008) reported that many of the characteristics of *Acinetobacter* ecology, taxonomy, physiology, and genetics point to the possibility of exploiting its unique features for future applications. *Acinetobacter* strains are often ubiquitous and robust (Gutnik, 2008). Some provide convenient systems for modern molecular genetic manipulation and subsequent product engineering. These characteristics are being exploited in various biotechnological applications including novel lipid and peptide production, enzyme engineering, biosurfacant and biopolymer production and engineering of novel derivatives of these products. It is anticipated that progress in these fields will broaden the range of applications of *Acinetobacter* for modern biotechnology (Gutnik, 2008).

Burkhoderia cepacia was able to degrade plastics (9.5%) and polythene (35.5%). This bacterium can be used in the remediation of environment polluted by these wastes. This bacterium is found in water and soil and can survive for prolonged periods in moist enviroments hence easy to isolate and culture for remediation purpose. This bacterium is also clinically important as it is a human pathogen which most often causes pneumonia in immunocompromised individuals (Mahenthiralingam, 2005).

Erwinia nigrifluens and *Tatumella ptyseas* were able to degrade plastics and polythene (12.5%, 11%) and (11.5%, 21.5%) respectively. These bacteria can be used for remediation of plastic and polythene polluted environments. Apart from being important in biodegradation they are also clinically important. *Erwinia*

nigrifluens is the causative agent of shallow bark canker of walnut (Wilson *et al.,* 1957) while *Tatumella ptyseas* is a human pathogen.(Berka,2001).

Moraxella sp. was able to degrade plastics (6.50%) and polythene (19.0%). Kathiresan, (*2003*) reported that *Moraxella sp.* was able to degrade 7.75% of polythene and 8.16% of plastic per month. This bacterium can be utilized in bioremediation of the environment from these pollutants. *Proteus penneri, Chryseobacterium meningosepticum* and *pseudomonas cepacia* were also good in degradation of both plastic and polythene. Apart from being important in biodegradation, *Chrysebacterium meningosepticum* is also clinically important as it causes opportunistic infections in immunocompromised patients (Murrey *et al*., 2007). *Pseudomonas cepacia* degraded plastic (9.50%) and polythene (35.50%). Kathiresan, (2003) reported that *pseudomonas sp*. degraded polythene at 20.54% and plastics at 8.16% per month. It is typically found in water and soil hence easy to isolate and culture for remediation purposes. *Yersinia pseudotuberculosis* was unable to degrade both plastics and polythene whereas *Morganella morganii* was unable to degrade polythene.

The type of microorganism affects the rate of degradation of polymer (Artham and Doble, 2008). Hence there were different rates of degradation of both plastics and polythene depending on the species of the bacteria present. Different bacteria species were able to degrade plastic and polythene at different rates although they had received the same amount and type of nutrients. *Sphingomonas paucimobilis* had the highest percentage of degradation compared to the rest of the bacteria species. This bacterium is known to be metabolically versatile since it can utilize a wide range of compounds as well as pollutants. It was able to metabolise the plastics and polythene at a higher percentage than the rest of the bacteria. Other microorganisms that were good in degradation of both plastic and polythene were *Streptococcus pyogenes, Tatumella ptyseas, Pseudomonas cepacia, Erwinia nigrifluence, Chryseobacterium meningosepticum* and *Moraxella sp*

The surface area of the plastic and polythene exposed to microorganism affects the rate of degradation. The more the surface area exposed, the higher the rate of degradation (Goldberg, 1995). The higher rate of degradation by bacteria on the polythene bags may be attributed to the surface area exposed to the bacteria. More polythene discs were put in the experiment set up than the number of plastic discs to achieve the same mass. Hence more surface area of polythene was exposed to the bacteria than that of plastics leading to a higher percentage of degradation of polythene than that of plastics.

Generally, increase in molecular weight of the polymer decreases its degradability by microorganisms. High molecular weight results in a decrease in solubility making them unfavourable for microbial attack. This is because bacteria require the substrate to be assimilated through the cellular membrane and then be further degraded by cellular enzymes (Gu *et al*., 2000). Plastics have a higher molecular weight and are thicker than polythene. In this research, this might have contributed to the higher weight loss of the polythene than that of plastic for each bacteria species. The weight loss of polythene was higher than that of plastics for each bacteria species except for *Erwinia spp.* and *Morganella morganii*. *Erwinia spp*. had a higher weight loss of plastics than polythene while *Morganella morganii* was unable to degrade polythene. These bacteria could be having enzymes that are more specific to the degradation of the compounds found in the plastic cups or in the polythene bags.

Polymer degradation is a change in the polymer properties such as tensile strength, colour, shape or molecular weight under the influence of one or more environment factors such as light, chemicals, and in some cases by galvanic action (Faudree, 1991). Degradation is due to the scission of polymer chain via hydrolysis leading to a decrease in the molecular mass of the polymer. The initial breakdown of a polymer can result from a variety of physical, chemical and biological forces with chemical hydrolysis being the most important. Embrittlement which is one of the physical forces initiating degradation of polymers is activated primarily by sunlight or heat (Goldberg, 1995). These leads to reduction of molecular weight of the polymer and hence increase in the microbial accessibility (Ghazali, 2004).

In this study, initial reduction of molecular weight is attributed to the physical and chemical forces which were activated by heat generated during shaking (Doi, 1990). The moleculer weight reduction may have been as a result of carboxyl group oxidation. Oxidation starts at tertiary carbon atoms because the free

radicals formed are more sTable and long lasting making them more susceptible to attack by oxygen (Faudree, 1991). Discolouration on the surface may have been as a result of the deposition of carbonates from the salts added. Lapishin *et al.,* (2010) reported that salts cause the discolouration effect on plastic during the process of degradation. Chlorine gas also has an oxidizing effect on polymer. This gas attacks sensitive parts of the chain molecules, oxidizing the chain cleavage. Cracks can be formed by Ozone.

In the plastic experiment 36.5% weight reductions occurred in the negative control. This may be attributed to physical and chemical forces (Faudree, 1991). In the polythene experiment, 8.5% weight reduction occurred in the negative control. This is attributed to the physical and chemical forces of degradation (Goldberg, 1995).

In conclusion, the bacteria from Lake Nakuru can be used to eliminate pollutants through biodegradation and hence leading to soil's nutrient replenishment. The processing of waste degradation using living organisms is environmentally friendly, relatively simple, and cost effective.

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THEME 6: SOIL AND WATER MANAGEMENT

Underground water management and pollution threats in dry season vegeTable growing in Tabora, Tanzania

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Abstract

Small-scale vegeTable growing is an important economic and the climate change adaptive activity during the dry season in Tanzania. Open shallow underground water wells are used by farmers for vegeTable growing. Sustainable use of open shallow water wells is threatened by various factors such water depletion in response to prolonged droughts. However, the human caused factor of polluting scarce water resources has not adequately studied. This study was conducted in 2009-2012 to assess pathways of underground water resources pollution in vegeTable growing. The objective of this study was to identify causes of underground water pollution and the role of human activities in causing water pollution. The methodology used was onsite inspection of underground water wells, identification of invasive plants growing in water wells. Laboratory analysis was carried out Kitete hospital in Tabora for testing *Escheria coli* a gram positive bacterium in water samples. Results show that, decomposition of aquatic plants, frogs and organic manure in water as well as the concentration of livestock urine significantly contribute to water pollution. Poor handling of pesticides allow pesticide residues to flow into water. Water management in semi-arid environment in Tanzania is needed for protecting the scarce water resources.

Key words: aquatic plants, dry season, underground water, Tanzania.

Introduction

Rain water on the surface of the earth percolates through the soil, and occupies subterranean permeable layers, is called ground water (Driscoll, 1986; Fetter, 2001; Hamil and Bell, 1986). Relatively little is known about agricultural ground water use and the agricultural ground water economy of sub-Saharan Africa. However, the use of groundwater in agricultural production has transformed rural economies in large parts of developing world leading to "Groundwater Revolution". Groundwater plays an important role in the livestock sector in sub-Saharan Africa (Giordano, 2006). Ground water use is increasing in agricultural production and support of the growing global population as a result it is termed as a "Silent Revolution" that cannot be ignored (Llmas and Martinez-Santos, 2004). Groundwater use is cheaper to use than conventional irrigation systems (Llmas and Martinez-Santos, 2004). Small-scale groundwater irrigation offers significant potential to mitigate the effects of drought and erratic rainfall on agricultural production in semi-arid, sub-Saharan Africa. Ground water supplies are less prone to drought than surface water since its level is less correlated with rainfall (Calow *et al.,* 1997; Giordano and Villholth, 2007). The use of underground water for smallholder economic improvement in Africa has a big potential (Amuzu, 1978; Ayibotele, 1985; Kortasi, 1994). VegeTable production is an important agricultural activity engaging local farmers for food security in Tabora region (Mongi *et al.,* 2010). In semi-arid environments in Tanzania underground water supplies support human and livestock populations but few studies have been carried out to assess water pollution threats.

Materials and methods

Study area

The study was conducted in Tabora municipality, Tabora region in the western plateau in Tanzania. The study involved a 35 km stretch from Tumbi to Inala village. Dry season vegeTable sites along the stretch was visited and assessment of crop management was carried out. Mapping of study area location was done by using Geographical Information System (GIS) Technology with Global Positioning System (GPS) Model: Gamin etrex – Legend c. The spatial data (maps and coordinates) of Tabora region existing in the GIS database at ARDI Ukiriguru, Mwanza, and Lake Zone were also used to prepare the location map of the study area.

Water pollution studies

The study employed a combination of methods, such as ground water well inspection, discussion with farmers and laboratory analysis of water samples for *E. coli*. Identification of aquatic plants found in water was undertaken with the support of literature review.

VegeTable crops grown

A number of crops are produced in the dry season. VegeTable crops are produced for home consumption and local marketing.

Table 1: Dry season vegeTable crops produced in Tabora

Common name	Dry season land use	Frequency	Crop frequency (%)
Sweetpotato (*Ipomoea batatas* L.)	Vine multiplication	23	26.1
Cucurbita maxima	Multiplication of leaves for vegeTable	11	12.5
Cowpea (*Vigna unguiculata* L. Walp)	Leaves for vegeTable use	4	4.5
Okra (*Abelmoschus esculentus* L.)	Fruits	5	5.6
Beans (*Phaseorus vulgaris* L.)	Beans and leaves for vegeTable	3	3.4
Cucumber (*Cucumis sativus* L.)	Fruits for vegeTable use	3	3.4
Tomato (*Solanum lycopersicum* L.)	Fruit for vegeTable use	8	9.0
Water mellon (*Citrullus vulgaris* L.)	Fruits and vegeTable	1	1.1
Brinjal (*Solanum melongena* L.)	VegeTables	2	2.2
Chinese spinach (*Amaranthus tricolor* L.)	Green leafy vegeTables	6	6.8
Cabbage	Leafy vegeTables	6	6.8
Green maize (*Zea mays* L.)	Fresh cobs	13	14.7
Sweetpotato	Leafy vegeTables	3	3.4

Source: Dry season vegeTable growing study Tumbi,2010

Tests of **Escherichia coli** *in water samples used in vegeTable production*

Good quality water is odourless, colourless, tasteless and free from faecal pollution and chemicals in harmful amounts. The organisms most commonly used as indicators of faecal pollution are the coliform group as a whole and particularly *Escherichia coli*. Gram negative, oxidase-negative, non-sporing rods capable of growing aerobically on an agar medium containing bile salts and are able to ferment lactose within 48 hrs at 35-37^{0} C with the production of both acid and gas. (WHO,1982).The bioassay for water collection and coliform tests in water followed the procedures described for Medical laboratories (Cheesbrough,1984).Presumptive *E. coli* colonies appearing yellow on MacConkey broth were recorded for each water sample analysed.

Table 2: Pesticides used in vegeTable and frequencies of application for three months at Tumbi village in Tabora

Pesticide	Type	Active ingredient	No. of applications
LINKONIL 500SC	Protective and curative fungicide	50%Chlorothanol	12
SELERON 720EC	Insecticide	Profenofos 720 gm/litre	14-21
KUNG FU 5EC		Lambda-cyhalotrin 50 g/litre	12
FUNGO ZEB 80WP 800g/Kg	A broad spectrum protecting fungicide	Mancozeb 805 WP	12
AmeCron 720EC	Non-systemic fungicide and acaricide	Profenofos 720 gm/litre	7-12
ATTAKAN C244 SE	Insecticide	Cypermethrin, 144 gm/litre+ Imidacloprid 200 gm/litre	12
BOOSTER	Foliar Fertilizer	12%N, 8%$P_2 0_5$, Mn, B, Zn, Cu, Mo	7-12
SUBA CHLO 55 EC	Insecticide	Chloropyrifos 50%+Cypermetrin 5%	12
BLUE COPPER 40gm/20litres	Protective fungicide	Copper oxychloride 84%	12
LINKMIL 72 WP	Protective and curative broad spectrum fungicide	Metalaxyl 80 g/kg + Mancozeb 640 g/kg	7
SUPALAXYL 72 WP	Broad spectrum systemic and contact fungicide	Mancozeb 460 gm/kg+Metalaxyl 80 gm/kg	7
SUPAKINGA	Protective and curative broad spectrum fungicide	200gm/kg Fosetyl-al + 300 gm kg Mancozeb	7

Source: Survey data 2009-2011

Indicator plants of polluted water

Pistia stratiodes (L.)(Araceae) reproduce and grow well in polluted water. Studies show that, *P. stratiotes* was an indicator of polluted environment (Sharma and Sridhar, 1981). A study in Uruguay by Sommaruga *et al*., (2007) show that *P. statiotes* leaves contains nitrogen about 14% which enhance their faster decomposition and cause water quality decline after decaying.

Typha domingensis Pers(Typhaceae) is another aquatic plant found in (4.6%) of shallow open wells.It has been documented that *T. domingensis* grow in polluted water rich in phosphorus under low redox potential Eh (Shuweni *et al*.,2010).

Pycreus lanceolatus (Poir) (Cyperaceae) was in (2.3%) of the wells. This plant grows aggressively that it replaces the dominant *P.stratiotes* whenever they are in association. *Ipomoea aquatica* Forsk (Convolvulaceae) is the second important invasive plant after watter lettuce (*Pistia stratiotes*) in wells. The plant was occupying (22.8%) of all wells studied. Leaves of *Ipomoea aquatica* Fors are rich in the diversity of nutrients, it is a good source of K, Mn and Fe for all categories of people, while Mg is adequate enough for adult female and children (Umar *et al*., 2007).Farmers in the study area use *I. aquatica* leaves as a dry season vegeTable as water availability limits production of the common vegeTable species.

Table 3: Escherichia coli assessment in water and the irrigated vegeTables

Irrigated crop	Sub-culture on MacConkey broth action	Chemical reaction	Water quality
Tomato	No *Escherichia coli* colonies	No gas production	SuiTable for human consumption
Cabbage	No *Escherichia coli* colonies	"	"
Tomato	*Escherichia coli* colonies(2)	Gas and yellow media	UnsuiTable for human consumption
Tomato	"	"	"
Tomato	"	"	"
Okra	"	"	"
Tomato	*Escherichia coli* colonies(4)	"	"
Green maize	*Escherichia coli* colonies(3)	"	"
Green beans	*Escherichia coli* colonies(2)	"	"
Livestock water point	*Escherichia coli* colonies(3)	"	"
Sweetpotato vines	*Escherichia coli* colonies(2)	"	"
Cucurbita spp.	*Escherichia coli* colonies(3)	"	"
Cowpeas	"	"	"
Tomato	"	"	"
Cucumber	"	"	"
Tomato	*Escherichia coli* colonies(2)	"	Gas and yellow media

Table 4: Plant species in water wells and their frequencies in surveyed area at Tumbi

Common name	Cover (%)	Frequency	Guard plants around the well
Waterlettuce (*Pistia stratiotes*)	50-100	20(28.5%)	*Hyparhenia rufa, Phragmite mauritianus*
Ipomoea aquatica Forsk	30-100	16(22.8%)	*Paspalum* spp
Commelina benghalensis L	<5	1(1.4%)	*Paspalum* spp., *Ageratum conyzoides*
Paspalum spp	25-80	5(7.1%)	*Pasparum* spp
Ludwigia decurrens Walt	<5	2(3.0%)	*Pasparum* spp.
Pycreus lanceolatus (Poir)	40-80	2(2.8%)	*Digitaria* spp
Nymphaea maculate Schum	<5	1(1.4%)	*Paspalum* spp
Algae	<5	4(5.7%)	Paspalum spp.

Source Survey Data (July 2010)

The livestock factor

Livestock dung and urine change water chemistry when concentrated in water. This is particularly important because under water scarcity one singe water source serves different uses including irrigation, domestic use and watering of animals**.**

Table 5: Chemical differences of open shallow wells with different uses in Tabora

Sample	pH	EC dS/m at standard temp. of 25ºC	Sodium (m.e/l)	Calcium (m.e/l)	Magnesium (m.e/l	Phosphorus Mg/kg soil
Donald well, (disturbed water)	5.3	0.06	0.16	1.54	0.26	0.4 (Bray method)
Donald well (clean water)	6.0	0.09	0.17	2.10	0.38	0.7 (Bray method)
Pond/dam for livestock - Donald	7.8	0.27	0.63	2.52	0.44	3.0 (Olsen method)

Discussions

VegeTable growing during the dry season is an important economic and the climate change adaptive strategy in semi-arid Tabora in Tanzania. Diverse vegeTables are produced for consumption and local marketing (Table 1). The use of underground water for dry season agriculture is considered to be an important economic activity in different parts of Africa (Amuzu, 1978; Calow *et al*., 1997; Llmas and Martinez-Santos, 2004). The use of groundwater in open shallow water wells is threatened by water pollution causing factors. The areas used in this production are hardly a quarter of a hectare. Therefore, concentration of pesticides (Table 2) and the use of pesticides very close to water sources indicate a big threat to water pollution. High concentration of pesticide use in vegeTable production and the close proximity of vegeTable plots to water sources pose a potential epidemiological and human health danger (Ohayo-Mitoko, 1997). This study has shown that aquatic plants growing in water contribute significantly to water pollution after decomposition. There is flow of human dung into open shallow water wells. The high frequency of *E. coli* presence into water used for irrigating vegeTable crops is an indicator of water pollution (Table 3).Livestock play an important role in water pollution particularly when they concentrate dung and urine in a small pond. Livestock dung and urine raise the pH of water and its available phosphorus content (Table 5). Kortasi (1994) documented the importance of groundwater use in Ghana but pointed out that this resource was at risk.

The results of this study call for close monitoring and management of underground water used for dry season vegeTable production. It is not known for example what would be the nature of microbes found in water following the decomposition of frogs(Figure1) Ground water availability was playing a vital role in livestock production. These observations had been documented (Giordano, 2006). However, livestock can pray a significant role in polluting small water bodies (Table, 5).

Conclusions

Dry season vegeTable growing is an important social and economic activity for farmers in Tabora municipality. Farmers indicated that cereal crop failures due to poor decadal rainfall distribution are common. But, total rainfall mighty be enough to affect well discharge for vegeTable growing. The high density of wells is associated with little water discharge inadequate for vegeTable cultivation. There is a serious water competition among water users which leads to deliberate water pollution to reduce competition. Water contamination with *E. coli* indicating fecal contamination is a serious threat to human health via vegeTable food chain. Lack of research and extension support to develop appropriate technologies for water use, management and water quality control is considered to be a factor for persistence of subsistence vegeTable production in the study area.

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Status review of the adopted soil and water management technologies in kenya as a critical component of the environment

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Abstract

Land degradation processes are evident on Kenyan landscape, more serious signs being realized in cultivated and pastoral areas as productivity continue to decline. Unsustainable land use practices are leading to low food production in comparison to demand of the growing population. There is need to promote adoption of appropriate natural resource management technologies that will protect the marginal lands and forest areas from overgrazing and unsustainable cultivation practices. There are enough studies to show that combination of soil and water conservation and soil fertility amendment technologies can improve crop yields and improve other ecosystem services. However performance and adoption of these technologies may vary depending on agro-climatic regions. This paper examines status of soil and water management practices that have been practiced / tested in the ASALs, sub-humid and humid agro-climatic areas of Kenya using published and gray literature but also drawing on discussions with extension experts / agents in sub-districts representing the three major agro-climatic regions of Kenya. The study shows that across each region physical soil and water measures (water harvesting), biological structures (grass strips, mulching, agroforestry), organic and inorganic soil fertility, conservation agriculture / farming and pasture management have been tested and adopted across the agro-climatic regions despite variation in extent and magnitude. The paper provides the researchers and extension agents a better view of the gaps in promotion of the soil and water management practices. Particular areas that needs redress is in promotion of minimum tillage and combining organic-inorganic fertilizer amendments for improved food production, while reducing soil and water losses in the watersheds.

Keywords: soil and water management, ASALs, sub-humid, humid, Kenya.

Introduction

The land degradation issues in Kenya comprise of soil erosion, declining soil fertility, agrochemical pollution, salinization of land and land cover conversions. Although, in 1997 Kenya's land mass was rated as 64% moderately degraded and about 23% very severely degraded, these had increased to nearly 30% in early 2000s with the cultivated areas and grasslands being particularly affected. Such considerable rates of degradation pose serious problems to food security and environmental concerns. Enhanced agricultural output and productivity is declining and it is associated with high soil erosion rates, loss of agro-biodiversity, poor regulatory framework and overreliance on rain-fed agriculture (GoK 2007; GoK 2009). The low agricultural output and productivity results from unsustainable land use practices and the low adoption of appropriate natural resource management technologies. Improved land management practices like mulching, contour and tied tillage, minimum tillage, cover cropping, application of organic and inorganic fertilizers and rotational grazing have potential to improved soil and water productivity and very important in agricultural production. The objective of this paper was to review the adoption status of soil and water management technologies in Kenya focusing on the three major agro-climatic regions (ASALs, humid and sub-humid regions). The study shall highlight broadly the successful practices in terms of extent of application and impact on soil and water conservation and food productivity in these agro-climatic zones.

Methodology

This is a review paper which gives a critical analysis of the current management practices of soil and water resource in three main agro-climatic regions; arid and semiarid lands (ASALs), with indexes of less than 50% and a mean annual rainfall of less than 1100 mm, sub humid and humid with an index greater than 50% have high potential for cropping. In order to achieve this, the results of this paper relies mainly on secondary source of information which includes relevant books, journals, conferences proceedings, national development plans and other Kenya based periodic reports and policy documents. Also visits to various sub-county agricultural offices to extract information from annual and quarterly reports and holding discussion with relevant officers were explored.

Results and discussion

Land and water management in ASALs

Soil and water conservation. In this region the effects of soil erosion and runoff losses cause high nutrient depletion and decreased soil water availability leading to decreased crop and pasture productivity (Itabari *et al.,* 2011). The level of adoption of soil erosion control measures and harvesting of water for crop production varies but below optimal levels.

Table 1: Soil conservation works in Kangundo District

Division	Practicing farmers (%)	Interventions (%)						
		Fanya juu	Bench terraces	Grass strips	Un-ploughed strips	Retention ditches	Trash line	Stone lines
Kangundo	61	4	6	33	50	23	20	0
Kakuyuni	36	90	64	-	-	46	80	50
Kivaani	3	6	30	67	50	31	0	50

Source: Ministry of agriculture (2012/2013)

Table 2: Water harvesting methods for crop development in Kangundo District

Division	Practicing farmers (%)	Interventions (%)				
		Contour bunds	Semi-circular bunds	Water spreading bunds	basins	Road runoff harvesting
Kangundo	72	7	6	4	3	7
Kakuyuni	22	86	70	64	-	-
Kivaani	6	7	24	32	97	93

Source: Ministry of agriculture (2012/2013)

Further, some studies in the region have shown that modified (enlarged) fanya juu terraces are effective in controlling soil erosion but not effective for water conservation as runoff benefit only few rows of crops (Kiome 1992). The technique is reported to be marginally economical in long run. The semi-circular bunds (hoops) have been tested for rehabilitation of degraded grazing lands (Smith and Critchley, 1983) in the semi arid areas of Kenya. However, the high labour requirements associated with semi-circular bunds have hampered high rate of adoption. Gibberd (1995), reported that runoff harvesting using a micro catchment to cultivated area ration of 1:1 increased yield in most dry land crops by 30-90%. Therefore use of high ratio than this in semi-arid may lead to either erosion or under-irrigation more so in soils with inherently low SOM levels.

A study by Kilewe and Mbuvi (1988) on effect of crop cover and residue management on runoff and soil loss reported that maize with minimum tillage reduced runoff by 0.8 and soil loss by 39.2%. Application of

3t/ha of maize residue reduced soil loss by 58.7 and 78.6% during the 1983 long and short rains respectively, as compared with bare fallow.

Recent studies have shown that type of tillage and improvement of soil organic matter (SOM) can have significant effect on germination of a crop. (Table 3). The study established that application of chemical nitrogen fertilizer (+/-N) had no significant change in percentage germination of maize crop in any season.

Table 3: Effect of tillage and organic resources with/out inorganic on percentage germination of maize at Machang'a in Mbeere, Kenya during the September to July 2006

	SR 2005		LR 2006		SR 2006	
Tillage system	-N	+N	-N	+N	-N	+N
conventional (control)	83.3	85.8	93.0	89.0	81.7	81.7
conventional + CR + manure	83.3	75.3	91.7	93.0	83.3	83.3
conventional + manure	91.7	81.7	95.0	91.3	78.3	85.0
No-till + CR + manure	80.0	86.7	89.7	92.3	73.0	85.3
no-till + manure	80.3	91.7	87.0	89.7	80.0	80.0
Tied ridges + CR + manure	75.0	85.0	89.0	88.3	73.0	56.7
tied ridges + manure	83.3	88.3	88.3	87.3	57.0	60.0

Modified from: Kihara *et al.*, (2011). CR= crop residue, SR2005 = short rain of 2005, LR2006 = long rain of 2006, SR 2006 = short rains of 2006. +/-N=with addition of Nitrogen from inorganic fertilizer and without addition of Nitrogen from inorganic fertilizer

It has been reported that tillage under tied ridge in Katumani shows little or no variation in soil moisture status. Alfisols (chromic luvisol) in semi-arid eastern Kenya under tied ridge cultivation, its water content at the end of the rainy season is high with significant high dry matter and grain yield of maize. (M'Arimi, 1978) (Table 4).

Table 4: Effect of tillage methods on maize crop yield (kg/ha)

Period	Crop	Minimum tillage	Conventional tillage	Tied ridging	SE*
Long rains	Maize (dry matter)	1068	1047	1105	+- 63
Short rains	Maize (dry matter)	2040	1920	1760	+- 0.09
	Maize (grain yield)	337	221	513	+- 51

Source: M'Arimi (1978);* SE =Standard error

Soil amendments. Soil fertility rates in semi-arid soils are perceived to be fairly good in content. Consequently, crop yields are very low even when rainfall is non-limiting. Declining soil fertility has been attributed to continuous cultivation without adequate replenishment of nutrients and loss of nutrients through erosion and leaching (Gachimbi *et al.,* 2005). Available estimates indicates that about 88% of the resource poor subsistence farmers in semi-arid eastern Kenya use farm yard manure as their principal soil fertility input. Kihara *et al.,* (2011) have shown that combination of crop residue and manure in semi arid lands of eastern Kenya results in additive maize yield than manure only treatment even without addition of inorganic sources of nitrogen fertilizer.

Combined organic and inorganic fertilizer is the major soil fertility management practice undertaken in the semi-arid lands of Kenya (Table 5).

Compost is most suited for ASALs, for instance it gives a higher maize yield i.e. 2449 kg/ha when treated with 16.2t/ha compost, greater net cash benefits and a better return on labour. Adoption of this method has however been limited by scarcity of labour, shortage of organic materials, insufficient cattle, lack of

transport, limited water supply and lack of technical knowhow on large scale production of high-quality compost (Onduru *et al*.,1999).

Table 5: Major soil fertility management practices during two rainfall periods in Kangundo sub-county

		Oct-Dec 2012		Jan-Mar 2013	
Practice	Reason why method is used	Practicing farmers (%)	*Usage level	Practicing farmers (%)	*Usag e level
Composting	Availability of manure	10	2	10	2
Farmyard manure	Improves soil structure	39	2	36	1
Fertilizers	Government subsidy and low production areas	44	2	47	1
Rotation	Manage soil fertility and diseases	2	3	2	3
Cover crops	Soil moisture conservation and erosion control	2	3	2	2
Zero tillage	Soil conservation and cost saving	1	3	1	4

Source: Ministry of agriculture 2012/203 report. *Level of use scale 1= very high, 2= medium, 3=low, 4=very low

Adoption of inorganic fertilizers is very low, mainly due to lack of cash and appropriate incentives. Kihara *et al*. (2011) observed that chemical nitrogen fertilizer has a positive and significant effect on maize yield. They further noted that there is a great response to fertilizer nitrogen in manure than in crop residue and manure fields. Miriti *et al*. (2011) reported the highest yield with 80kg N/ha when combined with manure.

Conservation agriculture. No-till system in semi-arid lands of eastern Kenya has the lowest yield in the first two seasons compared to conventional farming manly due to depleted soil organic matter, poor nutrient use efficiency and poor retention of rainwater.

Agroforestry. Agroforestry is defined as a dynamic, ecologically-based, natural resources management system that integrates trees on farms and in the agricultural landscape in order to diversify and sustain production. Many scientists have reported that runoff loss in traditional farming practice is over 50% during a heavy storm and that ridging does not fully control runoff compared to mulching and agroforestry where runoff does not occur. Water loss through soil evaporation is high under ridging and low under mulching. Kinama *et al*. (1999) reported that mulch combined with hedgerows was effective in controlling soil erosion and runoff compared to sole crop (control), mulch, hedgerows and grass strip. Maize yields were however high in control plots this was attributed to competition by senna tree for light, nutrient and water.

Pasture management. Coughenour *et al*, (1990) pointed out that range conditions and trends over the years have pointed to worsening productivity of natural pasture in both arid and semi arid regions. To minimize forage scarcity fodder banks technology was introduced reducing pressure on vegetation resource hence regeneration and conservation of biodiversity (Esilaba *et al.,* 2011).

Degradation of rangelands is a major cause of pasture loss in dry environments, as surface crusting reduces infiltration and inhibits pasture growth. Scratching the ground surface with animal-drawn implements like tine harrow improves grass growth in degraded rangelands. Spreading farmyard manure and grass seeds on scratched land lead to even better results (KRA, 2012).

Land and water management in sub-humid lands

Soil and water conservation. In sub humid highlands of central Kenya, soil nutrient degradation is associated with rapid population increase and continuous cropping. Napier hedge are best vegetative hedge in soil conservation. This is attributed to root characteristic as rhizomatous roots reinforces soil

around them (Mutegi *et al.,* 2011). Soil and water conservation structures such as fanya juu, fanya chini and cut-off-drains have been promoted extensively in the region by ministry of agriculture. Adoption of the same has been low possible due to small per-capita landholdings, farmers perceiving that soils are not being lost/degraded due to deep soils and abundant rainfall.

Soil fertility management. Soil properties of sub-humid highlands of Kenya under continuous cultivation over time have an effect on both soil physical and chemical properties. There is a decline in crop yields in a continuous cropping system regardless of the inputs utilized. Maize yield in no-input plot decline from 4.0-2.0 t/ha within 10 years. Application of chemical fertilizers increase yields by 50% for first 5 years followed by decrease in the sixth year, while combination of chemical fertilizers and farmyard manure will continue to give higher yields (Kibunja *et al.,* 2011).

Conservation agriculture/farming. Application of organic amendment under conservation tillage system provide long term source of nitrogen reducing need of nitrogen fertilization. Residue application significantly increases soil organic carbon. This is attributed to beneficial effects of residue to erosion control, nutrient cycling and soil quality enhancement. (Anyanzwa *et al*.,2011).

Agroforestry. Mutegi *et al*. (2011) indicated that establishment of calliandra and leucaena along the contour slopes of central highlands of Kenya was effective for soil and nutrient management. They further noted significant high soil pH, exchangeable bases and carbon in sole leguminous hedge treatment and combination hedge.

Soil and water management in humid lands

Soil and water conservation. Large agricultural productive lands in the humid highlands of Kenya are constrained by slope steepness, soil erosion and loss of nutrients and water. Conservation of this water through agronomic management and different types of structures can improve soil productivity by 50-100%. This intervention is through slope reduction achieved by constructing soil and water conservation structures. These structures reduce surface runoff, soil erosion, and water loss achieving soil and water conservation by increasing infiltration and soil water storage. Studies indicate that annual loss of 0.25 cm of surface soil is equivalent to removal of about 98.8 t/ha of soil.

Nzabi *et al*. (1999) found out that at early stages maize stover trash line had best control on runoff with least soil erosion. This was a study on effective methods of controlling soil erosion using cheap and locally available material in Kisii district in western Kenya. (Table 6). The study underpins the potential benefit of using locally available materials, less-labour intensive to overcome the high rates of soil and water losses in steep slopes of Kisii highlands.

Table 6: Effect of soil erosion control methods on cumulative eroded soil measured in three farms in Nyamonyo village, Kisii district from May 1996-May 1998

Treatment	Average soil loss (t/ha)
Makarikari grass strip	16.47
Vetiver grass strip	37.17
Sweet potato cover	37.07
Maize stover trash line	9.33
Control	90.53

Source: Nzabi *et al.*, (1999)

Soil amendments. Studies have shown that use of green manure will double farmers yields when used on their own from 2t/ha to 4t/ha and when used in combination with fertilizers they tripled farmers yields from 2t/ha to 6t/ha. *Lupines mutabilis* is capable of fixing 400 kg N/ ha while *Mucuna pruriens* adds about 150 kg N/ha (Bunch 1995). Codja 1997 recorded a maize yield increase of 98% after mucuna short fallow

without chemicals and 179% increase of maize yields with mucuna, 51kg N, 46 kg P, and 28 kg K per hectare.

Conclusion

Land and water resources are interdependent i.e. land conservation and management include both soil and water conservation. Water conservation in broad sense, is the most important practice in the field of soil management. This is true because the practices that conserve water are also those that conserve soil and promote a high state of productivity, the real goal in soil management. There is enough evidence that there is diversity of soil and water management practices in different agro-climatic regions of Kenya.

Recommendation

There is need to upscale level of research in these aspects but also adoption of the appropriate natural resource management technologies bearing the climatic capacity of each ecosystem.

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Soil physical and hydrological properties modifications under *Arachis* species in Ibadan, southwestern Nigeria

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Absract

Lack of conservation of soil moisture is one of the major limiting factors to crop production. Improvement of soil physical properties could enhance soil moisture conservation, improve crop productivity and reduce food insecurity in sub-Sahara Africa. A field study was carried out to determine the effects of three plant densities (33333, 66667 and 83333) per hectare on soil properties and water loss through evaporation from soils under two cultivars of *Arachis hypogaea* L. (SAMNUT 10 and SAMNUT 21) and *Arachis pintoi* (PINTOI) in Ibadan, southwestern Nigeria. The experiment was set in a split plot in randomised complete block design with *Arachis* varieties as the main plot and plant densities as sub-plot with three replications. Data were collected on daily soil water evaporation, bulk density, saturated hydraulic conductivity, particle size, total porosity and permeability. The soil was loamy-sand. Marked reductions in soil water evaporation were observed in surfaces under *Arachis* varieties compared to bare soil. Reductions in soil water evaporation were 44.5% under SAMNUT 21, 41.1% under PINTOI and 34.7% under SAMNUT 10. There was significant ($p = 0.05$) improvement on soil structure and hydraulic conductivity under *Arachis* varieties. Plant density of 66667 ha^{-1} had the best positive effect on the improvement of soil physical structures. The cultivation of SAMNUT 21 at plant density of 66667 ha^{-1} and PINTOI at 83333 ha^{-1} along with other measures of sustainable soil water conservation are recommended.

Key words: *Arachis* species, plant densities, evaporation, soil hydrological properties, food insecurity.

Introduction

Soil and water are basic, vital and essential resources for sustainable agriculture. Hence, the knowledge of soil properties is essential and its proper management is a major factor to crop productivity and sustainability (Anikwe and Ubochi, 2007; Franzluebbers, 2002). The hydrological conditions and related physical properties of the soil are important factors in crop growth, and should be considered when selecting measures for different sites for crop production and soil-water conservation (Lundin, 1982; Nyberg, 1995). This implies that these resources should be utilised in ways that ensure little or no damage whilst guaranteeing their continuous usage while still providing food and fibre for the teeming population.

Several methods have been recommended for conservation of soil. These include the planting of cover crops such as groundnut, peanut, vetiver grass to reduce erosion, zero tillage and minimum tillage, use of plant (crop) residues, green manures, animal manure, mulches and household waste. Farmers have adopted some of these practices but have not been able to sustain them because of affordability and availability of the inputs. A review of technology that is accepTable to resource-poor farmers (Hocking, 1993), involves the combination of practices into a farming system that considers physical factors such as soil and climate, available resource input, especially cash and labour. Thus, cover crops due to its low input and long-term benefits has widely been accepted and occasionally used by farmers at all levels (Smith *et al.*, 1987).

Over two-thirds of the global crop production occurs in rainfed regions where rainfall is erratic and insufficient (Wright and Nageswararao, 1994). Evaporation, which is often the largest component of substantial water loss in soil poses severe consequential implications on crop production since surface soil-water content is important in crop production. However, with series of work, cover crops had been used as mulch which are planted to manage soil water, soil physical properties and soil fertility; and for the suppression of weeds, pests and diseases (Lu *et al.*, 2000). Thus, the utilisation of the stored moisture will

depend on the favourable soil physical environment which can be achieved by maintaining desired soil surface conditions through the use of cover crop. This plays an important role in preventing loss of water by evaporation which is beneficial to crop growth. If some of this unproductive loss of water could be retained in soil and used as transpiration, yields could be increased without the use of supplemental irrigation.

This trial aimed at reducing soil water loss using different *Arachis* spp. and *Arachis* densities as a way of soil moisture conservation and to determine their effect on soil physical and hydrological properties.

Materials and methods

Study area

The experiment was carried out at the University of Ibadan (7° 26′.37″ N; 3°54′.08″ E) at an altitude of 233 m, Oyo State, Nigeria, between August and November 2011. It is at the edge of the rain forest belt of Nigeria and the soil type is Alfisol derived from basement complex (Iwo Series). The area lays in the sub-humid tropics. The climate is divided into wet season (April-October) and dry season (November-March). The mean annual rainfall is 1200-1300 mm while monthly variation in temperature is between 23 and 31° C.

Experimental materials

The test crop used in the trial was groundnut (*Arachis hypogaea*) (varieties SAMNUT 10 and SAMNUT 21) and *Arachis pintoi.* Microlysimeters were used to determine daily evaporation.

Cover crops can be defined as close-growing crops that provide soil protection, and soil improvement between periods of normal crop production, or between trees in orchards and vines in vineyards (SSSA, 1997). It is planted primarily to manage soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in agroecosystems (Lu *et al.,* 2000). Cover crops are of interest in sustainable agriculture as many of them improve the sustainability of agroecosystem attributes and may also indirectly improve qualities of neighbouring natural ecosystems. Leguminous species are the most common cover crops planted in soil conservation practices, among which is *Arachis* spp., to which *A. hypogaea* and newly introduced *A. pintoi* belongs.

The seeds varieties of SAMNUT 10 and SAMNUT 21 were collected from the Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Zaria, Kaduna State, Nigeria. Stem cuttings of *Arachis pintoi* were collected from Department of Agronomy Garden, University of Ibadan.

Brief descriptions of the varieties as provide by the IAR, ABU, Zaria are given below:

SAMNUT 10: This Groundnut variety is adapted to Guinea and Forest Savanna of Nigeria. It is late maturing variety with duration of 135-150 days. The colour of seed is variegated (tan and white) with a potential yield of 2000 kg ha^{-1}.

SAMNUT 21. This is adapted to Guinea and Sudan Savanna of Nigeria. It is medium in maturity with duration of 110-120 days. The seed colour is variegated (tan and white). It can yield of 2000 kg ha^{-1}.

Arachis pintoi. Pinto peanut; perennial peanut is a forage plant native to *Cerrado* vegetation in Brazil. *A. pintoi* is a perennial, crawling herb with shallow root system, long flowering duration, many branches and rooting in every node. This wild perennial relative of the groundnut has been of increasing importance to pasture improvement in the tropics. It is suiTable for growth in tropical or sub-tropical regions. Its height of straw layer is 15-30 cm. Owing to its merits of acid-tolerance, barren land-tolerance, stoloniferous growth habit and drought-tolerance; it has been widely cultivated for water-soil conversation, soil fertility enhancement and as an ornamental turf grass (Huang Yi-bin *et al.,* 2004).

Microlysimeter. Also called evaporimeter were made of PolyVinyl Chloride (PVC) pipe of 10 mm thickness and 10 cm diameter cut into 10 cm length. A perforated metal base plate were used to cover their bottom to hold the soil in place and to allow free drainage.

Experimental design and treatments

The experimental design used was split plot in a randomised complete block design with three replications. *Arachis* varieties were the main plot and plant densities the sub-plot. The three plant densities were 66667 ha^{-1} at 75 × 20 cm, 33333 ha^{-1} at 75 × 40 cm, and 83333 ha^{-1} at 60 × 20 cm. Dimension of each main plot were adopted as 14 × 5 m and subplot as 5 × 4 m. After land clearing, ridges were made using the specified inter-row spacing; seeds of *A. hypogaea* and stem cuttings of *A. pintoi* were planted manually using the specified intra-row spacing.

Data collection and analysis

Evaporation measurement. After crop establishment at 52 days after planting (DAP) when canopies had fully developed, microlysimeter tubes were inserted into the soil under a representative canopy, removed with the soil intact; they were capped at their bottom with a metal base plate and then placed back into the holes. This was done in each plot and on a bare soil so as to measure daily evaporation under cropped and bare soil. Lysimeter measurements were obtained until senescence. Readings were recorded at 24-h intervals using an electronic weighing balance (sensitivity at one gramme). Microlysimeters were extracted from the soil profile immediately after rain; the soils in the tubes are poured off so as to obtain a new representative drained soil sample and its replacement within 4 h.

Soil sampling and analysis. Soil sampling and analysis were carried out before land preparation and after harvest to determine physical and hydrological properties using a soil auger and a 100 cm^3 soil cores. Bulk density was determined from oven dried undisturbed cores as mass per volume of oven-dried soils, saturated hydraulic conductivity was determined using constant head of water above undisturbed core and particle size distribution was determined using hydrometer method. Total porosity was calculated from the parameters of bulk density and particle density (assumed value of 2.65 Mg m^{-3}) while saturation percent was determined from total porosity and permeability from saturated hydraulic conductivity.

Statistical analysis was done applying the analysis of variance. Least significant difference was used to separate means at 5 % level of significance.

Results and discussion

Particle size distribution

The particle size distribution of the experimental site before planting showed that the soil texture is loamy sand (Table 1). The soil is principally sandy; with sand accounting for more than 75% of the inorganic mineral fragment in the soil. The corresponding soil bulk density was 1.36 Mg m^{-3}, soil porosity obtained was 54.8 %. Hydraulic conductivity was 1.05 cm min^{-1} while permeability was 1.6×10^{-11} m^2.

Soil texture and structure is important in describing the health of agricultural soils and it is important for water infiltration, aeration and plant root development (Fageria, 2002).

Sand (2-0.05 mm in diameter). *Arachis spp***.** did not significantly influence sand particles although, a reduction was observed under each of the variety used when comparing initial values to post harvest values (Table 2).

Sand fraction were significantly ($P > 0.01$) varied under *Arachis* densities. Plant density of 66667 ha^{-1} improved soil condition by reducing the sand content when compared to the initial status. Whereas, increased sand fraction were observed under densities 33333 and 83333 ha^{-1}.

Table 1: Soil Physical and hydrological properties of the site prior to planting

Parameters	Values
Sand (g kg^{-1})	823.4
Silt (g kg^{-1})	110.2
Clay (g kg^{-1})	66.4
Textural Class	loamy sand
Bulk density (Mg m^{-3})	1.36
Total porosity (%)	54.8
Sat. hyd. Con. (cm min^{-1})	1.05
Permeability (m^2)	1.6 x 10^{-11}

Table 2: Post-planting soil physical and hydrological properties at organo-mineral: Fertiliser Research Plant Site along Barth road, University of Ibadan in 2011

	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Hydraulic conductivity (cm min^{-1})	Perme-ability (m^2)	Total porosity (%)	Bulk density (Mg m^{-3})	Saturation (%)
Initial	823.4	110.2	66.4b	1.05b	1.63E^{-11}	54.82	1.36	0.55
PINTOI	814.9	105.8	79.2a	1.61a	2.32E^{-11}	53.94	1.38	0.54
SAMNUT 10	813.3	109.1	77.6a	0.83b	1.62E^{-11}	54.29	1.42	0.54
SAMNUT 21	818.4	104.0	77.6a	0.79b	1.59E^{-11}	55.71	1.44	0.56
LSD	NS	NS	8.88*	0.401**	NS	NS	NS	NS
Initial	823.4a	110.2b	66.4	1.05	1.63E^{-11}	54.82	1.36	0.55
(60 × 20) cm^2	831.2a	94.9b	73.8	1.13	2.12E^{-11}	54.85	1.41	0.55
(75 × 20) cm^2	793.3b	131.6a	75.1	1.24	2.02E^{-11}	55.46	1.47	0.56
(75 × 40) cm^2	828a	95.4b	76.6	0.85	1.23E^{-11}	53.76	1.36	0.54
LSD	21.29**	21.14**	NS	NS	NS	NS	NS	NS
V × S(LSD)	42.57**	42.28**	NS	0.69**	NS	NS	NS	NS

V x S = variety by spacing interaction, Values followed by the same letters are not significantly different from each other *= ($p<0.05$); **= ($p<0.01$); ***= ($p<0.001$); NS= Not Significant. E = 10^{-11}

The magnitude of change indicate that sand particles in respect to initial status of soil under Arachis varieties improved soil condition with SAMNUT 10 performing best (Table 3).

Silt (0.002–0.05 mm in diameter). *Arachis* spp. did not significantly influence silt content of the soil (Table 2), but there was reduction in silt content when compared to initial soil status. There was more reduction in silt content in SAMNUT 21 than in SAMNUT 10.

Table 3: The magnitude of change (%) in soil properties under variety and plant spacing with respect to soil initial status

	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Hydr. conduc (cm min^{-1})	Perme-ability (m^2)	Total porosity (%)	Bulk density (Mg m^{-3})	Saturation (%)
PINTOI	-1.03	-3.99	19.28	52.85	42.33	-1.61	-1.47	-1.8
SAMNUT 10	-1.23	-1.00.	16.87	-21.10	-0.62	-0.97	-4.41	-1.8
SAMNUT 21	-0.61	-5.63	16.87	-24.54	-2.45	1.62	-5.88	1.82
(60 x 20) cm^2	0.95	-13.88	11.15	7.22	30.06	0.06	-3.68	0.00
(75 x 20) cm^2	-3.66	19.42	13.10	17.59	23.93	1.17	-8.09	1.82
(75 x 40) cm^2	0.56	-13.43	15.36	-19.39	-24.54	-1.93	0.00	-1.8
Soil condition (-)	better	worse	Worse	worse	Worse	better	worse	Better
Soil condition (+)	worse	better	Better	better	Better	worse	better	Worse

Silt content varied significantly ($P < 0.01$) under *Arachis* densities (Table 2). *Arachis* density of 66667 ha^{-1} increased the silt content with at about 20 % (Table 3). The increase in silt content is attributed to the development of dense cover and maximum utilisation of space which helps to suppress soil erosion.

Arachis spp. significantly ($p < 0.05$) influenced the clay content of the soil when compared to initial soil status (Table 2). There was increase in clay content under all the three varieties with PINTOI showing greater influence on the soil clay content by increasing the clay content by about 20% in the initial soil status. Varieties SAMNUT 21 and SAMNUT 10) increased clay content by about 17%.

Although *Arachis* densities of 33333 ha^{-1} increased the clay content of the soil by 74%, 66667 ha^{-1} by 75% and 83333 ha^{-1} 76 % (Table 3), there were no significant influence (Table 2).

The change in clay content of soil at harvest with respect to initial soil status showed that all treatments resulted in the increase of the clay content (Table 3). This result indicates that all treatment imposed on the trial reduce erosion by wind dispersion and water dispersion by reducing impact effect of rain drop on soil surface through its canopy architecture and also reduce dislodging of clay particles through efficient rooting system. This implies that the increase in clay content of the soil will increase water holding capacity of the soil. This finding agree with that reported by Aiyelari and oshunsanya (2008) who stated that any practice that increases clay particles of a soil will enhance water retention of the soil.

Hydraulic conductivity (Ks) and permeability (K). *Arachis* spp. significantly ($p < 0.01$) influenced the hydraulic conductivity of the soil (Table 2). However, only plot planted with PINTOI improved saturated hydraulic conductivity of the soil at 53%, while reduced saturated hydraulic conductivity were observed under groundnut plot. *Arachis* spp. did not significantly influence permeability, although the PINTOI plots had an improvement of of 42%, while reduced permeability were observed under groundnut plots.

On the other hand, both saturated hydraulic conductivity and intrinsic permeability of the soil were not significantly influenced by Arachis densities (Table 2). 66667 plants ha^{-1} and 83333 plants ha^{-1} improved soil condition by increasing saturated hydraulic conductivity and permeability with a magnitude of 7%, 18% and 30%, 24% respectively.

Plots planted with PINTOI and those under 66667 and 83333 ha^{-1} treatments improved the soil condition in initial soil status. The result obtained supports series of research which indicates that cover crops are good soil conditioners because their vigorous, shallow and fibrous root systems loosen the soil and improve soil tilth.

Improvement in soil hydraulic conductivity and infiltration by modifying soil structure, aggregate stability and macro pores using cover crop have been reported by Murphy *et al*. (1993) and Kumar and Goh (2000).

Total porosity, saturation percent and bulk density. Although there were changes in all the three parameters, *Arachis* spp and *Arachis* densities did not significantly influence any of these parameters. Total porosity was considered to be improved under PINTOI, SAMNUT10 and density of 33333 ha^{-1} since reduction in porosity obtained under these three factors varied their values towards 50%. This indicates equal proportion of pores (macro and micro) in soils.

The result observed for saturation percent also follow the same trend as total porosity, this indicate that degree of wetness of the soil would permit optimal aeration of the soil.

The bulk density which is the measure of soil weight varied under all the treatments, except under *Arachi*s density of 83333 ha^{-1} which remained unchanged.

Effect of different *Arachis* varieties and *Arachis* densities on soil evaporation: conserving soil moisture. The result from soil evaporation study under *Arachis* canopy and bare soil (Figure 1) shows that soil moisture depletion achieved a significant decrease under cropped land than in open bare soil, particularly under SAMNUT 21. It conserved soil moisture by about 44.5%, followed by PINTOI with 41.1% and SAMNUT 10 at 34.7%. This is as a result of several reasons, amongst is varietal differences, changing evaporative demands of the atmosphere especially in the controlling factor of insolation, and heterogeneity in soil characteristics. Conserving soil moisture with cover crop residues is reported by among others Smith *et al.* (1987) and Sustainable Agriculture Network (1998).

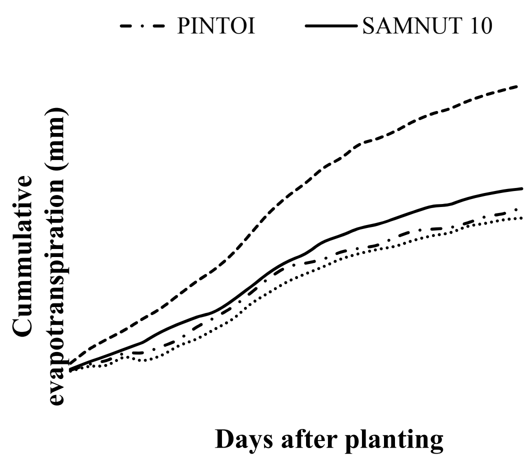

Figure 1: Cumulative evaporation under *Arachis* varieties as compared to bare soil

Evaporation under canopy at different *Arachis* densities shows that plant density of 66667 ha^{-1} performed best in reducing soil evaporation followed by the 83333 ha^{-1} and the 33333 ha^{-1}.

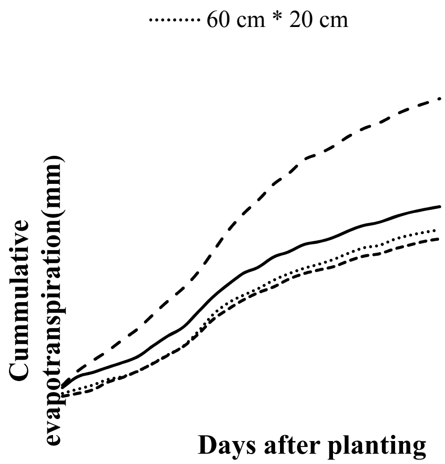

Figure 2: Cumulative evaporation under *Arachis* densities as compared to bare soil

When residues are left on soils, it improves infiltration of rain water and also reduce evaporative losses, resulting in less moisture stress during drought periods (Smith *et al*., 1987). The greatest differences in water contents between mulched and bare soils can be expected during short dry periods of 7-14 days (Smith *et al*., 1987).

Combine effect of variety and plant spacing on soil properties. Interactive effect of variety and *Arachis* densities significantly ($p < 0.01$) influenced sand fraction, silt content and saturated hydraulic conductivity of the soil while other parameters were not significantly varied (Table 2). These interactions show how well a variety best suit or perform at different plant spacing.

Combined effect of variety and *Arachis* densities were observed on sand fraction of the soil (Figure 3). PINTOI at 66667 ha^{-1} and SAMNUT10 at 83333 ha^{-1} improved the soil significantly ($p < 0.01$) by reducing sand fraction. This implies that PINTOI at a spacing of 75 × 20 cm and SAMNUT10 at a spacing of 60 × 20 cm enhance soil sustainability through sand reduction.

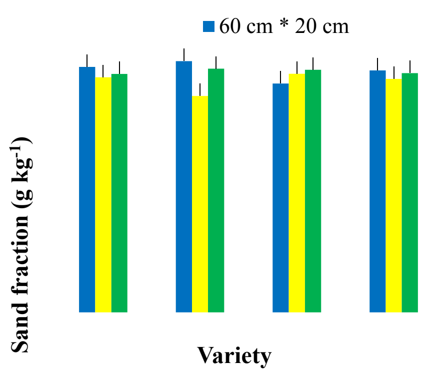

Figure 3: Interactive effect of variety and spacing on sand fraction after harvest

Interactive effect of variety and *Arachis* densities on silt fraction of the soil follows the same trend as in sand fraction (Figure 4). This result indicates PINTOI at 66667 ha^{-1}, SAMNUT 10 at 83333 ha^{-1} and SAMNUT 21 at 66667 ha^{-1} improved the soil significantly ($p < 0.01$) increasing silt content of soil.

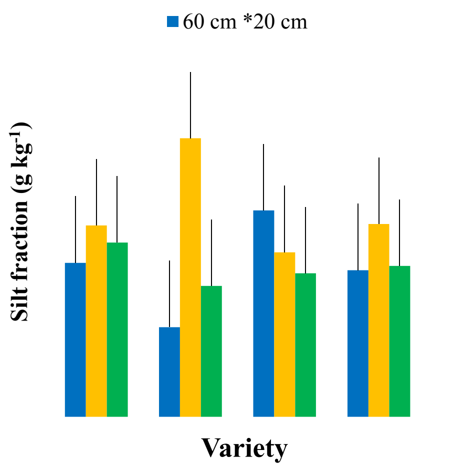

Figure 4: Interactive effect of variety and spacing on silt fraction after harvest

Interactive effect of variety and spacing on hydraulic conductivity of the soil (Figure 5). PINTOI at a spacing 75 × 20 cm had the best improvement on hydraulic conductivity while spacing 75 × 40 cm improved hydraulic conductivity of the variety planted.

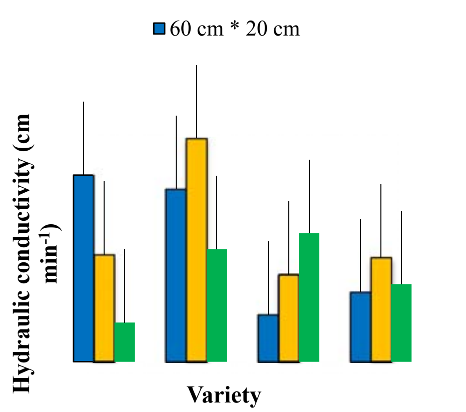

Figure 5: Interactive effect of variety and spacing on hydraulic conductivity after harvest

Conclusion

Arachis spp. and densities used reduced water evaporation from the soil, which indicates that more water is made available for efficient crop production. *Arachis* spp. (with PINTOI performing best) improved the soil properties significantly in clay content, porosity, permeability and hydraulic conductivity. These

properties have close relationship with water holding capacity of the soil and therefore, will increase water availability and distribution in soil. SAMNUT 21 performed best in soil water conservation.

Recommendations

It is therefore recommended that for optimum performance, PINTOI should be spaced at 60 × 20 cm (83333 ha^{-1}), SAMNUT21 at 75 × 40 cm (33333 ha^{-1}) and SAMNUT 10 at 75 × 20 cm (66667 ha^{-1}). Planting cover crops before or between main crops as well as between trees or shrubs of plantation crops can improve soil physical as well as chemical, and biological properties and consequently lead to improved soil health and yield of principal crops.

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Screening of yam genotypes for drought tolerance in southwestern Nigeria

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Abstract

Amongst the most important factors affecting yield of tropical tubers, soil moisture is considered as a vital factor that could impose a significant impact ontuber yield.Screening of thirty-two genotypes of *Dioscorea alata* was carried out for their varied responses to moisture stress at the International Institute of Tropical Agriculture, Ibadan, Nigeria. Perforated pots filled with 5kg of sterilized soils were irrigated and left to equilibratefor 24 hours. Thirty yam setts of 40g were prepared from each genotype. The setts were pre-germinated for 3 weeks in sterile carbonized rice husk medium. After transplanting, each vine was passed through the hollow part of short poly vinyl chloride (PCV) pipes, and the pots were tightly wrapped with transparent polyethene bags to prevent moisture loss. The design of the experiment was randomized complete block with three replicates. The experiment was maintained within a glasshouse for three months without further watering. Data collected include: weekly pot weight, number of days to wilting, interval leaf counts, vine length and leaf area, shoot and root weight. The data were subjected to analysis of variance and multivariate cluster analysis. The 32 genotypes differed significantly (P<0.01) with respect to the seven phenotypic traits. Four clusters emerged from the grouping of the 32 genotypes. Genotypes in cluster three had the best performance for biomass yield (37.05g), fresh shoot weight (21.43g) and vine length (127.62 cm) and could be potential materials for selection as drought tolerant genotypes. These genotypes include: TDa 03/00185, TDaOlesunle, TDaSagbe, TDa 93-36, TDa 00/00060, TDa 03/00090, TDa 00/00104, TDa 98/01166, TDa 00/00045 and TDa 00/00064.

Key words: *Dioscorea alata*, drought tolerance, genotypes, moisture stress, screening.

Introduction

Yam (*Dioscorea* spp.) is a multi-species crop that originated fromAfrica and Asia before spreading to other parts of the world (Hahn*et al.,* 1987). Water yam (*Dioscorea alata* L.)is the most widespread species throughout the world but second to the white yam in Africa. The tuber shape is generally cylindrical, but can be extremely variable. The tuber texture is watery and flesh colour is usually white.

Altered and unpredicTable weather patterns can increase crop vulnerability to pests, diseases and the effects of extreme climate events such as high temperatures, droughts and torrential rains have become contemporary issues (Rosenzweig*et al*. 2001). Drought will cause shifts in areas suiTable for cultivation of a wide range of crops. Although majority of new crop varieties released have been bred for improved resistance to pests and diseases, yet it is claimed that abiotic stress is the primary cause of crop loss, reducing average yields of most major crops by more than 50% (Wang *et al.,* 2003). This proportion will rise with increasing irregularity and frequency of extreme climate events.Amongst the most important factors affecting yield of tropical tubers, soil moisture is considered a vital factor (Turner, 2000) as it affects root development and hence could impose a significant impact on yam tuber yield (Yamauchi *et al.,* 1996).

Food production and sustainability is being grossly affected by the changing global climate. The need to make drought tolerant genotypes available for environments where less water is available is therefore necessary to enhance food security. Consequently, breeders need to urgently turn their attention to the introduction of drought and heat resistance into yam varieties to reduce losses of yield from climate change impacts and to allow cultivation in areas that are not currently suiTable or may become unsuiTable. This

Three

study was therefore carried out to screen *D. alata* varieties for drought tolerance with a view to supplying farmers with selected ones in order to address food insecurity.

Materials and methods

Study site and soil preparation

This study was carried out in a glasshouse at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Soil samples were collected from an experimental plot at IITA, Ibadan in the derived savanna of Nigeria. The soils were sieved through a 2 mm sieve and filled into containers of 6 kg capacity. Chemical and physical properties of the collected soil showed the soil to be neutral (pH =7) and predominantly loamy sand (790 g kg^{-1} sand) with organic carbon, total nitrogen, available P, Ca, Mg, Na and ECEC all below critical level.

Experimental procedure and Treatments

Thirty-two genotypes (26 IITA improved lines and 6 landraces) of *Dioscorea alata*obtained from IITA were used for the trial. Yam tuber of each genotype was cut into 40 g setts, with a knife. The yam setts were planted in sterile growth medium (carbonized rice husk) for three weeks to sprout before transplanting into the 5 kg capacity pots. Sprouted yam setts were selected based on their growth and shoot vigour. Each pot was irrigated and left to equilibrate for 24 hours after which sprouted yam were planted. Short polyvinyl chloride (PVC) tubes were passed through each sprouted vine and fixed at the base. Each pot was wrapped with transparent polyethylene (poly) bag which was in turn tightly fixed on the PVC tubes using twines, and then firmly secured onto the pots using masking tape.

Tubes were insulated using cotton wool, leaving only a smallopening at the top for vine growth. The plastic bagging was to minimize water loss from the soil surface. The initial pot weights were taken with a sensitive weighing balance. The trials were arranged in a randomized complete block design with three replications. The plot size was 5 pots. The experiment lasted for 90 days.

Data collection

Data collected were pot weights, plant survival rate and vigour (assessed by scoring with a scale of 1 –very weak, 2 – weak, 3 – moderate, 4 - vigorous and 5 – very vigorous), number of leaves and length of vine (measured fortnightly).Leaf area, root and shoot weight were measured at the end of the experiment, 90-days after transplanting.

Harvesting

Each plant was cut at the base of the pot and the leaves and vines separated. Roots were collected after emptying the soil mass on a 2 mm wire mesh and washed under a water tap prior to weighing.

Statistical analysis

Statistical analysis was carried out using SAS package (SAS, 9.2). Multivariate cluster analysis was used and clusters formed using a mixed model where genotypes were considered as fixed effects and replicates as random effects. The canonical analysis of the data set was used to display the clusters in 2 dimensional graphics.

Results

The 32 genotypes differed significantly ($P<0.01$) from oneanother with respect to the overall means of the seven phenotypic traitsassessed during the study (Table 1). The seven traits measured included plant weight (30.94 g), shoot fresh weight (18.24 g), leaffresh weight (11.06 g), root fresh weight (12.7 g), plant vigour (0.86), vine length (95.79 cm) and total leaf area (931.82 cm^2) (Table1).Five (TDa00/00045, TDa03/00090, TDa03/00185, TDa93-36 and TDa02/00012) of the 32 genotypes had means which were higher than the grand means for each of the traits. On the other hand, the performance of five other genotypes (TDa291, TDa00/00046, TDa02/00006, TDa05/00086 and TDa05/00141) was far below the grand mean for each of the phenotypic traits.

Table1: Mean values of the morphological traits of the screened thirty- two *D. alata* genotypes

Genotype	Shoot fresh weight	Leaf fresh weight	Root fresh weight	Plant vigour +	Vine length	Total leaf area
		g/pot			cm	cm^2
TDa 291	13.5	8.7	9.6	1.7	63.5	573.2
TDa 00/00046	11.5	8.6	10.9	2.7	53.5	597.0
TDa 00/00066	15.2	8.1	10.3	3.3	51.5	1003.6
TDa 01/00015	16.7	10.2	16.4	1.7	66.1	706.6
TDa 02/00006	17.4	10.7	6.6	3.3	50.5	712.5
TDa 02/00246	12.0	7.4	12.9	2.0	84.6	639.8
TDa 05/00086	13.4	8.9	6.6	1.7	66.2	467.5
TDa 05/00141	13.8	8.9	14.8	3.3	72.2	579.4
TDa 00/00103	16.1	11.2	10.2	1.7	60.1	890.2
TDa 02/00088	18.4	11.2	9.0	4.0	84.6	1056.6
TDa 02/00092	18.4	12.3	15.9	4.0	87.7	667.4
TDa 02/00151	18.5	12.2	9.3	1.3	79.0	673.2
TDa 05/00048	18.4	12.5	13.7	4.7	79.4	942.8
TDa 98/01176	18.8	11.6	12.5	2.0	72.3	1106.7
Kesofunfun	19.8	11.9	16.6	2.0	69.2	998.0
Lotosson	18.5	10.2	13.9	3.0	101.9	621.6
Agara white	19.2	12.2	9.6	2.7	98.6	960.8
TDa 00/00045	22.7	13.6	15.6	3.3	112.7	1180.2
TDa 00/00060	19.7	12.4	13.5	4.3	119.3	909.5
TDa 00/00064	22.9	13.4	13.1	2.7	116.6	958.1
TDa 00/00104	21.8	12.1	15.5	2.3	173.0	782.2
TDa 03/00090	18.9	11.5	24.2	2.3	101.7	1302.1
TDa 03/00185	24.7	13.4	13.2	4.7	144.2	1382.8
TDa 93-36	21.4	13.1	16.0	3.0	148.9	973.3
TDa 98/01166	22.2	13.1	13.3	2.3	111.1	921.7
Olesunle	19.0	10.4	19.3	1.7	95.1	1199.2
Sagbe	21.1	12.4	12.7	1.7	153.7	931.0
TDa 297	14.4	9.5	7.7	3.3	106.3	1113.2
TDa 00/00194	21.6	11.9	8.7	4.0	145.7	1187.9
TDa 02/00012	18.5	11.6	14.0	3.3	102.7	1164.8
Agara red	19.8	10.3	8.0	2.3	120.7	978.9
Sharmgbagada	15.7	8.5	12.9	3.0	72.7	1636.4
Mean	18.2	11.1	12.7	2.8	95.8	931.8
SE	1.89	1.13	1.25	0.34	22.37	192.93
P-Value	<.0001	0.0005	<.0001	0.0005	0.0039	0.0024

SE= Standard error of the mean + Values in the Table are transformed means of subjective scores (1-5 where 1 = poor, 2 = weak, 3 = moderate, 4 = good, 5 = excellent)

Cumulatively, the two canonical axes (Can 1 and Can 2) explained 96% of the total variation among the genotype. Can 1 separated genotypes in Group 1 from those in Group 3. Genotypes in group 2 and 4 were dispersed. Group 4 genotypes were located northward of Can2 while genotypes TDa00/00103 and Agara white were aligned on the Can 2 axis. Genotype TDa02/00088 fell northward of the equatorial axis (Can 2). The remaining six genotypes in Group 2 fell southward of Can 2. The highest diversity exists between genotypes in Groups 1 and 3. The first two canonical axes are most important in classifying the 32 *D alata* genotypes; the first explained 79% of the total variation, the second 17% (Table 2). The discriminatory role of each trait in the classification of the 32 genotypes was revealed. Traits of higher importance in Can 1 are fresh leaves weight, fresh shoot weight, and plant weight and vine length while in Can 2, plant vigour and

total leaf area were important in discriminating the 32 genotypes. The role of fresh root weight was negligible in discriminating between the 32 genotypes.

Table 2: Eigenvalues, proportion of variation explained by each canonical axis and coefficients of correlation between original and canonical variables of *D. alata* genotypes

Canonical Axes	Eigenvalue	Proportion of variance
Can 1	7.57	79.02 (%)
Can 2	1.63	16.96
	Coefficient of correlation	
Variables	Can 1	Can 2
Leaf fresh weight	0.47	0.53
Root fresh weight	0.18	0.28
Shoot fresh weight	0.53	0.29
Plant vigourat12 WAP	0.20	0.30
Vine length	0.48	0.15
Total leaf area	0.34	0.36

WAP: weeks after planting Can: canonical

Genotypes in Group 3 had the best performances for most of the traits (Table 3). The significantly higher performance of genotypes in Group 3 were observed in mean plant weight (37.05g), shoot fresh weight (21.43g), leaf fresh weight (12.54g), root fresh weight (15.63g) and vine length 127.62cm. The mean of genotypes in Group 4 was however higher than those in group 3 for plant vigour.Genotypes in Group 1 had a significantly lowest mean values for shoot fresh weight (14.18g), leaffresh weight (8.92g), vine length 63.52 cm and total leaf area (659.95cm^2) compared to the other groups. Generally, the performances of genotypes in groups 2 and 4 for the six traits were intermediate.

Table 3: Means of the four groups of *D. alata* genotypes generated by cluster analysis

Groups	Shoot fresh wt	Leaf fresh wt	Root fresh wt	Plant vigour	Vine length	Total leaf area
		g/plant			cm	cm^2
1	14.2	8.9	11.0	0.6	63.5	660.0
2	18.5	11.7	12.3	0.7	81.4	879.7
3	21.4	12.5	15.6	1.0	127.6	1054.0
4	18.0	10.4	10.3	1.2	109.6	1216.3
Mean	18.0	10.9	12.3	0.9	95.5	952.5
Sdev	3.0	1.6	2.4	0.3	28.6	238.6
uppL	21.0	12.5	14.7	1.2	124.1	1191.1
lowL	15.0	9.3	9.9	0.6	67.0	713.9

*Sdev: standard deviation; uppl: upper limit; lowl: lower limit

The relationship among the seven traits is presented in Table 4. Total plant weight correlated positively and significantly (P<0.001) with fresh shoot weight (r = 0.77), fresh leaf weight (r = 0.70), fresh root weight (r = 0.83) and vine length(r = 0.56). The correlation (r = 0.45) of plant weight with leaf area was significant at P = 0.05 (Table 4). The correlation of the fresh shoot weight with fresh leaf weight (r = 0.89), vine le (r = 0.73) and total leaf area (r = 0.47) were positively significant (P<0.001). The fresh leaf weight corre positively and significantly (P<0.001) with the length of the vine. On the other hand, the plant vigour positively and significantly (P<0.05) correlated with vine length (r = 0.44) and leaf area (r = 0.43) (Table 4).

Table 4: Correlationcoefficients among the six traits of *D.alata* genotypes

	Shoot fresh weight	leaves fresh weight	Root fresh weight	Plant Vigour	Vine length
Leaf fresh weight	0.90***				
Root fresh weight	0.29ns	0.27ns			
Plant vigour	0.33ns	0.31ns	0.20ns		
Vine Length	0.72***	0.58***	0.22ns	0.45*	
Leaf area	0.46**	0.30ns	0.27ns	0.42*	0.31ns

***: significant at <0.001, **: significant at 0.01, *: significant at 0.05, no significant effect

Discussion

Moisture stress imposition resulted in variation among the 32*D. alata* genotypes used in this study. According to Abo-Ghalia and Khalafallah (2008)the application of water stress to yams has been identified to reduce all growth parameters and plant productivity. The variation in response of plants to water stress is an indicator for selecting potentially drought tolerant genotypes. The seven phenotypic traits distinguished the 32 genotypes of *D. alata,* leading to the grouping of the genotypes.The weight of the leaves shoot and roots are the basic components which determine the biomass. Some of the genotypes performed poorly under moisture stress. Poor performance was observed among genotypes in Group 1 and 2 for most of the traits. Thiswould have resulted from the cessation of the initiation of new leaves and a decrease in the expansion of individual leaves as a result of water stress. Studies have also shown that water stress reduces plant growth and yield of sweetpotato (Weisz *et al*., 1994; Nadler and Heuer, 1995). Leaf growth is one of the first processes affected by water stress (Vajrabhaya*et al* 2001). This study shows that genotypes in Group 3 and 4 had higher overall performance for growth and yield parameters such as vine length, plant vigour, and total leaf area, shoot and leaves fresh weight. The high performance recorded for the genotypes in these groups imply that they had better efficiency in accumulating assimilates for higher biomass under water stress conditions than in the others. Jefferies and Mackerron (1993) also reported that drought tolerant genotypes consistently showed less growth reduction than other genotypes.

Conclusions and recommendations

The study showed that yam genotypes varied significantly in growth under water stress conditions. Based on their performance, four groups of genotypes were observed from the 32 genotypes. Genotypes 03/00185, Olesunle, Sagbe, 93-36, 00/00060, 03/00090, 00/00104, 98/01166, 00/00045 and 00/00064 had the highest overall performance. Such genotypes with good performance are potential candidates to be selected for moisture stress tolerance or for planting in semi-dry regions of Africa.

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Effect of tillage practices on soil moisture and selected soil physical properties in maize-bean intercropping systems in Mwala District, Kenya

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Abstract

Soil moisture conservation through tillage is one of the appropriate ways of addressing soil moisture deficits in changing climates. This study was conducted in the long rains (LR) and short rains (SR) of 2012 to evaluate the effects of tillage practices on soil moisture conservation in Mwala District, Eastern Kenya. Six tillage systems: Mouldboard (MB), Mouldboard and harrowing (MBH), Ox-ploughing (OX), Subsoiling – ripping (SR), Hand hoe and Tied Ridges (HTR) and Hand hoe only (H) and, three cropping systems, namely, sole maize, sole bean and maize-bean intercrop, were investigated in a split-plot design with four replicates. Soil moisture decreased over time ($p < 0.001$), between soil depths ($p < 0.001$) and also varied among the tillage methods ($p < 0.019$) in LR, 2012. The moisture trend was at HTR > MBH > H > OX > MB while in the SR at OX > SR > MB > HTR > H > MBH. In the SR, 2012, there was a significant interactions between time and cropping systems ($p = 0.003$). Results show that tillage influenced soil surface roughness ($p < 0.001$) and crust strength ($p < 0.001$). High surface roughness observed in HTR is due to the raised ridges and basins created during tied ridging and higher crust strength observed in the SR and OX plots. These results suggest that tillage methods influence soil moisture conservation and soil properties in the semi arid areas of Kenya.

Key words: tillage systems, cropping systems, soil moisture, semi arid areas.

Introduction

Many parts of semi-arid areas are characterized by temporal and spatial variability of rainfall. In most of the semi-arid and arid areas of Kenya, the rainfall is usually low and unreliable. The timing and relative lengths of each growing period vary substantially with location (Mudjeci *et al.,* 2010). This leads to reductions in yields by 75% when they occur (Barron *et al*., 2003).

The deficit of soil water in these areas is also attributed to low infiltration rates (due to surface sealing and crusting and low organic matter content) and subsequent high runoff rates (Rockstrom *et al*., 2003). The conservation of soil water in semi arid areas requires appropriate tillage practices that not only improve rain infiltration but also conserves adequate soil moisture for plant growth. Conservation tillage practices such as tied ridging, subsoiling and ripping have the potential of soil moisture retention and mitigation of intra-seasonal dry spells that would otherwise result in low productivity and crop failure (Manyatsi *et al*., 2011). Conservation tillage also conserves available rainwater currently lost in the magnitude of 70 - 85 % of rainfall from the cropping systems in Sub Saharan Africa, both through soil evaporation and through deep percolation and surface run-off (Rockstrom *et al*., 2003) and therefore makes it beneficial to the crops. Although conservation tillage is highly advocated, there is strong evidence that this kind of tillage may not be good with soils prone to surface crusting and sealing, a characteristic of most of the soils in semi arid areas of Kenya (Unger *et al*., 1991).

The success of any tillage practices is directly related to the improvement of the soil physical properties. Research has shown that soil bulk density, porosity, soil surface sealing and crusting, surface roughness, hydraulic conductivity and infiltration rates are very important soil properties affecting soil moisture (Gicheru *et al*., 2005). This study was conducted to quantify the comparative effectiveness of selected tillage practices in conserving soil moisture and improving soil physical properties in Mwala District, Eastern Kenya.

Materials and methods

Study site description

This study is being conducted in Mbiuni Location, Mwala District, Kenya (1°15'S, 37° 25'E). The study area is characterized by low, erratic and poorly distributed bimodal rainfall that makes crop production difficult under rain fed conditions. The main crops grown in the area are maize and beans. Soil chemical properties at the site (Table 1) indicate that initial soil N and P at the site were very low. Soil N contents below 0.12 % and P below 15 ppm are considered inadequate for crop production (Okalebo *et al.*, 2002). The soils had low organic carbon content of < 2%. The CEC of the soil was low (< 12 cmol/kg) indicating that the soil has low nutrient retention capacity (Gachene and Kimaru, 2003). This implies there is need to supplement the nutrients in the study area to achieve reasonable crop yields through application of mineral fertilizers, animal manures and plant residues.

Table 14: Selected soil physical and chemical properties of the experimental site (0 - 30 cm)

Soil property	pH (H_2O)	pH (0.01M $CaCl_2$)	% C	% N	K cmol/kg	Na cmol/kg	Ca cmol/kg	Mg cmol/kg	CEC cmol/kg	P ppm	Textural Class
	6.50	5.61	1.1	0.09	2.35	0.46	2.31	0.39	6.70	13.5	Clay loam

Experimental design and layout

The trials were established during the long rains (LR) of 2012 and short rains (SR) of 2012. Six tillage systems; Mouldboard (MB), Mouldboard and Harrowing (MBH), Ox-ploughing (OX), Hand hoe and Tied Ridges (HTR), Hand hoe only (H) and subsoiling - ripping (SR), three cropping systems namely, sole maize, sole bean and maize-bean intercrop were investigated in a split-plot design with four replications.

Data collection

Soil moisture was monitored from crop emergence to the time of harvesting at depths of 0 - 20 cm and 20 - 40 cm using the gravimetric method (Okalebo *et al.*, 2002). Soil surface roughness was measured immediately after the tillage operations and before weeding was done. A micro-relief meter similar to that described by Kuipers (1957) was used to measure surface roughness. Crust strength (penetration resistance) was measured at the soil surface using a hand-held penetrometer (Eijkelkamp equipment type 1B). Crust strength was calculated using the formula;

$$CR = I \times (Cs / AC)$$

Where, CR is the cone resistance (N cm^{-2}), I is the impression on the scale (cm), Cs is the spring constant (N cm^{-1}) and AC is the area of the cone (cm^2).

Saturated hydraulic conductivity (Ksat) determinations were done in the laboratory using the constant head method described by Klute and Dirksen (1982). The bulk density was determined using undisturbed core samples from each plot. Total porosity was then calculated from the bulk density.

Statistical analysis

The soil properties were subjected to analysis of variance (ANOVA) to evaluate the treatment effects. The Genstat for Windows® 14th Edition statistical analysis software was used.

Results and discussion

Soil moisture

Moisture trends as affected by tillage methods. Soil moisture decreased over time during the growing seasons (LR and SR 2012) at different weeks after planting (WAP) ($p < 0.001$). In both seasons, the soil moisture was higher in the 20 - 40 cm than in the 0 - 20 cm depth ($p < 0.001$) and varied among the different

tillage methods. The changes in profile water content could thus be attributed to a combination of rainfall, soil evaporation, transpiration or crop water uptake (Hobbs *et al.,* 2008).

In LR, 2012, there were also some significant interactions between time × depth ($p < 0.001$) and between time × tillage × cropping system ($p = 0.005$). Soil moisture trend in the 0 - 20 cm was in the order of HTR > MBH > H > OX > MB while in the 20 - 40 cm in the order of HTR > OX > MBH > H > MB. At both depths, the moisture trend was HTR > MBH > H > OX > MB. The greatest differences occurred when soil water content was highest shortly after the rain (Figure 1). The tied ridges (HTR) had high moisture levels due to the microbasin formation allowing more storage and infiltration. According to Guzha (2004), the higher moisture reported in ridges has been associated with higher roughness resulting from ridge conFigureuration through tillage and has benefits of harvesting rainwater and increasing the time for infiltration.

In the short rains (SR, 2012), there were some significant interactions between time × cropping system ($p = 0.003$) and time × depth ($p < 0.001$). There were no variations within the tillage methods ($p = 0.158$). Soil moisture trend in the 0 - 20 cm was in the order of OX > SR > MB > H > HTR > MBH while in the 20 - 40 cm was in the order of OX > SR > HTR > MB > MBH > H. At both depths, the moisture trend was at OX > SR > MB > HTR > H > MBH.

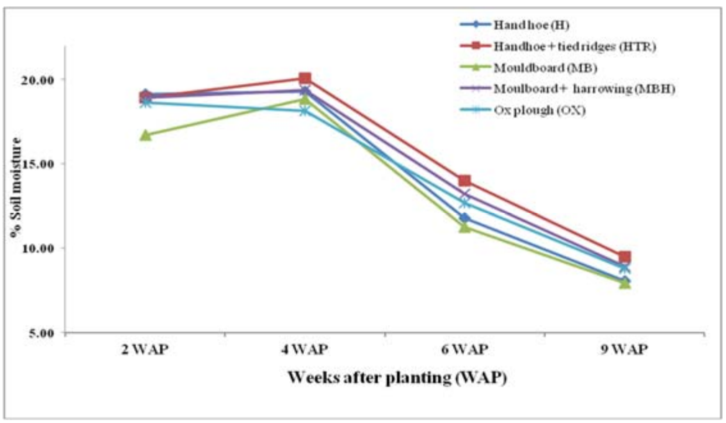

Figure 1: Moisture trends as affected by tillage methods in the long rains of 2012 (LR, 2012)

Moisture trends as affected by cropping systems. In the long rains (LR, 2012), there was significant interaction between time × tillage × cropping system ($p = 0.005$). Soil moisture distribution for LR, 2012 as affected by cropping systems is shown in Figure 2. The sole bean and the intercrop had higher soil moisture than sole maize. The low moisture levels in sole maize plots suggest that maize consumes more moisture and extracts greater moisture than sole bean during its growth. The canopy cover provided by the bean and the maize-bean intercrop help reduce evaporation, regulate the soil temperature thus improve infiltration and therefore reduces the wastage of available water (Steiner, 2002).

In the SR, 2012, there was no significant variations of moisture among the cropping system ($p = 0.684$). A time × cropping system interaction was observed ($p = 0.003$). In contrast to LR, 2012, the sole maize plots had more moisture (14.21 %) followed by bean (14.19 %) and intercrop (14.07 %) respectively. The intercrop had the lowest moisture content because of the increased plant population density per plot resulting in higher moisture extraction.

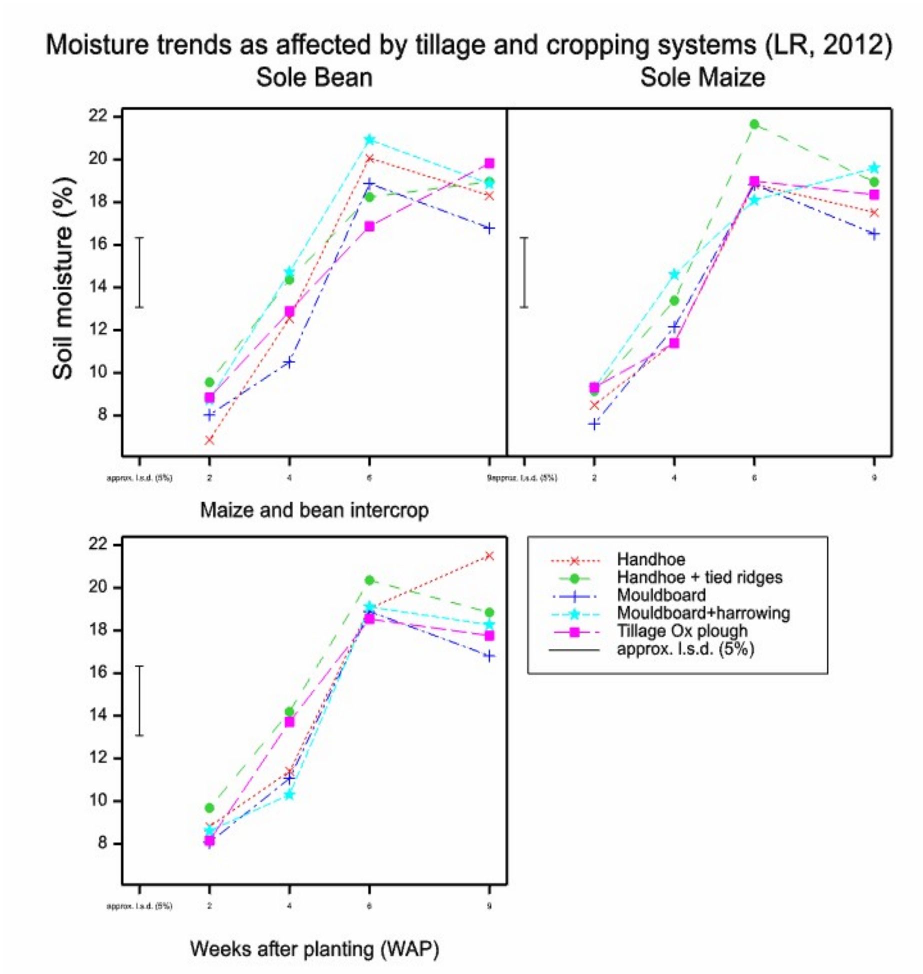

Figure 2: Moisture trends as affected by tillage and cropping systems (LR, 2012)

Soil surface roughness (SSR)

Soil surface roughness varied over time in the growing seasons ($p < 0.001$) and between the tillage methods ($p < 0.001$). In the SR, 2012, there was also a time × tillage interaction ($p < 0.001$). Soil surface roughness trend in the LR, 2012 was in the order of HTR > MB > OX > H > MBH while in the SR, 2012 in the order of HTR > SR > OX > MBH > MB > H (Table 2). The high surface roughness in HTR is due to the raised ridges and basins created during tied ridging. Soil surface roughness soon after tillage was significantly different among the tillage methods ($p < 0.001$). Thereafter, surface roughness decreased progressively in each season. This could have been attributed by a combination of raindrop action and human traffic during

planting and data collection. Soil surface roughness and concave soil surfaces have high ability to conserve rainfall and of increasing depression water. This explains why HTR had higher moisture levels in the LR, 2012 due to the depressional storage important for conserving rainfall which probably would have lost as runoff. Therefore, management practices aimed at adjusting the soil surface characteristics can promote soil processes that encourage soil moisture storage within the root zone (Lipiec *et al.*, 2006; Moreno *et al.*, 2008).

Table 2: Effect of tillage on soil surface roughness (SSR)

Tillage	Long rains (LR, 2012)			Short rains (SR, 2012)		
	At ploughing	Before planting	2 WAP	At ploughing	Before planting	3 WAP
Handhoe (H)	36.8	31.8	27.1	30.7	23.0	16.2
Handhoe + tied ridges (HTR)	75.0	72.5	65.2	67.8	64.9	58.6
Mouldboard (MB)	53.7	48.5	40.7	33.0	26.6	22.5
Mouldboard+harrowing (MBH)	29.8	17.9	13.5	36.9	33.7	21.2
Ox-plough (OX)	48.1	38.7	32.1	46.7	32.0	17.0
Subsoiling - ripping (SR)	-	-	-	50.8	47.2	36.6
Mean	48.7	41.9	35.7	44.32	37.88	28.7
LSD (5 %)	12.09	7.69	10.75	5.212	6.85	8.12
CV %	9.4	6.5	7.7	4.8	6.3	7.8

(-) = not measured in that season

Crust strength

Soil crust strength is an important soil physical property that provides information on the ability to allow water movement into the soil. The crust strength increased as the season progressed ($p < 0.001$) and varied among the tillage methods ($p < 0.001$) as shown in Figure 3. The increase in crust strength as the season progressed is attribuTable to natural formation of crust under raindrop impact since there was minimal human interference, only during weeding and data collection. According to Shivonje *et al.*, (2005), higher crust strength has been reported to reduce soil moisture storage due to the reduction of crust conductance and infiltration rates. The trend observed in SR, 2012 was in the order of SR > OX > MBH > H > MB >HTR with values ranging from 10 - 12 kg cm^{-2}. The high crust strength observed in SR and OX plots is therefore likely to cause raindrop splash, restrict water movement in the soil which can lead to runoff and low soil water storage. However, those findings contrast this study results as SR and OX had higher soil moisture content at the 0 - 20 cm soil depth compared to the other tillage methods. The crust formed on the ridges was weaker than other tillage methods as the season progressed. A probable cause of this was the inversion and mixing of top soil when constructing the tied ridges and this could have affected the structure of the top soil. Though not significant ($p = 0.546$), cropping system affected the crust strength with the intercrop having values of 11.68 kg cm^{-2} followed by sole bean (11.52 kg cm^{-2}) and maize (11.48 kg cm^{-2}) respectively.

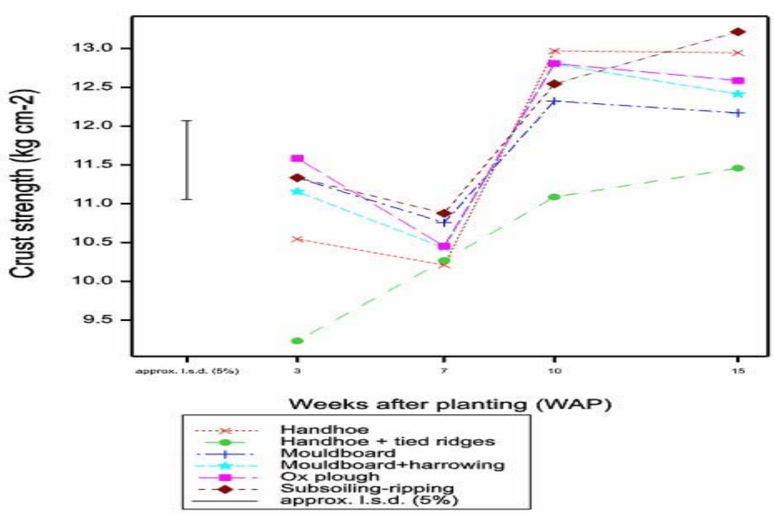

Figure 3: Soil crust strength as affected by tillage methods (SR, 2012) ($p < 0.001$)

Bulk density, porosity and saturated hydraulic conductivity (Ksat)

The results for hydraulic conductivity, porosity and bulk densities are shown in Table 3. The soil bulk densities ranged from 1.20 - 1.40 g cm^{-3} across the seasons which is within the accepTable range for a clay loam (Landon, 1991). At the beginning of SR, 2012, there were lower values as compared at harvest at the end of that season. According to Lal (1997), the lower bulk density and hence high porosity at the start of the season could be attributed to the loosening effects of tillage. This increase in bulk density could be due to a combination of raindrop impact and soil compaction due to repeated human traffic during weeding, data collection and other crop management activities.

Though not significant ($p = 0.424$), there were differences observed in the different tillage methods used in the study. The trend was MBH > HTR > OX > H > MB > SR. The high densities in MBH and HTR could be attributed to the second passes of soil manipulation (harrowing and tied ridges) to the initial tillage method of mouldboard (MB) and handhoe (H). The cropping systems also influenced the bulk densities in SR, 2012 at 2 WAP ($p = 0.005$). The intercrop had slightly higher densities (1.31 g cm^{-3}) than sole maize (1.29 g cm^{-3}) and sole bean (1.21 g cm^{-3}). This was also noted over the two seasons, intercrop (1.38 g cm^{-3}), sole maize (1.36 g cm^{-3}) and sole bean (1.35 g cm^{-3}).

Porosity values of the soils varied across the seasons ($p < 0.001$) and ranged from 44 - 47 % in the LR, 2012 and 47 - 53 % in SR, 2012. There was improved pore space from 46 % to 51 % in the last season (SR, 2012). Soils with < 40% total pore space are liable to restrict root growth due to excessive strength (Brady and Weil, 2008). The current study shows that the soils were thus not liable to restrict root growth. Though not significant, tillage ($p = 0.424$) showed a trend of SR>MB>H>OX>HTR>MBH. This trend is an inverse of

the bulk density trend thus indicating high bulk densities leads to low porosity values. For any given soil, the higher the bulk densities, the more compacted the soil is and the lower the pore space. This also affects the rate of movement of water into the soils (Brady and Weil, 2008). Cropping system did not show a significant influence on the porosity ($p = 0.139$) but sole bean and maize had higher porosity values than the intercrop.

Ksat values were very slow (< 0.8 cm/hr) in LR, 2012 and slow (0.8 – 2.0 cm/hr) in SR, 2012 (Landon, 1991). The Ksat values varied across the season ($p < 0.001$) with LR, 2012 and SR, 2012 having mean values of 0.63 cm/hr and 1.43 cm/hr respectively. Tillage did not show significant effect on Ksat values ($p = 0.528$) but a trend of HTR > SR > OX > MB > H > MBH was noted. The low Ksat values imply low infiltration rates, low rainwater intake and probably higher runoff within the plots. There were no significant interactions observed among the cropping systems.

Table 3: Effect of tillage methods on bulk density, porosity and saturated hydraulic conductivity (Ksat)

Bulk density (g/cm^3)				Porosity			Ksat (cm/hr)		
	LR, 2012	SR, 2012		LR, 2012	SR, 2012		LR, 2012	SR, 2012	
		2 WAP	Harvest		2 WAP	Harvest		2 WAP	Harvest
Tillage (T)									
H	1.42	1.24	1.36	0.47	0.53	0.49	0.61	1.36	1.09
HTR	1.42	1.28	1.33	0.46	0.52	0.50	1.08	1.85	1.26
MB	1.41	1.26	1.34	0.47	0.52	0.50	0.59	2.07	0.78
MBH	1.42	1.31	1.39	0.46	0.51	0.48	0.53	2.15	0.48
OX	1.46	1.24	1.31	0.45	0.53	0.51	0.46	1.72	1.76
SR	-	1.32	1.32	-	0.50	0.50	-	1.54	0.87
Mean	1.43	1.27	1.34	0.46	0.52	0.49	0.65	1.79	1.03
SED‡	0.033	0.054	0.027	0.012	0.025	0.0101	0.334	0.657	0.517
Cropping system (C)									
Bean	1.43	1.21	1.35	0.46	0.54	0.49	0.52	1.90	1.12
Maize	1.40	1.29	1.36	0.47	0.52	0.49	0.86	1.64	0.87
Intercrop	1.45	1.33	1.32	0.45	0.5	0.50	0.58	1.82	1.10
SED ‡	0.0269	0.0335	0.0195	0.0101	0.0126	0.0073	0.268	0.445	0.376
CV %	1.8	8.1	5.6	2.1	7.5	5.8	21	18.2	40.9

H = handhoe, HTR =handhoe + tied ridges, MB = mouldboard, MBH = mouldboard + harrowing, OX = oxplough, SR = subsoiling-ripping, (-) = not measured in that season, ‡ = for comparing means within a treatment

Conclusion and recomendation

These results suggest that tillage methods influence soil moisture conservation and soil properties in the semi arid areas of Kenya. However, there were disparities observed in the data collected in the two seasons hence more seasons are required to validate the findings.

Acknowledgement

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THEME 7: SOCIO-ECONOMICS

Ensuring food security by promoting uptake and scaling up the application of agricultural lime to combat soil acidity in Kenya

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Abstract

Soil acidity is rapidly becoming a serious problem in Kenya. Acidic soils create production problems by limiting the availability of some essential plant nutrients and increasing that of the soil solution's toxic elements, such as aluminum and manganese, the major cause of poor crop performance and failure in acidic soils. Results from several decades of natural resource management (NRM) research have shown that farmers in different environments can increase their farm productivity by up to 5 times if they adopted sustainable soil fertility management (SFM) technologies that are already available. These technologies include the use of agricultural lime to combat soil acidity. However, despite the availability of several technologies, including liming, little impact has been registered so far because only a small proportion of research results or good practices are scaled up, accessed and utilized by the extension workers, farmers, Non-Governmental Organizations (NGOs), the Private Sector, and policy makers. This paper highlights the main policy-induced constraints with respect to use of agricultural lime in Kenya and the key steps that stakeholders, including government, need to take to remedy the situation. These include the need to prioritize soil acidity as a constraint within National Agricultural Research and Extension Systems (NARES). This can be achieved through development of comprehensive policy documents on crop yield increases due to use of agricultural lime for different cropping systems and agro-ecological zones. Secondly, the Government of Kenya needs to increase and maintain budgetary allocations to agricultural sector Ministries to a minimum of the 10% of Gross Domestic Product (GDP) as recommended by NEPAD and improve both input and output markets. In addition, the Government of Kenya need to develop, support and strengthen institutional frameworks such as research-extension linkages for efficient and effective coordination of soil fertility and land management by empowering them and providing the requisite resources. There is also need to fast track harmonization of the existing policies and institutional arrangements for efficient delivery of SFM technologies including use of agricultural lime.

Summary

Results from several decades of natural resource management (NRM) research have shown that farmers in different environments can increase their farm productivity by up to 5 times if they adopted sustainable integrated soil fertility management (ISFM) technologies that are already available. ISFM is a set of soil fertility management practices that use a combination of mineral fertilizers and organic inputs, improved germplasm, knowledge of how to adapt the practices to local conditions, and which ensures agronomic efficiency of applied nutrients in order to improve crop productivity.

However, despite the availability of several technologies, including ISFM, little impact has been registered so far because only a small proportion of research results or good practices are scaled up, accessed and utilized by the extension workers, farmers, Non Governmental Organizations (NGO's), the Private Sector, and policy makers.

This policy brief highlights the main policy-induced constraints with respect to liming as a practice within ISFM in Kenya and the key steps that stakeholders, including government, need to take to remedy the situation:

- There is need to prioritize liming as an ISFM practice within National Agricultural Research and Extension Systems (NARES). This can be achieved through development of comprehensive policy

documents on crop yield increases due to liming as an option within ISFM for different cropping systems and agro-ecological zones

- The Government of Kenya needs to increase budgetary allocations to agricultural sector Ministries to a minimum of the 10% of Gross Domestic Product (GDP) as recommended by NEPAD and improve both input and output markets.
- The Government of Kenya need to develop, support and strengthen institutional frameworks such as research-extension linkages for efficient and effective coordination of soil fertility and land management by empowering them and providing the requisite resources.
- There is need to ensure harmonization of the existing policies and institutional arrangements for efficient delivery of use of lime and other ISFM technologies

Context and importance of the problem

Acidic soils are have less than 7.0 pH values and cover about 13% (7.5 million hectares) of agricultural land of Kenya. Areas covered by acidic soils contribute significantly to the Kenyan economy through cash crop and dairy production (Kanyanjua *et al.,* 2002). In the traditional ecological zone map of Kenya (Figure 1), areas with acidic soils are referred to as 'tea–dairy', 'coffee–tea' and 'main coffee' climatic zones (Jaetzold and Schmidt, 1982). This reflects the high potential for cash cropping and dairy keeping.

Figure 1: Acid soils distribution in Kenya

In addition to soil acidity, Land degradation is a major threat to food security and natural resource conservation in Kenya. As a result of catastrophic land degradation, soil-fertility depletion in smallholder farms is now recognized as the fundamental biophysical root cause for declining per capita food production, poverty and food insecurity. Yields for major staple crops such as maize will need to be raise from the current average level of 3 bags per acre to 15 bags per acre to avert a major food security disaster.

Several decades of Natural Resource Management (NRM) research to address this situation have produced copious amounts of results in their effort to halt soil acidity and the degradation of stressed environments and fragile ecosystems where poverty is increasing. However, production and availability of results has not been matched by a similar uptake. Lime materials have invariably been applied to soils in form of calcium hydroxide Ca(OH)2, calcium oxide (CaO) or calcium carbonate (CaCO3) to neutralize soil acidity. Addition of such materials has been found to stimulate crop growth and to also provide Ca2+ h and have

also lowered aluminium (Al) toxicity. Other workers have recommended use of Rock Phosphate (PR) to neutralize soil acidity (Kanyanjua *et al.,* 2002; Nekesa, 2007). Past research has shown that farmers in different environments can increase their farm productivity by up to 5 times if they adopted sustainable integrated soil fertility management (ISFM) and liming technologies that are already available. However, relatively little impact has been registered because only a small proportion of research results or good practices are scaled up, accessed and utilised by the poor farmers, their support agents, and policy makers. As a result of this low uptake and utilization of the promising technologies, productivity at farm level has remained low and in many cases declined. Only 'islands of success' or working pilot schemes have been registered from many years of participatory research in Agriculture and Natural Resource Management (NRM).

- Many organizations, public and private, are very concerned with the lack of impact from research and other knowledge undertakings in integrated natural resource management. They are increasingly calling for a serious focus on uptake promotion and scaling up of what is already known, especially to deal with agricultural and rural stagnation in Sub-Saharan Africa (SSA). This perception is also shared by regional organizations such as the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and various International and National Agricultural Research Institutes. The Millennium Development Goals (MDG) Project observes that knowledge is not lacking, what is lacking, as ever, is the will to turn this knowledge into practice.
- Experience shows that a narrow focus on the technical aspects of sustainable soil fertility management alone fails to achieve improvements in productivity, economic growth and food security. Therefore, a two-pronged approach focusing both on technical issues, and on external factors such as policies and institutional arrangements that influence how farmers manage their soils and general crop husbandry will create the required enabling environment for scaling

Key policy questions

A number of key policy questions remain unanswered:

- In view of the identified dismal situation, the question for policy-makers for supporting agriculture is, then, how best to support farmers to increase productivity and income growth, especially for smallholders using available technology?
- What explains the poor performance of policy formulation, implementation and advocacy on the role of lime and ISFM ? Despite Kenya having successfully implemented a fertilizer market reform policy, the place of lime, organic fertilizers such as manures and other green nutrient sources has not been addressed at policy level.
- Evidence from long-term experiments has shown that a combination of organic inputs, with modest amounts of mineral fertilizer, which is the core theme of ISFM, offers the most affordable and efficient means of addressing soil fertility decline and improving and sustaining crop yields. Application of lime to neutralize acidity would enhance achieving ISFM benefits.
- If the key policies that are shown to have a bearing on uptake and scaling up of lime use are related to awareness creation, marketing, public and private investment, taxation and credit, then, what can the government and other stakeholders do?

Policy options

Some of the key elements of remedying the situation include;

- Setting favorable overall conditions for growth of the Agricultural sector within the National Economic Development blueprints;
- Recognizing the public good role played by Agriculture;
- Recognizing the role of the private sector, and
- Remedying inputs and output market failures

These three building blocks of support for Agricultural Development act in concert: unless all three are attended to, then growth will be difficult to achieve.

- It is observed that most institutions dealing with lime usage are fragmented and lack the requisite human capacity and matching financial resources to implement their activities, especially the Ministry of agriculture. The scattering of lime issues across many policy documents has resulted in wastage of efforts and resources and in some cases conflicts and duplication of efforts between ministries, and departments. This calls for a more coordinated and harmonized approach and consolidation of efforts amongst different sectors. Moreover, the scattering of the issues across several sectors has resulted in overlapping of policies and the creation of some gaps in the policies themselves, and lack of clear ownership of the issues.
- Governments need to strengthen and increase the support of institutional frameworks such as research-extension linkages for efficient and effective coordination of soil fertility management including use of limeby empowering them and providing the requisite resources.
- Currently, investment in the Agricultural Sector in Kenya is lower than that recommended by NEPAD and both input and output markets are inefficient. For example percentages of national budg*et al*locations for agriculture sector Ministries is between 4-5%. There is therefore urgent need for the Government to increase budgetary allocations to agricultural sector to a minimum of 10% of Gross Domestic Product (GDP) recommended by NEPAD and improve input and output markets as well as the Backbone Agricultural and Last Mile Infrastructure, such as roads with connection to the farm gates, marketing, storage and processing facilities. This in turn will enable the Agricultural Sector to drive the overall economic growth

Recommendations

- There is need for comprehensive policy documents showing productivity gains associated with soil fertility management, including liming for different cropping systems and agro-ecological zones in Kenya. Harmonization of the existing policies and institutional arrangements for efficient delivery of new and existing technologies will be useful in attracting investments in both the input and output markets.
- The Government of Kenya needs to increase budgetary allocations to agricultural sector Ministries to a minimum of the 10% of Gross Domestic Product (GDP). as recommended by the New Partnership for Africa's Development (NEPAD) and improve both input and output markets. NEPAD, an economic development program of the African Union, adopted at the 37th session of the Assembly of Heads of State and Government in July 2001 in Lusaka, Zambia. NEPAD aims to provide an overarching vision and policy framework for accelerating economic co-operation and integration among African countries.
- In addition, the Governments of Kenya needs to prioritize ISFM within National Agricultural Research and Extension Systems (NARES) as the single most important factor for increasing agricultural productivity in order to ensure food security. This prioritization of ISFM would ensure improved access to mineral fertilizers through harmonization of tariffs and/or subsidies, credit facilitation and elimination of non-tariff barriers.
- The Government of Kenya needs to strengthen and increase support for institutional frameworks such as research-extension linkages for efficient and effective coordination of Soil fertility management including use of lime by empowering them and providing the requisite resources. This would ensure mass production and dissemination of soil fertility management options including the use of lime targeted at all relevant stakeholders.
- There will be specific need to address the question of both Backbone Agricultural and Last Mile Infrastructure, such as roads with connection to the farm gates, marketing, storage and processing facilities

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An analysis of policy related documents in the context of integrated land and water management in Kenya

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Abstract

Agriculture is the single most important sector in the economy in terms of GDP generation and employment creation. Water and land resources are vital for humans and economic development of a country, hence, need to maintain available water and land and provide good quality water for optimum development of the country. Therefore, integrated land and water resources management (ILWRM) system is fundamental. Agricultural policies in Kenya focus on increasing resource productivity and incomes; enhanced food security, emphasizing on irrigation for agricultural output stability, thus underlining the importance of sustainable ILWRM through an integrated approach, and therefore a need for an enabling policy environment. Main objective of the study was to undertake a review of the extent the existing policies favour or hinder implementation of ILWRM practices and propose interventions and recommendations for improvement. Materials on policies and strategic documents related to ILWRM were collected, reviewed and analyzed for strength, weaknesses identified, and recommendations on improvement proposed. Results showed that most materials that were reviewed have strong and sustainable indicators of natural resources and environmental management issues. However, from the broader ILWRM perspective, most of the materials appeared weak on specificities of ILWRM, although these seemed implicitly embedded in soil, water and environmental management issues. Therefore, there is need to explicitly incorporate ILWRM issues in the existing policies and strategic plans, have an enabling legal framework, identify gaps between the proposed policies and actual implementation, as well as lobby the policy makers for enhanced incorporation of ILWRM issues in the relevant policies.

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Key words: integrated, land, management, water, sustainable.

Introduction

Agriculture remains the backbone and the single most important sector in the Kenyan economy, contributing approximately 25% of the GDP, and employing 75% of the national labour force (Republic of Kenya, 2005). The importance of the sector in the economy is reflected in the relationship between its performance and that of the key indicators like GDP and employment. Trends in the growth rates for agriculture, GDP and employment show that the declining trend experienced in the agriculture's growth, especially in the 1990s, is reflected in the declines in employment and GDP as a whole (Alila and Atieno, 2006).

Land and water are vital for human survival and for economic development of a country. The need to maintain available land and water resources, provision of good quality water for utilization by the increasing population and for the optimum benefit in development of the country should therefore be a priority for any country hoping to improve and sustain adequate standard of life for its populace. However conflicting demands for these resources often make decisions very critical. There is therefore a need to have clear, long-term land and water management policies to ensure optimum benefit to the country. The Integrated Land and Water Resources Management (ILWRM) facilitates appropriate planning and implementation of water and land resources projects, and management through development of policies, while considering important driving factors including economics, social aspects, environment and political climate.

According to Sadrudin (2005) in Thalmeinerova (2007), the main objective of Integrated Water Resources Management (IWRM) system is to maintain a sustainable source of water supply that provides optimum benefit to the population in the catchments by satisfying their personal needs, while allowing them to undertake socio-economic activities without unnecessarily damaging the environment and also to control the resource in a way that minimizes the impact of natural disasters. Thus, IWRM calls for knowledge application from an array of disciplines and stakeholders for developing and managing water resources in a way that balances socio-economic needs, and ensures the protection of ecosystems for future generations. IWRM is also a cross-sectoral policy approach, replacing the fragmented sectoral approach to water resources and management that has led to poor services and unsustainable resource use. Like water, land is recognized as an important factor of production that needs to be managed well for agricultural productivity, equity, environmental sustainability and culture conservation (NLP, 2011).

Agricultural policy in Kenya revolves around the main goals of increasing productivity and income growth, especially for smallholder landowners; enhanced food security and equity; and emphasis on irrigation to introduce stability in agricultural output (Alila and Atieno, 2006). Kenya has 540,000 hectares of irrigable land but less than 90,000ha have been irrigated (SRA, 2004). Hence, there is need to exploit this potential through an integrated approach in an enabling policy environment. It is in this context that this review was undertaken to understand the extent of ILWRM incorporation in policy documents and strategic plans. The main policies and strategic plans related to ILWRM that were reviewed include the Economic Recovery Strategy for Wealth Creation and Poverty Reduction (GoK, 2003), Strategies for Revitalization of Agriculture (SRA) (GoK, 2004), National Water Policy on Water Resources Management and Development (GoK, 1999), Kenya Forest Services Strategic Plan (GoK, 2009), VISION 2030 (GoK, 2007) and Agricultural Sector Development Strategy (ASDS) (GoK, 2008), among others.

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Objectives

The objectives of this review on policy related documents in integrated land and water management in Kenya are to:

- Critically assess the extent to which the existing policy framework favour or hinder the advancement of ILWRM practices
- Identify strengths, weaknesses and gaps in the existing land and water related policies and strategic documents
- Propose recommendations for improved integrated land and water management issues at the policy level

Methodology

This work focused entirely on the critical review of relevant documents in the context of ILWRM. These included strategic plans, sessional and strategic papers and documents among others. The main strategic documents from the relevant departments like agriculture, water, environment and forestry among others were collected and formed case studies for this work. These materials were accessed through visiting relevant institutions, explaining the aims of the visits and requesting for materials that they have related to the work. The scientists implementing this activity perused through the materials and noted important information. Depending on the enormity and importance of the materials, the researchers also borrowed some of the materials for reading and noting for a specific periods of time. After collection of these documents, indicators for indicating extent of incorporation of ILWRM issues in each strategic and policy document were developed. These indicators included: (a) the extent of incorporation of natural resources management, soil and water conservation and broader ILWRM issues in the strategic objectives of the cases, (b) the extent of integration of the relevant sectors in the strategic documents and policies, and (c) the extent of technological integration of ILWRM interventions in the cases. By use of these indicators all cases were summarized and content analysis conducted and a report prepared.

Results

Analysis of the relevant main policies

National Land Policy (2007). The National Land Policy (GoK, 2007) recognizes the importance of land in the context of agricultural productivity, equity, environmental sustainability and cultural conservation. The policy emphasizes on security of legitimate rights and equiTable access to land in the interest of social justice and resolution of genuine historical and present land injustices. The policy document also indicates that vulnerability is a manifestation of poverty and deprivation and includes groups such as: subsistence farmers and pastoralists, and the need for their land rights to be recognized and protected. Thus, this policy focuses on putting structures in place for identifying, assessing and monitoring the vulnerable groups; redistribution of land and resettlement, their facilitation in decision making over land and protecting their land rights from unjust and illegal expropriation. It also recognizes three types of land tenure; public, community and private land.

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National Food and Nutrition Security Policy (2011). The National Food and Nutrition Security Policy (GoK, 2011) is framed in the context of basic human rights, child and women rights; including the Universal Rights to Food. The policy identifies human and environmental resources, economic systems as well as political and cultural factors to be the main causes of inequalities, disparities in resource access and discrimination on the basis of status, residence, gender and ethnicity among others. It also identifies food security as a national security issue as articulated in Article 231 (1) of the Constitution of Kenya (the right to free from hunger, to have adequate food of accepTable quality and uninterrupted supply of clean and safe water in adequate quantities at all times). The policy also emphasizes on promotion and support of sustainable land, irrigation and water management as one of the ways of increasing diversified food production. It also supports measures that can improve food security and access to land and water resources to all Kenyans; by taking necessary measures to enable the vulnerable groups have access to land use and water; and the accruing benefits. The policy also proposes increased funding for irrigated agriculture expansion in line with Vision 2030. In addition, the policy calls for review of the regulatory framework governing the land and irrigation subsectors for enhanced productivity and development.

Ministry of Agriculture Strategic Plan (2008 – 2012). The Ministry of Agriculture Strategic Plan outlines in the outset that one of the key functions of the ministry is to promote management and conservation of the natural resource base for agriculture. Hence soil and water being natural resources, it implicitly means that they are embedded in this core function. The mission statement also clearly outlines the importance of appropriate policy, environment, effective support services and sustainable natural resource management. In the strategic mission and objectives, promotion of sustainable land use and conservation of the environment is also one of the key strategic objectives.

Economic Recovery Strategy for Wealth Creation and Poverty Reduction (ERS). ERS envisages viable interventions to reverse alarming environmental deterioration and natural resource degradation. It recognizes that one of the serious challenges the country faces is mismanagement and uncontrolled profiting at the cost of the environment. Soil and water being natural resources, the policy therefore implicitly recognizes the importance of ILWRM.

Strategies for Revitalization of Agriculture (SRA). One of the key objectives of SRA is improvement of land, water and environment management. This therefore shows the importance that the document implicitly lays on ILWRM. SRA created Agricultural Sector Coordination Unit (ASCU) whose one of the key functions is integration and harmonization of operations of departments as well as programmes in the sector ministries.

Kenya Forest Services Strategic Plan 2009/10 – 2013/14. The KFS strategy aims at contributing to sustainable land use through soil, water and biodiversity conservation and tree planting. This therefore implies that the strategy embraces sustainable land and water resources management. The plan also has a strong component of sectoral integration and community participation for sustainable forest resources management.

Vision 2030. Kenya Vision 2030 is the latest long-term development blueprint for the country. The Vision is anchored on three key pillars: Economic; Social; and Political Governance. The economic pillar aims at achieving an economic growth rate of 10% per annum and sustaining the same till 2030 in order to generate more resources to address the Millennium Development Goals (MDGs). The vision indicates that some of the strategies of achieving the established targets is by coming up with land use polices for better utilization of high and medium potential lands; and developing more irrigable areas in arid and semi-arid lands for both crops and livestock; among others. Its main thrusts include transforming land use through improved land use policies.

Agricultural Sector Development Strategy (ASDS) (2010 – 2020). In 2004, the Government developed and launched the SRA as a follow up and response to the successes of ERS. With most SRA targets achieved by 2007, SRA was revised to capture new developments, thus coming up with ASDS. The ASDS expresses the need for strong partnerships and stakeholders participation among the sector ministries and private sector, hence the sustainability and strengthening of ASCU for sector wide coordination. The main challenges identified include insufficient water storage infrastructure, with water harvesting and storage infrastructure development identified as the main strategies to overcome this. ASDS also indicates that there is potential to increase productivity and the main areas outlined for this include better use of unused land in traditional farming areas, and through irrigated agriculture. Inappropriate land-use practices and environmental policies that have encouraged land fragmentation, cultivation of river banks, deforestation and encroachment into catchment areas and wetlands are also indicated as some of the existing challenges for improved agricultural productivity.

Discussions

The results indicate that different strategic documents and policies have embraced and incorporated ILWRM issues at different levels and in different ways. The National Land Policy (NLP) is very explicit on the land question that has been an issue in the country for a long time. It also takes a robust position on how land in the country would be utilized in an equiTable way for improved access and hence improved productivity. NFNSP takes the human rights perspective to access to land and its utilization. Its effective implementation will therefore lead to improved land and water management for improved food and nutrition security. In the context of Ministry of Agriculture Strategic Plan **(Author, year)**, the mission statement and strategic objectives, sustainable soil and water management is outlined as one of its core functions, hence, it can be argued that integrated land and water management is an important component of the ministry, though the extent of integration in terms of sectoral, view points/aspects or technological integration is not clear. In the case of ERS, the emphasis is on interventions that would reverse environmental deterioration and natural resources degradation, hence explicitly recognizing the importance of sustainable natural resources management, though not explicit on viable ILWRM interventions and strategies for sustainable NRM. Improvement of land, water and environment management being one of SRA's key objectives implies the importance it attaches to ILWRM. However, it is not explicit on exact processes that will need to be taken to achieve this and although explicit in the policy document it may be different at the implementation level. ASCU has integration and harmonization of operations for agricultural sector ministries as a key objective, hence an important policy statement in that it would enhance sectoral integration and a more harmonized ILWRM across sectors, projects and programmes.

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In the outset, Kenya Forest Services Strategic Plan **(Author, year)** aims at contributing to sustainable land use through soil, water and biodiversity conservation. Hence, it can be argued that if its spirit is translated into action, it would incorporate ILWRM strategies that would enhance sustainable forest resources and natural resources management. The recognition of the importance of working with stakeholders and community participation in management of the forests resources also creates an enabling policy environment for sectoral and partnership integration. With Vision 2030 having its main thrusts being transforming land use through improved land use policies; it implies that issues related to ILWRM are well embedded in the document. What is crucial in this context is to follow up on the specific projects and

programmes under these thrusts to find out to what extent are the ILWRM issues are incorporated. In the context of ASDS, its organizational structure from the national to the grassroots level creates strong sectoral integration both horizontally and vertically with envisaged high level of participation of other non-state actors, providing enabling environment for ILWRM. **Alt**hough use of unused land in traditional farming areas and irrigated agriculture are outlined in the document as some of the areas that can be exploited to increase productivity, ILWRM is not included as a strategy that can increase production of both traditional and non-traditional commodities in irrigated agriculture in both medium altitude and ASALs. Hence, it can be argued that this omission implies inadequate attention was paid in terms of ILWRM and its potential to increase productivity. In addition, ASDS identifies inappropriate land-use practices and environmental policies as some of the existing challenges for improved agricultural productivity. However, lack of appropriate ILWRM strategies and low adoption of the same may have also contributed to inappropriate land-use practices though not mentioned. Hence, it may imply the development strategy is not appreciating the important role that adoption of appropriate ILWRM strategies can play in improving land use practices.

Although ILWRM would be an important strategy in improving land use and crop production, and integrated development and management of rangelands, it is not featuring as a proposed intervention in ASDS, implying the development strategy may be underestimating the importance of ILWRM in this aspect. Although it indicates that managed and developed watersheds can contribute to sustainable water flow and availability, it does not mention integrated water resources management though an important component of water resources and irrigation development, particularly where water availability is limiting. However, the proposed multi-sectoral approach to irrigated agriculture is important for ILWRM because it brings all the relevant sectors on board while embracing stakeholders' participation.

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Conclusion

This review shows ILWRM issues are broadly incorporated in most policies but with some variances, with the recent ones like NLP, Vision 2030, NFNSP and Forestry among others having more embedded issues of ILWRM. The analysis also shows that most of the policies and strategic documents that have been reviewed like NLP, NFNSP, Forestry, ERS and SRA that are more recent appear to be embracing issues of sustainable soil, water, land and environmental management compared with the old documents. It is also shown that the NLP has taken a radical position on land rights, past and present land injustices, and access to land by vulnerable groups, which is a landmark shift from the past policies and hence if well implemented may be able to address the land question for improved access and productivity

However, from the context of the three ILWRM perspectives, most of the policies and strategic plans appear to be weak. At the same time, most of the policies and strategic plans that have been reviewed lack specifics on ILWRM strategies and issues but are 'clouded or believed' to be embedded in soil, water and environmental conservation. None of the policies or strategic documents that have been reviewed, that has clearly embraced the three perspectives of ILWRM (sectoral, view points/themes and technological integration). They either put a lot of weight in one while leaving out the other two. The thematic (social, economic, cultural and political) and technological (water harvesting, terracing and soil fertility, among others) integration have been poorly addressed in all the policy documents, except forestry strategic plan where social, ecological and economical perspectives / approaches have been well spelt out. Also, most of the documents highlight "stand alone" technologies like water harvesting, water storage and irrigation infrastructural development as the panacea to challenges of land and water availability and management. Thus, under estimating the role and synergies of incorporation of other technological interventions like adoption of appropriate crops for specific regions, soil fertility technologies, micro-dosing and agroforestry for sustainable NRM / ILWRM. Except for NLP, ASDS and Vision 2030, most of the policies and strategic plans that were reviewed focus on a specific sector without incorporating other relevant sectors and non-state actors that are important in ILWRM.

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Recommendations

ILWRM is important for improved natural resources management and agricultural productivity; hence, it is important to incorporate ILWRM issues more explicitly in the country's policies and strategic plans. This will create an enabling environment for sectoral, thematic and technological integration for improved agricultural productivity. It is also recommended that an enabling legal framework is put in place to ensure that the policy frameworks are effectively implemented and offenders appropriately sanctioned. Further, there is need to critically review and analyze the extent of policy implementation so as to identify and remove any disconnects and gaps for improved policy consumption. Dialoguing and sharing with policy makers and implementers on the importance of incorporation of ILWRM issues in the policy documents will also be crucial if ILWRM has to play its important role in agricultural productivity.

Acknowledgement

The authors of this paper sincerely acknowledge the funding from ASARECA / World Bank, through KARI, that enabled us to accomplish this study. We are also thankful to KARI Director, Centre Directors KARI-Katumani, Embu and Marsabit for the facilitation and all the logistical support that they extended to us while implementing this work. The many key informants and heads of departments in various ministries that accorded us a hearing and provided us with the materials, we salute you all. We also thank Mr. Kwena Kizito for bringing us on board to work on the policy component of the Integrated Watershed Management project..

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Notes:

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NLP, 2011

SRA, 2004

Citations and references by same author in one year have to be differentiated by inserting a, b, c against he year of publication, e.g. Government of Kenya (2008a), Government of Kenya (2008b), Government of Kenya (2008c); and these have to be listed in the same way!

Characterizing access to climate information and services by the vulnerable groups in semi-arid Kenya

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Abstract

Women and the elderly living in semi-arid environments of Kenya are vulnerable to the frequent exposure to impacts of changing climate and need to access climate information and services to build their adaptive capacity. This study characterised the channels through which the vulnerable people in a semi-arid area of Kenya access climate information and services from data collected from randomly selected sample in cross sectional survey using structured questionnaire. Over 70% of both women and the elderly perceived change in rainfall, drought, floods, human and livestock diseases to have been "severe" to "very severe" over the last five years. Majority of women (88.5%) most preferred radio while the elderly (83%) most preferred indigenous knowledge to access climate information and services. Women consistently rated radio higher ($P<0.05$) than the elderly for delivering reliable information, explaining details and use of local language understood to them. However, Principal Component Analysis (PCA) indicated that comprehensive informing on climatic hazards and support services for adaptation to changing climate is from extension service unlike the other channels which delivered information only on climatic hazards. The study concluded that combination of extension agents, radio and local administration would be more effective for disseminating climate information and services to vulnerable people in marginal areas. Capacity building for extension service is needed in interpretation of weather data to enable them effectively disseminate climate information and services to vulnerable people of arid and semi-arid environments.

Key words: dissemination, vulnerable groups, climate information, marginal areas

Introduction

Climate change is associated with increase in temperature and heat stress, more frequent droughts and intense flooding, windstorms and disease outbreaks (IPCC, 2001). These climatic hazards are projected that will have greatest impact on livelihoods in semi-arid environments of sub Saharan (Thornton *et al*, 2006). The vulnerability of livelihoods to impacts of climate change depends on the extent of exposure, sensitivity and adaptive capacity of the people affected (IPCC 2001). More than 70% of people living in the semi-arid areas are highly dependent on climate sensitive natural resources and agriculture for their livelihoods (Siri *et al*, 2008). The concern is that they may not be adequately empowered to respond and adapt to the magnitude of climate changes projected (Boko *et al.*, 2007).

Climate information and services play a critical role in providing Early Warning Systems (EAS) as well as increasing awareness for building the capacity and disaster preparedness to a changing climate. Choice of the dissemination channels can influence access and use of climate information and service disseminated to enable the vulnerable groups exposed to climatic hazards build adequate response capacities. Climate information and services relevant to adaptation in semi-arid areas include early warning signals, weather forecasts, food aid distributions, emergency guidelines, and financial support, medical and veterinary assistance.

Though the people living in semi-arid environments are in most need of access to climate information and services, they are yet to experience the full benefits of climate research, information and services to enable them effectively cope and build adaptive capacity to the changing climate (O'Brien *et al.,* 2008). Harvey *et al.,* (2009) expressed concern that information sharing among climate change actors in Africa is limited and

may be worse in semi-arid environments due to barriers of poverty, lack of infrastructure, illiteracy and socio-economic factors. Limitations also exist in the information delivery mechanisms in terms of reliability, timing, infrastructural development and even language (Chamboko *et al*., 2008).

In Kenya, the Meteorological Department (KMD) disseminates climate forecasts using different channels such as mass media, print media and the internet. Arid Lands Information Networks (ALIN) on the other hand, disseminates climate related information to people in semi-arid areas through use of Information and Communication Technologies (ICTs) (Nguo *et al*., 2005). Effective access by the vulnerable people especially women and the elderly in semi-arid Kenya to these dissemination channels has however not been evaluated empirically. The objectives of this study were specifically to:

- Determine perception of the vulnerable people about impacts of climate change that have experienced most in the last five years
- characterize the patterns of climate information and services that vulnerable people access,
- Identify the dissemination pathways that the vulnerable people in a semi-arid environment perceive most useful for delivering climate information and services to them,
- Determine the user-friendly attributes of those dissemination pathways for delivering climate information and services to vulnerable people in a semi-arid environment

Materials and methods

Conceptual framework

Access to climate information and services is necessary for coping, adaptation and mitigation strategies necessary in the face of changing climate. Figure 1 presents the conceptual framework adapted for this study, illustrating the hypothesized flow of climate information and services to vulnerable people. Underlying assumption is that vulnerable people can effectively access climate information and services if disseminated through channels which are accessible and effective with user-friendly attributes. The pathways through which climate information and services are disseminated include mass media, print media, electronic media, and contact with informed people. Those employing these pathways include researchers, meteorological departments, development agencies and indigenous knowledge systems. The attributes can influence information that users access such as timeliness, accuracy, reliability, ease of use, depth of content.

Study site

The study was in Marigat Division, a semi-arid environment experiencing frequent exposure to climate variability within areas identified as hotspots of climate change (Thornton *et al*., 2006). Rainfall is highly variable which makes both livestock keeping and crop production very risky, due to water and pasture shortage. Households here are agro-pastoralists who experience prolonged droughts with frequent cases of flooding during rains and outbreaks of human and livestock diseases (GoK, 2001). Frequent exposures to climatic hazards cause famine alerts and poverty and there is competition for scarce natural resources contributing to the area being conflict-prone (Mango *et al*., 2004). Five locations in the area most prone to impacts of climate variability were selected for sampling the vulnerable women and the elderly.

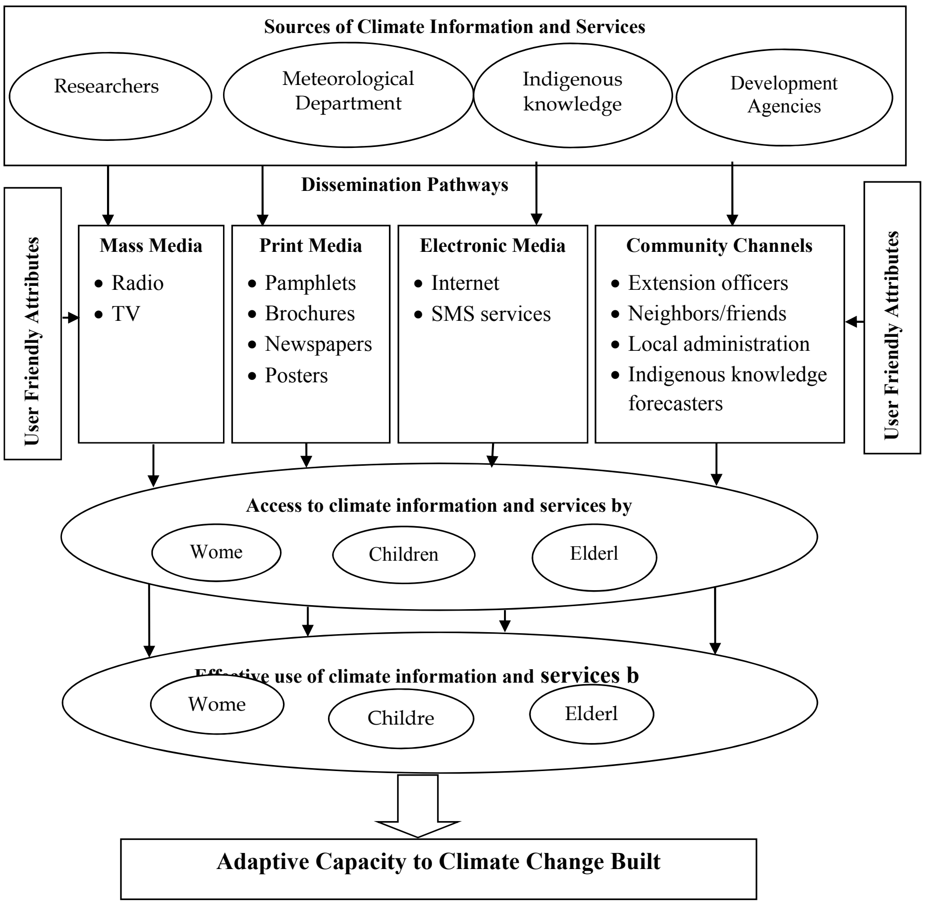

Figure 21: Conceptual framework on dissemination pathways of climate information and services to vulnerable people

Research design and data collection

Data required was obtained in a cross-sectional survey in which simple random sampling technique was applied to obtain a sample of representative vulnerable women and the elderly. Women sampled were those within the age group of 24 to 60 years old considered vulnerable because they are married and shouldering household chores and have to provide food for the family under impacts of climatic hazards. The elderly were both males and females aged at least 65 years old considered vulnerable because of old age yet exposed to climatic hazards. The local administration chiefs and agencies involved in food assistance program within the area facilitated identification of the individual vulnerable women and the elderly people within their administrative areas.

A structured questionnaire was administered to women and the elderly respondents to obtain data on their experiences in the past five years about impacts of climate change, dissemination channels through which they climate change and information and services, their preferences for each of the channels and user-friendly attributes of those channels to them. For each dissemination channel accessed, respondents rated on a Likert scale of 1 to 5 (1 = low to 5 = high) the climate information and services accessed, preferences and user-friendly attributes.

Data analysis

For each dissemination channel, Principal Component Analysis (PCA) was performed on type of climate information and services often accessed. PCA is a statistical approach (Cattell, 1978) for removing redundant information from correlated variables to represent the original variables with a smaller set of derived variables called principal components. The method was relevant for this analysis because the variables of interests were highly correlated. The derived principal components (PCs) are uncorrelated and account for most of the total variation contained in the variables fitted in the model.

Preferences of the vulnerable people were evaluated through cross tabulation in order to obtain chi square statistics for detecting proportional differences. The Likert scale measures of preferences attached to specific attribute of a dissemination channel were subjected to Kruskal Wallis test and where differences were detected, Mann U Whitney test was applied for pairwise comparisons. Instead of median and mean ranks outputs from the non parametric statistics, mean score for each attribute is presented to ease interpretation of the results.

Results and discussion

Characteristics of the sampled vulnerable people

The age, education, livelihood source and income levels of the sample vulnerable people are summarized in Table 1. About two thirds of (66.7%) of the elderly people lived on less than one dollar a day (1 US $ = KES 80) while about a similar proportion of women (63.3 %) lived less than two dollars a day, indicating high poverty incidences. Majority (64.7%) of the women and the elderly had attained only primary level of education, reflecting low literacy levels, which can be a barrier to effective access and use of early warning systems and climate forecasts disseminated through reading materials and in non local language. The major source of livelihood was rain-fed agriculture supplemented with remittances which provides important supplemental income that vulnerable people can spend in emergencies related vulnerability to climatic variability and shocks.

Table 1: Age, education, livelihood source and income levels of the vulnerable groups

Social characteristics	Women	Elderly	Statistics
Age (years)	37.7 ± 9.3	69.5 ± 5.7	t value 828.75***
Education			
Without formal education (%)	42.9	79.2	χ^2 value=1.26***
With primary level (%)	44.8	12.5	
With secondary level (%)	7.8	4.2	
With post-secondary level (%)	4.5	4.2	
Livelihood source			
None (%)	0.6	-	χ^2 value = 3.98***
Farming (%)	98.7	62.5	
Remittances (%)	-	37.5	
Casual labor (%)	0.6	-	
Income Level			χ^2 value = 3.26***
< $ 1/ day (%)	26.6	66.7	
< 2 $ / day (%)	63.0	29.2	
< 2-5 / day (%)	10.4	4.2	

*** Significant at P= 0.000

Perception about climate change

Figure 2 illustrates perception of the vulnerable people about impacts of climate change as having been 'severe' to 'very severe' in the last five years. Over 70% of both women and the elderly perceived change in rainfall, drought, floods, human and livestock diseases to have been "severe" to "very severe" over the last five years. They associated these changes with failure and destruction of crops and property and loss of human lives and livestock and frequent famine.

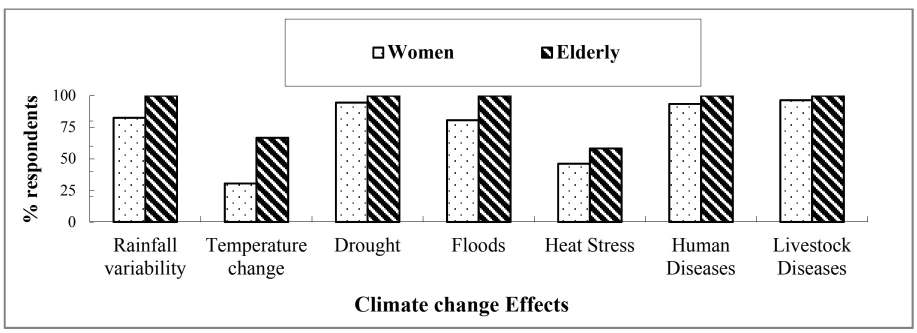

Figure 2: Perception of the vulnerable people about impacts of climate change as having been 'severe' to 'very severe' in the last five years

Patterns of climate information and services that vulnerable people access

Principal component analysis (PCA) was used to characterise climate information and services that the vulnerable people access through radio, extension agents, local administration and indigenous knowledge (Archer, 2003). . The rotated correlation coefficients associated with the Principal Components (PCs) extracted is explained on the basis of magnitude of the factor loading coefficients (≥ ± 0.30). The positive

coefficients indicate positive association while negative coefficients indicate negative association. For each PC, variables with the largest pattern coefficient make the largest contribution in explaining the total variation there is in the data.

Climate information and services accessed through radio

Table 2 shows PCA of the model fitted for radio. The model had goodness of fit from Bartlett's test of sphericity (Chi-square = 962.06; df =120; P value 0.000; KMO = 0.60). Seven principal components (PCs) were extracted which explained 69% of the total variance. The PC1 which explained most of the variance (17.06 %) indicate that through radio, vulnerable people mostly access information about diseases and rainfall variability and is thus labelled climate hazards information specific.

Table 2: Rotated correlation coefficients factor patterns for radio

Climate Information and services	Factor loadings						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Climate related livestock diseases	0.92						
Climate related human diseases	0.90						
Rainfall variability	0.31						
Drought		0.88					
Floods		0.86					
Veterinary services			0.73				
Human health services			0.71				
Adaptation technologies			0.57				
Relocation to safer places			0.54				
Heat stress				0.86			
Wind storm				0.87			
Early warning signals					0.76		
Weather forecasts					0.75		
Food aid						0.81	
Temperature change						0.45	
Financial support							0.83
Variance explained (total 69%)	17.06	11.22	10.50	8.92	7.76	7.06	6.52

Climate information and services accessed through extension services

The PCA results of the model fitted for extension agents presented in Table 3 had goodness of fit from Bartlett's test of sphericity (Chi-square =498.550, df =28; P value = 0.000, KMO =0. 715). Four PCs accounting for 62.35% of the total variance were extracted of which PC1 explained more than half (38.91%) of total variance. The largest contribution was from climate information and services accessed on drought, floods, diseases, early warning signals, veterinary and medical services, food aid and relocation of vulnerable people to safer places. The loadings indicate that through extension service, vulnerable people access comprehensive information on climatic hazards and support services. This can be labelled climate hazards with support adaptation responses. The results suggest that extension agents are very effective in reaching the vulnerable people with climate information and services that are necessary for building adaptation. Extension agents have regular contacts with rural farming community and in this sample, 98.7% women and 62.5% elderly people were engaged in farming activities. Though extension service can be effective in disseminating climate information and services in the semi arid and arid areas with marginalised infrastructural development, Ziervogel and Opere (2010) has warned that the agents are unable to interpret seasonal climate forecasts presented in probabilities. Capacity building is therefore necessary to enable extension agents understand weather reports.

Table 3: Rotated correlation coefficients factor patterns for extension services

Climate Information and Services Variables	Factor loadings			
	PC1	PC2	PC3	PC4
Climate-related human diseases	0.86			
Climate-related livestock diseases	0.83			
Adaptation technologies	0.81			
Floods	0.71			
Early warning signals	0.68			
Drought	0.67			
Relocation to safer places	0.64			
Veterinary services	0.64			
Human health services	0.58			
Food aid	0.46			
Heat stress		0.85		
Windstorm		0.82		
Rainfall variability		0.57		
Weather forecast			0.69	
Temperature change			0.01	
Financial support				0.81
Variance explained (62.35%)	38.91	9.39	7.42	6.62

Climate information and services accessed through local administration

Local administration is important in information dissemination in semi arid and arid areas where communication infrastructure is underdeveloped. The PCA results for climate information and services that the vulnerable people access through the local administration extracted seven PCs (Table 4) accounting for 62.79% with a model showing goodness of fit for the data fitted (Bartlett's test of sphericity (chi-square =562.700, df =28, P=0.000 and KMO =0. 540**)**.

The rotated correlation coefficients loading on PC1 explained 14.01% of the variation with largest contribution from information about climate-related diseases of both human and livestock. This reflects greater concentration on diss**e**minating disease information, hence labelled climate-induced disease information specific. Local administration includes local chiefs and village elders, often used by the government agencies to communicate with the grass root people through monthly village meetings "Baraza's".

Climate information and services accessed through indigenous knowledge informers

PCA results for climate information and services that vulnerable people access through indigenous knowledge informers are represented in Table 5. Seven PCs were extracted accounting 77.11% of the total variance. The model had a goodness of fit (p=0.000) Bartlett's test of sphericity (chi-square = 3130.244, df =120 and KMO =0. 559**)**. The factors loading on PC1 explain 19.58% of the total variance with most contribution from information on drought and floods. This is therefore labelled climatic hazards specific. Community members indicated that they were able to make predictions using various indicators while some of the elderly were recognized "experts", diviners, seers and even rainmakers. The elderly compared to the women were more sceptical about modern information probably because they do not understand them easily.

Table 4: Rotated correlation coefficients factor patterns for local administration

Climate Information and Services Variables	Factor loadings						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Climate related human diseases	0.84						
Climate related livestock diseases	0.84						
Floods		0.88					
Drought		0.85					
Temperature change			0.82				
Rainfall variability			0.80				
Food aid				0.68			
Veterinary services				0.61			
Human health services				0.60			
Early warning signals					0.66		
Relocation to safer places					0.62		
Weather forecast					0.58		
Windstorm						0.74	
Heat stress						0.72	
Financial support						0.43	
Adaptation technologies							0.84
Variance explained (62.79%)	14.01	9.62	9.41	8.58	7.65	7.14	6.39

Table 5: Rotated correlation coefficients factor patterns for indigenous knowledge informers

Climate Information and Services Variables	Factor loadings						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Drought	0.99						
Floods	0.99						
Veterinary services		0.93					
Human health services		0.92					
Early warning signals			0.98				
Weather forecast			0.98				
Climate related livestock diseases				0.96			
Climate related human diseases				0.95			
Rainfall variability					0.84		
Temperature change					0.83		
Relocation to safer places						0.77	
Adaptation technologies						0.76	
Heat stress						0.43	
Food aid							0.80
Windstorm							0.65
Financial support							0.33
Variance explained (77.12%)	19.58	13.28	12.41	9.64	8.45	7.31	6.46

Preferences of vulnerable people for the dissemination pathways

Results in Table 6 presents respondents' preference for the channels through which vulnerable people access climate information and services measured as never, seldom, sometimes, often or most preferred. Only the last two measures are presented hence the proportions indicated do not add up to hundred percent. Radio was the preference of a large majority of women (88.5%) while indigenous knowledge was the preference of the elderly (83%). In the study area, radio broadcast are in vernacular language so the news about climate information and services are easily understood by the vulnerable people. Extension service and indigenous knowledge were the next preferred channels for access climate information and

services by both women and the elderly. Hansel *et al* (2007) argues that radio and ICT-based communication offer immense potential to support the delivery of climate information services; but cannot replace the trust, visual communication of location-specific information, feedback and mutual learning that face-to-face interaction provides. Therefore extension service and indigenous knowledge can be utilized if key informants at the village level are identified and trained in interpreting weather data.

Table 6: Preferred Dissemination pathways by the vulnerable groups

Dissemination Pathway	Vulnerable Group	Sample (n)	Preference Rating (%)		Chi square Statistics
			Often preferred	Most preferred	
Radio	Women	154	24.0	68.8	χ^2 = 72.81 **
	Elderly	24	41.7	4.2	
Local Administration	Women	154	63.7	24.7	χ^2 = 31.58**
	Elderly	24	58.3	37.5	
Indigenous Knowledge	Women	154	59.1	32.5	χ^2 = 1.83**
	Elderly	24	16.7	83.3	
Extension Agents	Women	154	85.0	5.5	χ^2 = 1.77**
	Elderly	24	58.3	41.7	

** Significant at P = 0.00

User-friendly attributes of the dissemination pathways accessed by the vulnerable groups

Table 7 presents means of preference rating by the vulnerable people on a scale of 1 (very poor) to 5 (excellent) for user-friendly attributes of the channels for delivering climate information and services in a semi-arid environment. User-friendly attributes were rated on the basis of cost, timeliness, details, reliability and language from the perspectives of the respondents. Both women and the elderly expressed equally preferences for the attributes of the channels through which climate information and services are disseminated, except for ($P<0.05$) radio regarding information reliability, detail and language used in which the elderly consistently rated lower than women.

Table 7: Mean ratings for user-friendly attributes (1=very poor 5= excellent) of the dissemination Channels by the vulnerable people

Channels	Group	Cost	Timeliness	Detailed	Reliability	Language
Radio	Women	3.43 ± 0.68[a]	2.74±0.61[a]	2.88 ± 0.62[a]	2.66 ± 0.63[a]	4.03 ± 0.51[a]
	Elderly	3.17 ± 038[a]	2.50±0.51[a]	2.33 ± 0.51[b]	2.21 ± 0.51[b]	3.17 ± 0.38[b]
Extension	Women	3.09 ± 0.97[a]	2.73 ±0.61[a]	3.07 ± 0.53[a]	2.75 ± 0.56[a]	3.33 ± 0.53[a]
	Elderly	3.46 ± 0.51[a]	2.20 ±0.68[a]	3.00 ± 0.58[a]	2.00 ± 0.59[a]	3.67 ± 0.48[a]
Local Administration	Women	3.97 ± 0.47[a]	3.81 ±0.44[a]	4.04 ± 0.61[a]	3.99 ± 0.67[a]	4.62 ± 0.58[a]
	Elderly	3.79 ± 0.51[a]	3.67 ±0.48[a]	3.83 ± 0.38[a]	3.79 ± 0.42[a]	4.58 ± 0.50[a]
Indigenous knowledge	Women	3.71 ± 0.78[a]	3.64 ±0.51[a]	3.96 ± 0.52[a]	3.77± 0.59[a]	4.56 ± 0.58[a]
	Elderly	3.75 ± 0.68[a]	3.67± 0.36[a]	4.21 ± 0.51[a]	4.25 ± 0.61[a]	4.39 ± 0.41[a]

[ab] = means with different letter superscripts in a column differ significantly at α=0.05

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An assessment of crop, and soil and water management practises of smallholders in different climate scenarios of Zimbabwe

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Abstract

Food security and livelihoods of smallholders in sub-saharan Africa can be improved through suiTable strategies for handling climate-induced risks. Current projections suggest mainly negative effects of warmer climates on smallholder agriculture by the 2050s. Assessment of farmer practises in different smallholder areas can inform climate policy for effective adaptation smallholdeder to current and future climates. The objective of this paper was to outline the use of climate analogues in identifying adaptation options for current and future climates in wetter and drier smallholder areas in Zimbabwe. Climate analogue pairs selected for wetter sites were Mazowe/Goromonzi districts (cooler) and Kadoma district (warmer) and for the drier sites Matobo district (cooler) and Chiredzi district (warmer). Chiredzi was hypothesised to represent Matobo 2050s climates, and Kadoma was hypothesised to represent Mazowe/Goromonzi 2050s climates. Data on farming practises was collected through a structured questionnaire administered to a total of 627 respondents. Crops grown during the 2010/2011 season and soil and water management options used by farmers were compared between analogue pairs and between differently managed households. These were no differences in crops grown, and soil and water management strategies choices of male and female headed households. At the wetter sites the main crops grown were maize and groundnut. At the drier sites the main crops grown in Matobo included maize, groundnut, bambara nut and cowpea, and in Chiredzi maize, sorghum, groundnut, bambara-nut, cowpea, pearl millet. The main soil and water management startegies used at the wetter sites Mazowe/Goromoni district, Kadoma included conservation agriculture and mulching. Low proportions of households in Chiredzi (the drier, warmer site) compared to the other sites used soil and water mangent technologies Implications are that for current wetter climates in Zimbabwe, soil and water management stragegies are important options for smallholders while crop choices will important for drier sites in warmer 2050s climates.

Key words: climate change, adaptation, crop choices, soil and water management

Introduction

According to some climate models, temperature increases of about 3°C and ± 5 % to 15% changes in mean annual precipitation are projected for the sub-Saharan African region by the mid-century (Hulme *et al.,* 2001; Christensen *et al.,* 2007). The impacts of warmer 2050s climates on crop yields are projected to be mainly negative (Schlenker and Lobell, 2010, Zinyengere *et al.,* 2014). Some direct effects of climate change on crop production include increased evapo-transpiration, heat stress and shorter growing seasons. Decreased yields due to climate change may in turn affect food security and livelihoods. Smallholder farmers, who already experience low productivity due to socio-economic and biophysical challenges, are particularly vulnerable to climate change effects. Identifying adaptation options through better understanding of perceived risks and opportunities, and mainstreaming gender issues, specifically for women, is important for climate change planning and adaptation.

Smallholders in Zimbabwe, like in most of sub-Saharan Africa, mainly depend on rain-fed agriculture. Most smallholders are poorly resourced and productivity on their farms is usually low (e.g. FAO/WFP 2010; Chimhowu *et al*. 2009; Ministry of Agriculture 2007; 2012). They manage environmental stresses through use of different strategies that include use of tolerant crops and various soil and water management strategies that include use mulching and reduced tillage methods and soil fertility management. Choices of management strategies and technology adoption is influenced by bio-physical characteristics such as rainfall (Amsalu and de Graaff, 2007) as well as socio-economic characteristics of the farmers such as resource status, gender of head of household (e.g. Mazvimavi and Twomlow, 2009) and supporting institutions (e.g. Chhetri *et al.*, 2012) among other factors. Therefore farmers need to enhance capital assets for sustainability production. Smallholder systems are diverse; livelihood options, gender roles, capital assets as well as climate induced-risks differ and thus require different management strategies.

Increasing options for improved livelihoods for current and future climates in different smallholder areas requires an integration of methods that mainstream gender issues and include multi-stakeholder processes. Building on existing knowledge and farmer practices enables progressive adaptation (Cooper *et al*., 2008) to climate change. Climate analogue analysis can assist in assessing climate-induced risks and their interaction with other capital assets of the smallholder farmers. Spatial temperature analogue models assume that cooler regions will behave like the patterns observed in other regions currently with warmer climates if they were subjected to a climate-induced shift (Burke *et al*., 2009). Burke *et al*. (2009) demonstrated the existence of analogues for 2050s growing season temperatures for maize, millet, and sorghum in several African countries. It was on the basis of the existence of climate analogues in Zimbabwe and the need for progressive adaptation to climate change that this study was carried out.

This study was conducted in the framework of the Adapting agriculture to climate change: Developing promising strategies using analogue locations in Eastern and Southern Africa" (CALESA – Climate Analogue Locations in Eastern and Southern Africa) Project implemented by ICRISAT through on-station and participatory approaches. The participatory approach sought to characterise farming systems and document smallholder farmer perceptions. This paper outlines the use of climate analogues and farmer practices in assessing adaptation options for current and future climates of smallholder areas in Zimbabwe. It hypothesizes that crop choices and soil and water management technologies choices of smallholder farmers differ by climate and by gender of head of household.

Methodology

Site selection

Four sites representing two analogue pairs representing semi-arid and semi-humid agricultural areas in Zimbabwe were selected. The selection was based on average of mean annual temperature and mean annual rainfall of 30 years climatic data from the Zimbabwe Meteorological Services Department (ZMSD). Analogue pairs with similar average annual temperature and mean annual temperature differences of at least 2-4^{o}C consisted of Mazowe/Goromonzi (Reference site) and Kadoma (analogue site) representing wetter sites and, Matobo (cooler) and Chiredzi (warmer) representing the drier sites. Soils at the study sites consisted mainly of sands and sandy loams in Matobo, Kadoma and Mazowe/Goromonzi sites. Sandy soils are associated with poor water holding capacity and low fertility.

Data collection

Quantitative and qualitative data were collected through household interviews as well as key informant interviews. The household survey was conducted from July 2011 until September 2011. Selection of respondents involved multi-stage processes. Firstly, at least three wards were purposefully selected at each site to include smallholder areas and old resettlement areas only. In each ward a minimum of 150 respondents, and at least 30% representing female-headed households were interviewed. Data collected using semi-structured questionnaires included crops grown during the 2010/2011 cropping season, quantitative information on soil water and fertility management technologies used by farmers and qualitative information. Proportions of households who use each soil and water management technique

were compared between analogue pairs and between differently managed households at each site using the chi-square test.

Table 1: Description of selected sites

Surveys districts	Characteristics	Mean annual T°C	Mean annual Rainfall (mm)	Soil types
Matobo	Cool/dry (reference)	18.4	567.1	Greyish brown sands
Chiredzi	Hot/dry (analogue)	21.3	541.2	Heavy clays, vertisols, sands, sandy loams
Difference		2.9	-25.9	
Mazowe & Goromonzi	Cool/wet (reference)	18.2	842.9	Greyish brown sands and sandy loams
Kadoma District	Hot/wet (analogue)	21.8	721.7	Greyish brown sands and sandy loams
Difference		*3.6*	*-121.2*	

Results

Of the households selected, the proportion of female households for the survey ranged from 26% (Kadoma) to 43 % (Mazowe/Goromonzi). Greater than 80% of these were *de-jure* female headed households. *De-facto* female headed households were about 17% in Chiredzi (warmer, dry), and less than 10% at the other sites. Informal discussions with females showed that male labour migration accounted for most of the *de-facto* female headed households in Chiredzi.

Crops grown at study sites during the 2010/2011 season

At the wetter sites maize was the main crop. In addition to small grains in Chiredzi, main crops grown at the dry sites of Matobo and Chiredzi were maize, groundnut and cowpea (Table 2). There were differences in the range of crops grown by female headed households compared to male headed households.

Soil and water management strategies used by households

The identified differences in soil and water management uptake and usage within and across analogues, are shown in Table 3.

In general, higher proportions of households from wetter sites use soil and water management strategies compared to those from the drier sites. The proportion of households that used reduced tillage methods such as conservation agriculture, tied ridges and winter ploughing, was higher in higher in Kadoma district compared to Mazowe/Goromonzi district, and in Matobo district compared to Chiredzi districts. There was higher use of tied ridges and contour ridges in Mazowe/Goromonzi compared to Kadoma. There were no gender differences in soil and water management strategies used in male-headed households compared to female-headed households. Soil fertility usage was higher in Matobo, Mazowe/Goromonzi and Kadoma and lower in Chiredzi.

Table 2: Crop production characteristics at study sites during the 2010/2011 season

	Wetter pair			Drier pair		
	Mazowe & Goromonzi (cooler)	Adoma (warmer)	χ^2	Matobo (cooler)	Chiredzi (warmer)	χ^2
n	153	150		159	165	
Crops grown by >20% of households	Maize, Groundnut	Maize, Cotton, Groundnut	*N/A*	Maize, Groundnut, Bambara-nut, Cowpea	Maize, Sorghum (red, white), Groundnut, Bambara-nut, Cowpea, Pearl millet	*N/A*
Crops grown by < 20% households	Bambara-nut, Finger-millet, Sugar bean, Cowpea, Cotton, Sunflower, Tobacco, Rice, Okra	Sorghum (white), Cowpea, Bambara-nut	*N/A*	Sorghum(white, red) Pearl millet	Cotton, Sunflower, Sugar bean , Soya bean, Barley	*N/A*
Proportion maize area (%)	89.4	53.1	*N/A*	79.2	37.6	*N/A*
Households with small grains (%)	6.5	4.0	0.947	11.9	92.1	208.823***

*Significant at the 10% level; **Significant at the 5% level; ***Significant at the 1% level

Table 3: Proportion of households who have used soil and water management technologies

		Wetter pair			Drier pair		
	Strategy	Mazowe % hhds	Kadoma % hhds	χ^2	Matobo % hhds[1]	Chiredzi % hhds	χ^2
	n	153	150		159	165	
1. Soil and water	Reduced tillage	52.9	82.7	30.869***	53.5	9.1	74.700***
management	Mulching	60.8	64	0.334	28.9	15.2	9.7868
	Contour ridges	32.7	4.7	38.917***	47.2	27.7	14.648***
	Tied ridges	11.8	21.3	5.033*	11.9	3.6	7.859**
	Winter ploughing	3.3	14.7	12.988**	10.7	1.2	13.181***
	Water harvesting	5.9	2.7	1.907	3.8	2.4	0.493
	Pot holing	6.5	0.7	7.458*	0.6	5.5	6.304*
	Multiple weeding	0	0	-	1.3	4.8	3.490
	Gulleys	3.3	0	-	0.6	1.8	-
2. Soil fertility	Chemical fertilizer	99.3	96	3.758	89.9	4.8	235.584***
management	Animal manure	85.6	75.3	5.678	73	25.5	73.397***
	Compost	73.2	64	2.980	71.1	17.6	94.374***
	Crop rotation	54.2	63.3	2.580	35.2	25.5	3.660

*Significant at the 10% level' **Significant at the 5% level; ***Significant at the 1% level; [1]households

Discussion and lessons learned

This study hypothesizes that crop choices and soil and water management technologies choices of smallholder farmers differ by climate. The results from this study show that adaptation strategies for crop production with respect to crop choices and soil and water management differed between analogue pairs.

At the wetter sites implications are that crop choices will continue to be influenced by, among other factors, prevailing market forces. The importance of soil water and soil fertility management particularly at wetter sites is illustrated by high proportions of smallholder farmers who use strategies to conserve soil moisture and increase soils fertility such as use of inorganic and organic forms of fertilizer. This study showed that both male headed and female headed households used similar soil fertility and, soil and water management technologies. Tazeze *et al.,* (2012) illustrated that different socio-economic factors such as gender, age and literacy levels of the household heads, household sizes, and livestock ownership among other factors influence adaptation strategies. Increased access to agricultural resources, labour, information and inputs is required, for both male headed and female headed households, to improve adoption of various technologies for management of risks associated with climate change.

At the drier sites implications from this study are increased uptake of cereals such as sorghum and millets in Matobo and areas with similar rainfall and temperature characteristics in 2050s. Crop choices are one of the common coping and adaptation strategies employed by rain-fed smallholder farmers (Kurukulasuriya and Mendelsohn, 2008). Small grain production is associated with high labour demands for bird scaring, harvesting and processing. Meanwhile these small grains are grown in drier areas which are associated with high incidences of male labour migration. Results from in-depth interviews with the household heads and respondents showed that male labour migration accounted for higher proportions of *de-facto* female heads at the dry, warmer Chiredzi compared to Matobo and the wetter sites. In addition higher proportions of female heads who are full time farmers imply higher contribution by most rural women in domestic duties and agricultural production. Meanwhile there was lower use of soil fertility, and soil and water management strategies in Chiredzi compared to Matobo. Chiredzi farmers attributed lower use of soil fertility management strategies to high risks of crop failure due with low and erratic rainfall and high temperature. These results illustrate different climate–induced risks in current and future climates that require smallholder farmers to have increased access to different resources, skills and adaptation options for improved food security.

Conclusion and recommendations

Current and future projections on climate change and temperature increases in Africa as a whole, and in Zimbabwe in particular, means that there is a pressing need to seek adaptation strategies in agriculture, which may allow farmers to better cope with such changes. Due to a combination of lack of resources, skills and access to technologies, smallholder farmers including women, are especially vulnerable. Gender issues in climate change and agriculture differ and this suggests that context-specific approaches are needed so as to reach diverse male and female farmers.

Preliminary results show that climate analogue analysis and involvement of stakeholders such as smallholder farmers can contribute to the process of identifying adaptation options for current and future climates. At the wetter sites, implications are that in future climates there may be need for increased uptake of soil and water management strategies for Mazowe/Goromoni farmers and that prevailing market forces and household prefernces many influence crop choices. Policies are therefore required that increase access to resources that increase adoption of effective soil and water management startegies in differently managed households. These access to draft power, labour, agricultural assets, social and financial capital as well as enabling markets.

In drier areas such as Matobo district, implications are that in 2050s climates, one of the main adaptation strategies is increased uptake of drought tolerant crops such as sorghum and millet. Production and processing of small grains, against a background of male labour migration imply increased labour demands for women, in addition to their domestic and reproductive roles. Policies for such areas should promote

strategies and technologies for domestic and productive purposes with low labour requirements**.** There may also be need for increased investment for effective water management research that can easily be adopted by farmers, as well as technology dissemination for drier areas to increase productivity.

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Analysis of analytical tools for climate change impacts on agriculture in Kenya

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Abstract

Climate change poses a major threat to the environment, economic growth and sustainable development globally. Agriculture is arguably the most important sector of the Kenyan economy that is highly dependent on climate. Since the first Intergovernmental Panel on Climate Change assessment report was published in 1990, substantial efforts have been directed toward understanding climate change impacts on agricultural systems worldwide. The resulting advances have come from development of methods, models and data collection in addition to the observation of actual changes in climate and its impact. Although a large body of scientific data and models have been developed to predict the impacts of the contemporary and future climate, there is little knowledge on the level of application of the models in Kenya. The availability of such knowledge is critical for designing technologies and policies to mitigate climate change and facilitate adaptation to the changes that now appear inevitable in the next several decades and beyond. The study conducted key informants interviews to identify the analytical tools used to estimate the impacts of climate change and the level of utilization on productive sectors of the economy; namely crops, livestock, water and natural resources. The respondents were purposively selected from Universities, Research institutions and policy institutions. All respondents reported that climate change has already exerted stresses on the biophysical, social and institutional environments that underpin agricultural production. However, 77% of the respondents had not used any analytical tools to estimate the impact of climate change. on any sector of the economy; a meagre 3% used crop simulation models. This was attributed to insufficient knowledge on analytical tools that could be used to estimate the impact of climate change on major sectors of the economy and therefore requires capacity building to empower researchers and decision makers to use analytical tools that would enable them make informed decisions on the appropriate adaptation and mitigation strategies.

Key words: climate change impacts, agriculture, analytical tools.

Introduction

Climate change poses a major threat to the environment, economic growth and sustainable development globally. Sub-Saharan countries are threatened by the predicted effects of climate change because of their economic dependence on climate for development of agriculture which is the cornerstone of the economies, the basis of economic growth and the main source of livelihood (Boko *et al.*, 2007). Agriculture is arguably the most important sector of the Kenyan economy that is highly dependent on climate (GoK, 2007). The farming communities have continuously tried to get adapted to the techniques. It is therefore certain that if future climate change reduces precipitation, then it will present an additional challenge to agriculture and water resource availability which will be aggravated by existing low efficiency water-use farming techniques. This will add to the country's vulnerability due to widespread poverty, low economic and technological development that limits the adaptive capacity of its people (Herero *et al,* 2010; SEI, 2009).

About eighty percent of Kenya is arid and semi-arid (GOK, 2010). Non-irrigated agriculture dominates these areas and most crops grown are near their maximum temperature-tolerance; crop production is predicted to decrease even with small increases in atmospheric temperature (Odera *et al*., 2012; Thornton *et al*., 2010). The increasing climatic variability arising from extreme weather events will have serious implications on crop production and food availability (Mariara-Kabubo and Karanja, 2007). Population growth and development have driven up national demand for food leading to encroachment of farming activities on marginal lands and as competition for other land uses, water and energy intensifies, the impacts of climate change starts to take effect thus exacerbating the existing food production stress (Bryan *et al*., 2013).

Since the first Intergovernmental Panel on Climate Change (IPCC) assessment report was published in 1990, substantial efforts have been directed toward detailed understanding of climate change impacts on agricultural systems worldwide. The resulting advances have led to development of methods and models to brace the existing observation of actual changes in climate and its impact. Most existing research on agricultural impacts in Kenya has led to dire predictions of adverse impacts of climate change on agricultural production (Njiru *et al*., 2010; Kabubo-Mariara and Karanja, 2007). The public and private institutions that support agriculture could contribute towards averting the situation by empowering the farming communities adapt to climate changes in ways that would mitigate negative impacts and take advantage of positive impacts, especially when based on empirical evidence of the climate change impacts (Bryan *et al*., 2013).

After the publication of the first IPCC assessment report, a large body of scientific data and models have been developed to predict the impacts of the contemporary and future climate. However, there is little knowledge on the level of application of the models in Kenya. The availability of such knowledge is critical for designing technologies and policies to mitigate climate change and facilitate adaptation to the changes that now appear ineviTable in the next several decades and beyond. The study sought to identify the analytical tools that have been used to estimate the impacts and their level of utilization in major productive sectors of the economy.

Materials and methods

A baseline survey was undertaken to determine the type of analytical tools used to estimate the impact of climate change on crops and livestock production, water resources and natural environment between the year 2007 and 2012 (a five year period). Key informants from universities, research institutions and policy areas were purposively selected for interviews. About 90 respondents drawn from each of these groups were interviewed using open-ended questionnaires. Data were coded, entered, cleaned and analyzed using Statistical Package for Social Scientists (SPSS) version 18 computer program. Utilization of analytical tools in three broad thematic areas namely adaptation, mitigation and capacity building was assessed. The development sectors selected for analysis were agriculture, livestock, environment (natural resources), and water resources. To disconnect livestock from agriculture, the selected agricultural sector was left to crops sub-sector alone.

Results and discussions

The results from the survey show that 12% of the respondents used structural models in analysing climate change impacts, of which 9% were within the adaptation theme, 2% in mitigation and 1% in capacity building. Three percent of the respondents utilized spatial models of which 2% was employed in adaptation and1% in mitigation. The climate change models were applied by 2% of respondents in adaptation and 1% in mitigation. A total of 16% of the respondents employed analytical tools in evaluating adaptation. Generally more technical tools were used to address adaptation while the least technical tools were used in capacity building. This implies that adaptation was being addressed more than mitigation. The implication is in line with IPCC fourth assessment report's recommendations that adaptation be widely recognized as an immediate and vital component of any policy response to climate change while mitigation interventions should be considered as long term (IPCC, 2007). The situation is underpinned by the National

Climate Change Response Strategy (NCCRS) of Kenya that recognises adaptation as a short term intervention of cushioning sectors of the economy against adverse effects of climate variability and change (GOK, 2010). The Strategy also recognises mainstreaming climate change issues throughout all economic sectors to ensure coordinated implementation of climate change adaptation and mitigation activities. The NCCRS further acknowledges the importance of effective communication, education and public awareness programmes in improving the resilience of communities and productive sectors for adaptation to climate change which buttressed the use of analytical tools in capacity building. However, the low level utilization of climate models in capacity building could be explained by inadequate capacities among researchers or trainers to adapt such approaches as economics of climate change is in its infancy in terms of framework and tools (Chambwera and Stage, 2010).

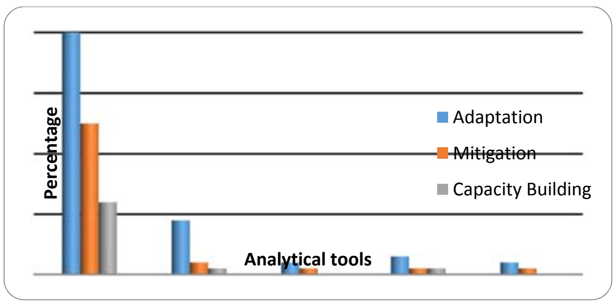

Figure 1 : Analytical tools used to generate estimates of climate change impacts in selected Thematic areas (n=178)

From the survey, 77% of the respondents had not used any models in analyzing the impact of climate change on selected productive sectors. Twelve percent of the respondents had applied structural models; 3% used spatial models, 5% and 3% used economic and climate change models respectively. Of those that used models in climate change impact assessment, 11% were involved in crops sub-sector, 6% in livestock sub-sector, 5% in environment and 1% in water. A total of 18% of the respondents had used models in crops and livestock, which could be attributed to importance of the two sub-sectors in alleviating hunger and malnutrition and contribute towards achieving the target two of the first goal of the millennium development goal. The utilization of the structural model is credited to ability of the approach to combine crop model through agronomic response with economic-farmer management practices; the approach is based on detailed experiments that determine the response of specific crop varieties on different climatic and other conditions. The crop simulation models that were imbedded in the structural models include CERES, Agricultural Production System Simulator (APSIM) and Decision Support System for Agrotechnology Transfer (DSSAT). Diminutive usage of climate change model could be due to lack of facilities and human resources to collect and process climate data. The wide use of economic analysis model could also be due to minimal data requirement and hence most parsimonious models are simple and therefore suiTable for developing countries that are normally financially constrained when searching for extensive data. The statistical packages that were used in conjunction with the models were General Statistical package (GENSTAT), Statistical Analysis System (SAS), SPSS and Excel.

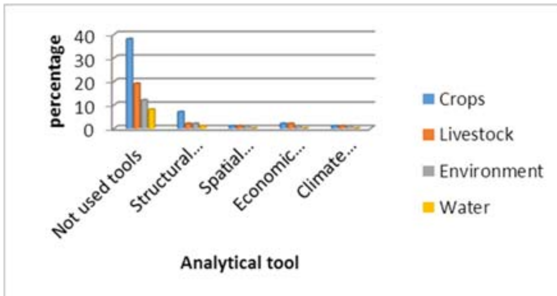

Figure 2: Analytical tools used to generate estimates of climate change impacts on selected productive sectors (n=178)

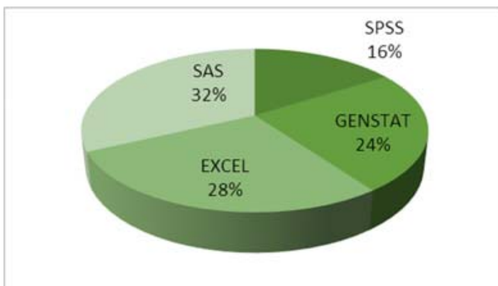

Figure 3: Statistical packages used in data analysis (n=184)

A meagre 3% of the respondents used crop simulation models within the structural approach. Agricultural Production System Simulator (APSIM) was reported as a popular crop modelling tool accounting for 46% of respondents using crop models, followed by 28% and 26% for CERES-maize and DSSAT respectively. Forty two percent of the crop models were utilized in the adaptation theme, 26% and 32 % in the Mitigation and the capacity building respectively. Wide use of the APSIM model could be explained by its wide use in farming systems and the ability to provide accurate predictions of crop production in relation to climate, genotype and soil management factor while addressing the long-term resource management issues. The model is also applied in support for on-farm decision making, farming systems design for production or resource management, assessment of the value of seasonal climate forecasting, risk assessment for policy making and as a guide for research and educational activities.

Climate change will pose a great challenge to agriculture in Sub- Saharan Africa (SSA) due to the region's vulnerability and low adaptive capacity (Shah *et al.,* 2008; Slingo *et al*., 2005). The study sought to identify the methods used to analyse agricultural sector's vulnerability to climate change. This study based the definition of vulnerability on the Intergovernmental Panel on Climate Change's definition, where a region's vulnerability to climate change and variability is described by three elements: exposure, sensitivity, and adaptive capacity (IPCC 2001). Exposure is interpreted as the direct danger (the stressor), and the nature and extent of changes to a region's climate variables (e.g., temperature, precipitation, extreme weather events). Sensitivity describes the human and environmental conditions that can worsen the hazard, ameliorate the hazard or trigger an impact. Adaptive capacity represents the potential to implement adaptation measures that help avert potential impacts

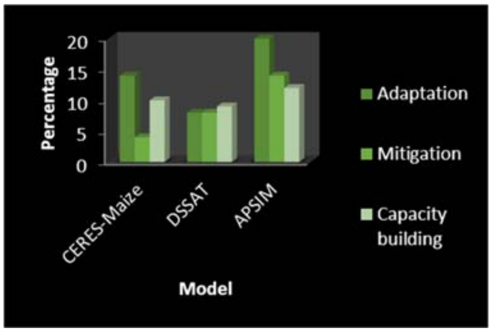

Figure 4: Crop simulation models used in selected thematic areas (n=30)

The results from this survey indicated that 15% of the respondents used the indicator approach which involved risk zoning and maps, 6% employed spatial-GIS related technologies, while 79% had not conducted any empirical study. The use of the indicator approach is attributed to its ease in detecting, their degree of vulnerability, the causes of their vulnerability, and what responses can lessen their vulnerability. The approach uses a specific set or combination of indicators (proxy indicators) and measures vulnerability by computing indices, averages or weighted averages for those selected variables or indicators. The indicator approach was favoured for its wide scale of application; used at household, county or district, and national level. The approach is used to develop a better understanding of the socio-economic and biophysical factors contributing to elicit vulnerability. Mapping helped in identifying the vulnerable areas and groups to guide on where to locate specific activities that improve the target group resilience to climate variability.

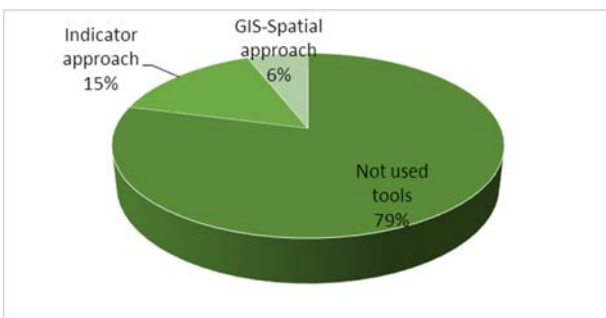

Figure 6: Analytical tools used in vulnerability assessment

Conclusions and recommendations

The results from the survey show that the application of analytical tools by researchers, academia and policy planners in assessment of climate change impact on the major sector of the economy is low. Most of the analytical tools were applied in adaptation; specifically in crops and livestock sub-sector while capacity building had the least application followed by mitigation. Structural models were most utilized in all the selected productive sector of the economy followed by the economic models, climate change models were

least applied in all the sectors. Agricultural Production System Simulator model was the most adopted crop simulation model to Decision Support System for Agrotechnology Transfer (DSSAT) and CERES-model.

In Kenya like many other African countries, economics of climate change is in its nascent stage in terms of analytical frameworks and tools. Practical applications of climate change impact analysis are limited within research institutions and policy arena. Vigorous capacity building to empower the researchers to rigorously estimate the impacts of climate change on an economy that would enable development of appropriate adaptation strategies is required. More research on varieties that are indigenous or locally adapted varieties to the country should be modelled and entered into the major crop simulation software such as APSIM and DSSAT to broaden the ability of climate change studies in the country in providing more informed choice of practices, technological tools that would be used as appropriate means of reducing long term vulnerability to climate change.

Acknowledgement

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Analysis of technical efficiency of sorghum production in lower eastern Kenya

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Abstract

Most Kenyan rural households depend on agriculture for food and livelihoods. Declining agricultural productivity has resulted in increased food insecurity in the country. Consequently, there is a renewed interest in promoting drought-tolerant orphan crops such as sorghum for increased production in the arid and semi-arid lands of Kenya. However, performance of sorghum production among the smallholder farmers has remained low. This study was conducted to determine technical efficiency of sorghum production and its associated factors in Machakos and Makindu districts. The study surveyed 143 sorghum farming households during 2010-2011 growing seasons. The Data Envelopment Analysis and Tobit models were used to estimate efficiency scores and factors that influence the technical efficiency. Results showed that mean technical efficiency was 41%, which is considered low. The technical efficiency was influenced positively by farm and farmer characteristics. It is concluded that technical efficiency of sorghum production in the study districts can be improved further by 59%. Similarly, innovative institutional arrangements enhancing farmer training should be instituted to enhance farmer capacity to efficiently use available resources to improve sorghum production.

Key words: technical efficiency, sorghum, DEA, tobit.

Introduction

Grain sorghum (*Sorghum bicolor* L Moench.) is the 5th most important cereal crop grown in the world (U.S Grain Council, 2010). Because of its versatility and diversity, sorghum is grown mainly in the arid and semi-arid lands (ASALs) of Africa and Asia for rural food security. Although sorghum is largely a subsistence crop, it is increasingly becoming part of the successful food and beverage component of the lager beer brewing industry (Taylor, 2010).

In Kenya sorghum is a traditional subsistence crop, which is grown in many ASALs of the country. However, sorghum lost favour with farmers when maize became the preferred and staple food crop in Kenya after its introduction by the white settlers. Notwithstanding, there is renewed interest in promoting drought-tolerant crops such as sorghum and pigeon pea to stabilize food security in Kenya. These crops are also well adapted to harsh environments (GoK, 2009).

Substantial research on sorghum breeding has been going on in Sub-Saharan Africa resulting in sTable, high-yielding sorghum varieties (HYSVs) that are being promoted for adoption (Olembo *et al.,* 2010). In Kenya, initiatives for promoting sorghum production are concentrated in the ASALs. This is in line with the government strategy of enabling the country meet household food security and increased rural income (GoK, 2009).

Sorghum production is important in lower eastern Kenya partly because this area is characterized by increasing drought occurrences. Over the past two decades, there have been repeated maize crop failures in this region because of droughts (Karanja *et al.,* 2009). The HYSVs, coupled with improved production technologies, can survive and yield well in the ASALs such as the lower eastern Kenya (Karanja *et al.,* 2009).

In recognition of the role sorghum plays in food security especially in ASALs, the government through the Kenya Agricultural Research Institute (KARI) has given priority to developing locally adapTable HYSVs with accompanying agronomic technologies. In addition the Ministry of Agriculture has initiated and implemented funded Orphan Crops projects to promote the production of crops like sorghum.

It is important to note that the area under sorghum production in Kenya has been increasing from 122,368ha in 2005 to 173,172ha in 2009, but the national average yield per hectare has been decreasing from 1.2tons/ha in 2005 to 0.5tons/ha in 2009 (GoK, 2010). Various public efforts supplemented by Non-Governmental Organizations (NGOs) and other stakeholders like International Sorghum and Millet (INTSORMIL) program and International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) have provided interventions for Harnessing Opportunities for Productivity Enhancement (HOPE), targeted at improving productivity and marketing of sorghum. These interventions include breeding, distribution of improved HYSVs that are pest and disease tolerant, and promotion of resource conserving management practices. Despite all these efforts, there has been variability in production from the expected potential yields and the actual yields. The expected potential yield for the Gadam sorghum variety is 2-2.5tons ha^{-1} but farmers have so far only realized production of up to 1.2tons ha^{-1} (GoK, 2009; Karanja *et al.,* 2009).

Variability in production is a function of differences in scales of operation, production technologies, operating environment and operating efficiency. Chimai (2011) noted that for small-holder farmers, variation in production due to differences in efficiency may be affected by various factors, which include regional and farm specific socio-economic factors. Technical efficiency (TE) differences could also be explained in the context of the management characteristics such as training, experience and motivation (Ahmed *et al*., 2005).

The study sought to determine technical efficiency of sorghum production and identified farm and farmer characteristics that influence levels of TE among smallholder sorghum producers in the lower eastern Kenya.

Different approaches are used to determine technical efficiency. It is observed that TE studies have been conducted on various crops including maize, wheat, Irish potatoes, coffee and millet. Most of these studies have however reported as low as 0.24 to moderately high technical efficiencies (chiona, 2011, Chimai, 2011,Nyagaka, 2011).

Two of the most frequently used methods for determining TE are the Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). As pointed out by various authors (Chiona, 2011; Coelli *et al*., 2002; Chimai, 2011), DEA approach has several advantages. It uses mathematical programming to measure relative efficiency of decision making units (DMUs). It does not make *a priori* assumptions about the functional form of the production function and the inefficiency term. Instead it makes general assumptions of monotonicity and convexity, which result in a flexible frontier that allows the production function to vary across DMUs. Thus, many empirical studies have applied and extended the DEA technology in studies of efficiency worldwide (Chimai, 2011; Mussa *et al*., 2011; Chiona, 2011).

There are also many studies that have determined factors that influence technical efficiency. A number of such studies have attempted to investigate relationships between technical efficiency and various socio-economic and demographic variables such as levels of education, age, family size, access to credit, extension services and experience (Chiona, 2011 and Nyagaka *et al*., 2011). Other studies have shown how technical inefficiency is influenced by managerial incompetence (Ahmed *et al*., 2005), and other factors such as membership to agricultural associations, land ownership, value of household assets, use of fertilizers and tillage methods adopted (Nyagaka *et al.,* 2011; Chimai, 2011). Many of these factors influence technical efficiency differently depending on unique characteristics of individual countries and agricultural products.

Materials and methods

Study area

This study was conducted in Makindu and Machakos districts of Makueni and Machakos counties respectively, both situated in the ASALs of the lower Eastern Kenya. The districts experience bi-modal rainfall distribution with two distinct cropping seasons. Machakos district lies at $1^{0}35^{1}$S and $37^{0}10^{1}$E and has a mean annual rainfall of 690mm, while Makindu lies at $2^{0}0^{1}$S and $37^{0}40^{1}$E with a mean annual rainfall of 580mm. Agriculture is mainly rainfed and crop and livestock production are constrained by low soil moisture and poor pastures because of erratic and unreliable rainfall(Kwena *et al.*, 2011a, 2011b). The Machakos and Makindu districts present great opportunities for improved production of appropriate HYSVs.

Sampling and data collection

The population of interest comprised of sorghum growing households (HHs) who grew sorghum in 2010-2011 cropping season. A sample size of 143 HHs (Makindu [71] and Machakos [72] was determined proportionately using total population of the districts. A multi-stage sampling procedure was employed.

Data was collected from the sampled HHs between June and August 2012 by use of pre-tested semi-structured questionnaires that were administered by trained enumerators. The questionnaires sought information on demographic, institutional, physical and socio-economic factors, and yields and inputs used during the 2010-2011 cropping season.

Data analysis

Data envelopment analysis model. This study employed Data Envelopment Analysis (DEA) model (Banker *et al.*, 1984) to analyse the collected data to determine technical efficiency of sorghum production. The model is based on output-orientation under variable returns to scale (VRS). VRS are assumed appropriate because sorghum farmers in the study areas were found to experience variations in agricultural production occasioned by multiple factors. The output-orientation seeks to determine the maximum proportional increase in output produced with inputs level held fixed.

Technical Efficiency scores are estimated by an output-oriented linear programming analytical model developed by Charnes *et al.* (1978). As defined in equation 1, parameters are solved *n* times – once for each HH in the sample:

$$\begin{aligned} & Max \quad \sum_{k=1}^{s} V_k Y_{kp} \\ & s.t \quad \sum_{j=1}^{m} U_j X_{jp} = 1 \\ & \sum_{k=1}^{s} V_k Y_{ki} - \sum_{j=1}^{m} U_j X_{ji} \leq 0 \qquad \forall\ i \\ & V_k, U_j \geq 0 \qquad \forall\ \text{k, j} \end{aligned} \tag{1}$$

All the DMUs with a score of 1 are regarded as being 100% technically efficient, while all the others scores less than 1 are regarded as technically inefficient.

The Tobit model. A two-step procedure, the most commonly applied, was used to estimate parameters in this study. In the 1st step, TE scores are estimated using the DEA output-oriented model, while in the 2nd step the estimated TE scores are regressed on farm and farmer characteristics variables to identify their influence on technical efficiency. Given that the TE scores range between 0 and 1, a two limit Tobit regression model (equation 2) (Coelli *et al*. (2002) was used as shown.

$$U_i^* = \beta_0 + \sum_{j=1}^{k} \beta_j Z_{ij} + \mu_i$$

$$U_i = \begin{cases} 1 & \text{if } U_i^* \geq 1 \\ U^* & \text{if } 0 \prec U_i^* \prec 1 \\ 0 & \text{if } U_i^* \leq 0 \end{cases} \quad (2)$$

Where i = the i^{th} DMU; U_i = efficiency scores of i^{th} DMU; U_i^* = latent efficiency; β_j = parameters that are estimated; Z_{ij} = farm and farmers characteristics variables; and μ_i = error term.

The analytical Tobit model used in this study is specified as:

$$\text{Eff score} = \beta_0 + \beta_1 \text{ Malehd} + \beta_2 \text{ H/age} + \beta_3 \text{ H/edu} + \beta_4 \text{ Prodadvice} + \beta_5 \text{ Adptill} + \beta_6 \text{ Hlabortill} + \beta_7 \text{ Offincm} + \beta_8 \text{ Asset} + \beta_9 \text{ Agrcredit} + \beta_{10} \text{ Othrincm} + \beta_{11} \text{ Srgmfarmsize} + \beta_{12} \text{ Ndependents} + \beta_{13} \text{ Srgmseed} + \beta_{14} \text{ Manure} + \beta_{15} \text{ Improvseed} + \beta_{16} \text{ Clubmbr} + \beta_{17} \text{ Expr} + \mu$$

Where: Malehd=Male headed HH, H/age=Age of HHH, H/edu=Education level of HHH, Prodadvice=Production advice, Adptill=Adopted tillage, Hlabortill=Hired labour, Offincm=Off farm income Asset=Household Assets, Agrcredit=Agricultural credit use, Othrincm=Income from other crops and livestock, Srgmfarmsize=Farm size used to produce sorghum, Ndependents=Number of dependants, Srgmseed=Sorghum seed rate, Manure=Improvseed=Improved seed varieties, Clubmbr=Club/association membership, and Expr=Experience in sorghum farming.

Results and discussion

Technical efficiency

For the TE scores, out of the 143 HHs surveyed, 22 HHs (15%) overall, 12 HHs (17%) Makindu and 15 HHs (20%) in Machakos were 100% technically efficient (Table 1).

The efficient HHs, defined the efficient frontiers and represents the best practices of decision making units (DMUs) in combining land, seeds and labour to produce maximum sorghum output possible. When the inputs are held constant, the HHs produce more output per unit area as compared with their inefficient counterparts. The overall mean TE was 41%, while the mean for Machakos and Makindu districts were about 43% and 48% respectively. This implies that more that 50% of the output was lost due to technical inefficiency. This also implies that there exits tremendous opportunity to improve technical efficiency among the HHs. On average, there was potential to increase farm output by 56.7% and 52.1% in Machakos and Makindu respectively using the existing levels of inputs. These results appear to concur with those of Chimai (2011) and Amaza *et al*. (2010) who estimated the TE of sorghum production in Zambia and Borno State in Nigeria respectively.

As presented in Figure 1, the TE indices varied widely between the two districts in which 18% of the surveyed HHs were below 10% TE in Machakos against 10% in Makindu district. Most of the HHs in Machakos (> 50%) were operating < 30% TE, while in Makindu district HHs operating < 30% TE consisted of only 35%.

Majority of the technical inefficient HHs in Makindu operated between 30 and 39%, while in Machakos majority operated between 10 and 19% technical efficiency. Observed variations between Machakos and Makindu districts could be explained by the apparent variations in some of the farm and farmer characteristics.

Table 1: Frequency distributions of technical efficiency scores obtained by DEA model

Efficiency scores	Frequency distribution of DEA		
	Overall TE VRS	Makindu TE VRS	Machakos TE VRS
1.00	22	12	15
>0.90<1.00	2	1	1
>0.80≤0.90	6	4	3
>0.70≤0.80	4	3	3
>0.60≤0.70	4	3	5
>0.50≤0.60	9	4	2
>0.40≤0.50	11	7	5
>0.30≤0.40	16	12	8
>0.20≤0.30	16	10	16
>0.10≤0.20	28	8	13
<0.10	25	7	72
Total DMUs	143	71	0.019
Minimum	0.015	0.032	1
Maximum	1	1	0.433
Mean	0.410	0.479	

TE VRS = Technical efficiency under variable return to scale assumption

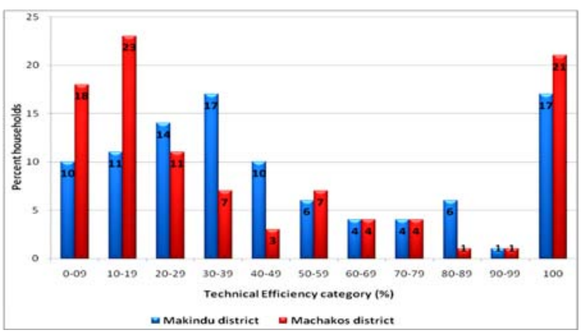

Figure 1: Technical efficiency distributions per district

Factors influencing technical efficiency

Many variables were relevant in explaining technical inefficiency obtained for sorghum production. Out of 18 variables, seven were influenced TE positively and statistically significant at 5% level (Table 2). These variables include formal education levels of HH heads, years of experience in sorghum farming, HH membership in farmer associations, size of land planted with sorghum, hired labour, use of manure and production advice on sorghum production. Their respective increase improved the TE of sorghum production. Only one variable, size of HHs, was found to influence TE negatively and significantly at 5% level. If the size of the household is big, the use of family labour could be very common hence reduction in labour efficiency which affects the overall efficiency of sorghum. These findings were found to be in line with those of Gul *et al.* (2009) but contrary to those of Ajewole and Folayan (2008).

Variables

Table 2: Tobit model results showing farm and farmer characteristics that influence technical inefficiency in lower eastern Kenya

	Overall			Makindu District			Machakos District		
	Coefficient	Std error	t-ratio	Coefficient	Std error	t-ratio	Coefficient	Std error	t-ratio
Male-headed HHs	0.0151	0.0602	0.25	0.0127	0.0917	0.14	-0.1275	0.0965	-1.32
Age of the HHH	0.0031	0.0022	0.166	-0.0041	0.0035	-1.17	0.0043	0.0038	1.11
Education of the HHH	0.3397*	0.1122	3.03	0.3161*	0.1402	2.25	0.3861*	0.1584	2.44
HH size	-0.0109	0.0168	-0.65	-0.0159*	0.0060003	-2.61	-0.0143	0.0295	-0.48
Number of dependents	0.0187	0.0162	0.67	0.0334	1.10e-07	1.10	0.0010	0.0257	0.04
Assets	1.41e-08	5.67e-08	0.25	2.81e-08	0.0202	0.25	1.48e-07	8.69e-08	1.70
Experience in sorghum farming	0.1346*	0.5284	2.55	0.0456*	0.0588	2.26	0.1420*	0.0670	2.12
Membership to farmer associations	0.1446*	0.0509	2.84	0.1933*	0.0034	3.29	0.3164*	0.1457	2.17
Seed rates used	0.00002	0.0029	0.01	0.0003	0.1400	0.08	0.0009	0.0034	0.27
Use of improved seed variety	0.0617	0.0682	0.90	0.0088	0.1838	0.06	0.0237	0.1015	0.23
Size of land planted with sorghum	0.1318	0.6955	1.89	0.5603*	0.0911	3.05	0.4210	0.3281	1.28
Land preparation method	-0.0626	0.0583	-1.07	-0.0430	0.0807	-0.47	-0.0455	0.0997	-0.46
Hired labour	0.1096*	0.0542	2.01	0.1968*	0.0540	2.44	0.2789*	0.1064	2.62
Manure use	0.1832*	0.0531	3.45	0.1660*	0.0679	3.07	0.2706*	0.0883	3.07
Production advice	0.2610*	0.0549	4.76	0.2474*	1.24e-06	3.64	0.2208*	0.1101	2.00
HH off-farm income	-9.26e-07	7.57e-07	-1.22	1.28e-06	0.1543	1.04	1.38e-08	1.26e-06	0.01
Credit use	0.1021	0.0932	1.1	0.1061	0.0993	0.69	0.1157	0.1018	1.14
Income from other farm activities	-0.0057	0.0476	-0.12	0.1157	-	1.16	-0.0622	0.0733	-0.85
Region	0.1015	0.0705	1.44	-	0.2697	-	-	-	-
Constant	0.4263*	0.1859	2.29	1.1141*		4.13	0.5372*	0.2439	2.20
Software used STATA * Significance at 5%	N=143; LR χ^2 df=111.91 Prop> χ^2 =0.00 Pseudo R^2=0.6741 Log likelihood=-27.047463 Sigma coefficient 0.2551064 Left censored=0 Uncensored=121 Right censored=22			N =71; LR χ^2 df=78.68 Prop> χ^2 =0.00 Pseudo R^2=0.9761 Log likelihood=0.96331317 Sigma coefficient 0.2125154 Left censored=0 Uncensored=59 Right censored=12			N =71; LR χ^2 df=55.81 Prop> χ^2=0.00 Pseudo R^2 =0.5483 Log likelihood=22.988456 Sigma coefficient 0.2828562 Left censored=0 Uncensored =57 Right censored=15		

Notes: HH=Households, HHH=Household head

However, there were other variables that influenced TE positively but not statistically significant. Some of those factors include male-headed HHs, number of dependants, HH assets, use of improved seed varieties, seed rate, HH off-farm incomes, income from other farm activities, and use of credits. Increase in these variables could have an impact on the technical efficiency of sorghum production.Variables such as age of the HH head and land preparation methods influenced TE negatively but not statistically significant.

Conclusion and recommendations

It is concluded that majority of the sampled smallholder sorghum producers were technically inefficient. The HHs were operating on a mean TE of 41%, with some of them in fact operating in as low as 1.5% TE regime. This gives potential opportunity for efficiency improvement. Several factors including years spent by HH heads in school, experience in sorghum farming and HH membership in farmer associations influenced TE of sorghum production positively and statistically significant.

It is recommended that a policy review, targeting formal education, youth capacity building in sorghum farming, collective actions and use of optimal inputs, be undertaken to provide an enabling environment to improve HHs' ability to enhance sorghum product value chains.

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Climate Change Adaptation and Agricultural Development Planning in Kenya

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Abstract

Climate change has become a major threat to economic development in sub-Saharan Africa (SSA). Studies indicate that the impacts of climate change will significantly add to the development challenges and hamper progress to meeting Millennium Development Goals (MDGs). There is a general consensus that agriculture-based livelihood systems predominant in the region will be most affected by the increased frequency and intensity of variable weather from predicted climate change. Kenya is among SSA countries that are already experiencing the climate change phenomena. The country is particularly vulnerable owing to the fact that the economy is heavily reliant on climate sensitive sectors such as agriculture. Agricultural production is predominantly rain-fed and hence fundamentally dependent on the vagaries of weather. It is dominated by smallholder resource-poor farmers who account for 75% of the total agricultural output and provide nearly all the domestic food requirements. A baseline survey to determine the status of climate change projects undertaken in Kenya in the past five years was conducted in 2012. The study targeted key informants in academia, research and policy makers. Results indicated that 60% of climate change projects undertaken were centered on adaptation, with over 66.7% of these being in the crop and livestock subsectors. However, 50% of the respondents did not know any source of information regarding climate change adaptation, while government departments had only 8.3% of the information data bases. In the absence of relevant scientific and technical information, adaptation investment planning by policy makers will continue to be prone to uncertainty.

Key words: agriculture, climate change, development, Kenya.

Introduction

Sub-Saharan Africa (SSA), a region which had been identified by researchers as particularly vulnerable to the consequences of global climate change by mid 1990s is already experiencing the climate change phenomena (IPCC, 2007; IPCC, 2001). Extreme weather variability associated with climate change is affecting water supplies and food production in many countries. Kenya is among SSA countries that are already experiencing the climate change (CC) phenomena (Nhemachena, 2009; Thornton *et al.*, 2009; IPCC, 2007). Agricultural production is predominantly rain-fed and hence fundamentally dependent on the vagaries of weather. It is dominated by smallholder resource-poor farmers who account for 75% of the total agricultural output and provide nearly all the domestic food requirements.

Projections indicate that Kenya's temperatures and rainfall variability will increase by about 4°C and 20%, respectively, by 2030. The overall impacts of CC on agriculture are expected to be negative (Nelson *et. al.*, 2010). Extreme weather variability associated with CC will affect water supplies and food security, which in turn will undermine economic development. There is a general concern that the projected impacts of CC on agriculture will significantly erode gains made to overcome poverty and food insecurity, and add to the country's development challenges. Some of the major economic slumps in the past decades occurred during major droughts in 1984, 1999, 2008 and 2011 (GoK, 2010; 2012). Recurrent production failure since 2008 has necessitated government-sponsored food imports to address food deficits in many parts of the

country. Consequently, the government has spent over Ksh. 20 billion annually to feed a population of between 3.5 to 4 million (GoK, 2009; 2012b). There is need for urgent action if Kenya is to meet its development agenda while adapting to climate change. To guide CC adaptation investment planning, it is necessary to undertake an inventory of major programmes and institutions currently engaged in CC activities, and how technical, policy and institutional interventions can enable smallholder farmers adapt to CC and variability.

Adaptation has the potential to lessen negative impacts of CC on agriculture (Hassan and Nhemachena, 2008; IPCC, 2007; Adger *et al*., 2003). However, researchers argue that adaptation is a site-specific phenomenon and hence requires local analysis for better understanding (Hinkel, 2011; Deressa *et al*., 2008; Boko *et al*., 2007). Generally, adaptations vary according to systems in which they occur, who undertakes them, climatic shocks that cause them, their timing, functions, forms and effects. Currently, economic planning and policy decision-making have become particularly tricky for many economies in SSA due to increasing climate variability (Brown *et al*., 2010b). Conventional wisdom suggests that investments that reduce current impacts of climate variability are likely to be the best adaptation decisions a planner can make. It is crucial therefore that any policy decisions to support their implementation are informed by a synthesis of the best available evidence from research findings.

Materials and methods

A baseline survey was undertaken to determine the current status of CC projects (CCPs) that have been undertaken in Kenya in the past five years. The survey was conducted at the headquarters of the Government Ministries of Agriculture, Livestock and Water based in Nairobi, and in selected public universities. Universities surveyed were; University of Nairobi, Moi University, Maseno University, Kenyatta University, Jomo Kenyatta University of Agriculture and Technology and Masinde Muliro University of Science and Technology. Literature was approached through a systematic survey of these three key stakeholder groups, viz; Academia, Research Institutions and Policy planners. About 90 respondents drawn from each of these groups were interviewed using open-ended questionnaires. Data were coded, entered, cleaned and analyzed using SPSS computer program. Results were first analyzed along three broad thematic areas; Adaptation, Mitigation and Capacity Building. These were further analyzed on the basis of four productive sectors; Agriculture (crops), Livestock, Environment (natural resources) and Water Resources. It was agreed by expert opinion and consensus that these four be adopted for analysis at local level as they were the most sensitive to climate change. To separate livestock from agriculture, the agricultural sector was left to crops only. In-depth analysis was then undertaken to evaluate responses on a series of attributes. These results are presented in the subsequent section.

Results

The survey results indicated that 60% of CCPsimplemented in Kenya during the past five years were on adaptation. Capacity building and mitigation accounted for 23% and 17%, respectively, as shown in Figure 1.

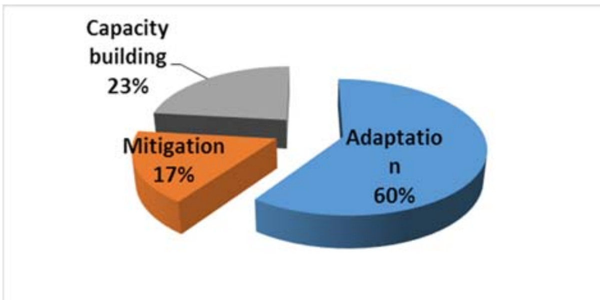
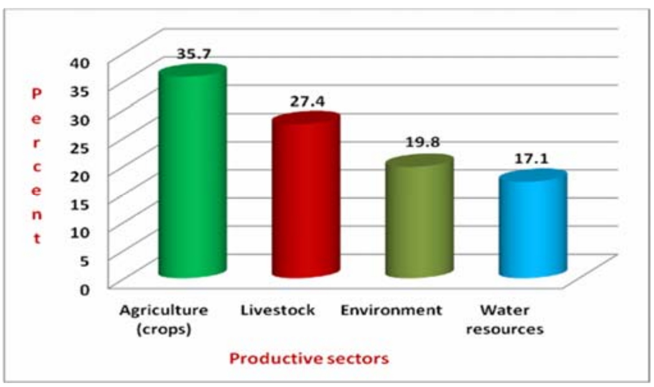


Figure 1: Projects addressing selected climate change thematic areas (n=263**)**

Further, the analysis revealed that agriculture and livestock sectors combined accounted for most of CCPs (63.1%) compared with environment and water resources sectors, which accounted for 19.8% and 17.1% of the projects, respectively, during the same period (Figure 2).



y axis-% CCPs

Figure 2: Projects addressing selected productive sectors (n=263)

With regard to perceptions about negative impacts of CC on agriculture, the greatest impacts were on crop yield losses at 18% and water resources at 12.5%. Pest and disease incidences (11%) and environmental and land degradation (8%) ranked third and fourth. Loss of livelihoods (5.5%) and increased risk of conflict over scarce resources (4%) were also of concern. Secondary stresses of deteriorating human health were perceived by 1.4% of the respondents (Figure 3).

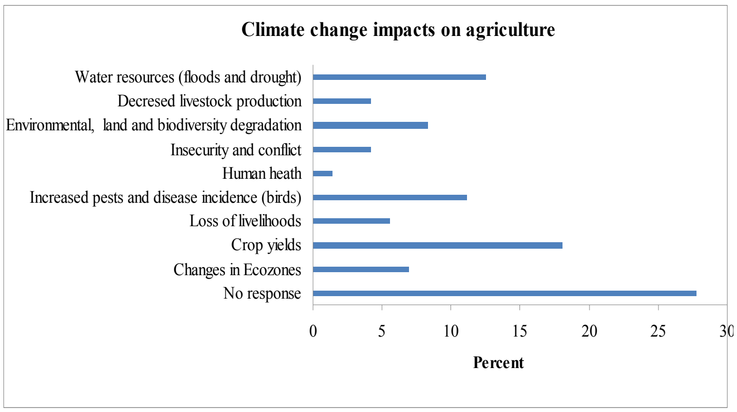


Figure 3: Climate change impacts on agriculture in Kenya

In spite of the fact that information and data management has been identified as one of the main challenges limiting climate change adaptation and mitigation in many SSA countries, the analysis revealed that 50% of the respondents did not know any source of information regarding climate change adaptation. Government departments which are actively involved in policy formulation and development planning have only 8.3% of the information data bases compared to the CGIAR and International Research Centres which have 16.7%. From the baseline study responses, currently known data bases for climate change adaptation and development planning are limited and scattered among different stakeholders (Figure 4).

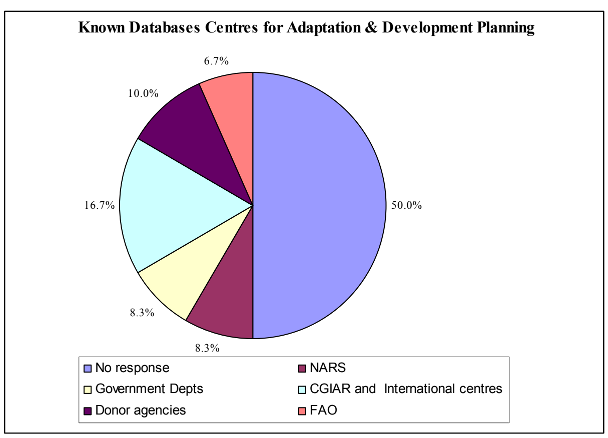


Figure 4: Known databases for CC adaptation and development planning

Results from the study show that utilization of climate information to inform policy decisions in all areas was below the 10% mark (Figure 5).

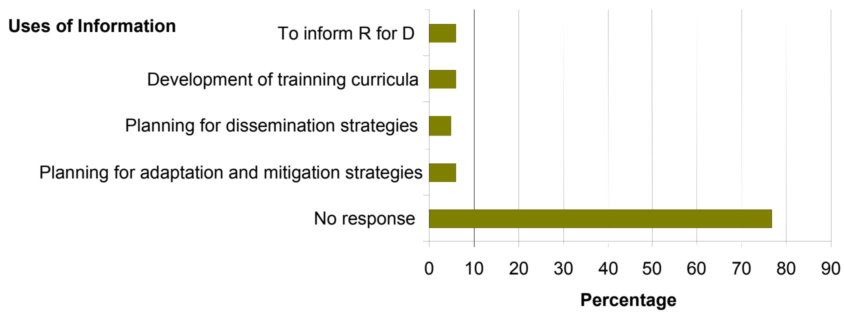


Figure 5: Utilization of information in decision-making processes

On the use of research recommendations by decision makers, the study revealed that most efforts were geared towards adaptation (Figure 6).

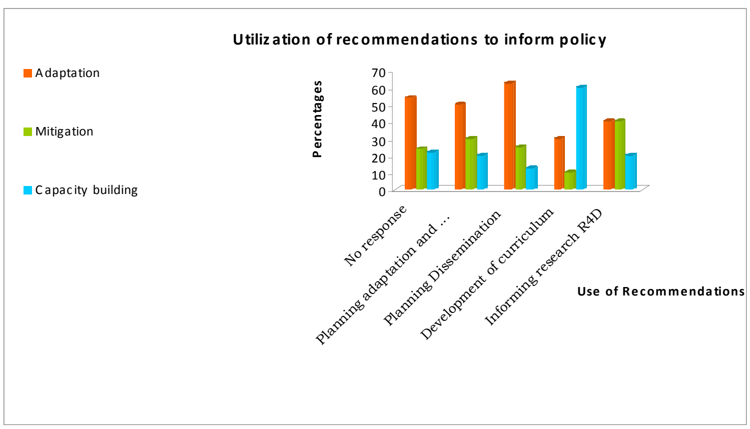


Figure 6: Utilization of recommendations to inform policy

Discussion

CC is expected to have a direct impact on crop and livestock productivity and indirect impacts on prices of food and income from agricultural production, both at the farm and country level. In the crop sub-sector, temperature increases occasioned by climate change are expected to reduce yield of desirable crops and encourage proliferation of weeds and pests. The anticipated greater variation in precipitation will increase likelihood of crop failures in the short-term and lead to production decline in the long-run. CC is also expected to transform ecosystem biodiversity in terms of soils and land species, pests and diseases and vegetation cover and thus further modify agricultural output. The resultant changes in agricultural production will ultimately impact food prices, thus affecting food access by vulnerable populations. Higher food prices occasioned by production failure offer mixed fortunes for resource-poor farmers. While they

may benefit from higher output prices, for those who spend a substantial proportion of their incomes on food purchases, higher prices imply threats to household consumption (Karugia *et al.,* 2011). Households, as an adaptation strategy, may sell off productive assets to purchase food (World Bank, 2011; Cooper *et al.,* 2008; IFPRI, 2007). Such adaptation strategies have serious welfare consequences and serve to compromise future production.

Overall, food security in the rural areas of the country where agricultural production activities are concentrated is already under considerable stress as a result of various factors such as rapid population increase, declining land sizes and degradation of the natural resource base. The predicted impacts of CC, therefore, are likely to exacerbate these stresses even further. Over the last three decades, frequency of droughts and floods has increased resulting in crop failures and loss of livestock with negative implications for food security and economic development (Ngigi, 2009). Impacts of CC are further compounded by local environmental degradation caused by illegal encroachments into forests and riparian areas, deforestation, overgrazing by livestock and cultivation in fragile ecosystems including wetlands and water catchment areas. This may partly be attributed to the increased demand for food against diminishing land sizes, which is driving expansion of agricultural activities without necessary productivity growth. This is consistent with what previous studies have predicted for SSA (Boko *et al*., 2007; Parry *et al*., 2007; Vanacker *et al*., 2005; Jones and Thornton, 2003).

Adaptation by the agricultural sector has the potential to buffer other sectors of the economy from the negative impacts of CC. However, results from the study indicated that utilization of CC information to inform policy decision-making was negligible. A possible explanation to this could be the lack of relevant information which limits policy insights in identification of target variables to enhance the use of adaptation measures in agricultural production. Although the national government is tasked with the role of formulating policy to mitigate CC risks, implementation of relevant adaptation action plans relating to agriculture and food security is generally lacking (Nzuma *et al*., 2010). A major constraint has been inadequate resources for climate change adaptation work due to low prioritization in the national budget.

The role of information and knowledge as a component of any climate- informed policy and practice can help reduce the burden of CC risk and contribute to adaptation. However, constraints associated with mandates, priorities and capacities often restrict flow of information and oblige potential users to get by without it. Analyses undertaken in Africa revealed that climate data is little used for development processes due to weaknesses in demand and supply of relevant information (UNECA, 2009). A possible explanation could be the limited interactions between researchers, policy makers and development institutions which impede communication and subsequent utilization of research outputs. In Kenya, information sharing protocols have not been developed and existing information sharing platforms are not fully exploited, hence hindering wider dissemination of research findings. The low understanding of CC issues by policy makers limits scaling up of promising interventions to enhance the adaptation process.

Conclusion

Kenya's ability to adapt to CC is compounded by many factors including poverty, weak institutions, poor infrastructure, lack of information and poor access to financial resources. Other constraints include low awareness levels, knowledge and personnel with relevant skills, and poor coordination across departments. Also important is the fact that most populations vulnerable to climate risks are often socially and politically marginalized, and therefore unable to influence government to work in their interest.

There is a need to avert risks posed by CC and variability through adoption of robust adaptation strategies as a means of mitigating severe food insecurity in the country. However, current policies have not adequately factored in CC adaptation and mitigation strategies to ensure a climate-resilient economy. The recent development of the National Climate Change Response Strategy to strengthen and focus nationwide actions towards CC adaptation and mitigation is therefore a positive step towards achieving the goal of CC adaptation planning. Emphasis is on the most vulnerable sectors of the economy such as agriculture, water, forestry and physical infrastructure for quick and immediate action.

However, specific efforts are required to prioritize incentives for CC adaptation and mitigation activities in agricultural livelihood zones across the country. To facilitate adaptation, the Government needs to integrate CC issues into development planning and policy making. The agricultural sector must be prioritized in terms of resource allocation. Further, the Government needs to formulate development policies that are locally relevant and globally consistent. Such effective policies can only be developed if impacts of CC on critical sectors of the economy and natural resources are assessed.

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Determinants of organic manure use to combat soil fertility declining in the semi-arid area of Kibwezi in Kenya

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Abstract

Soil fertility is declining in many areas of sub-Saharan Africa due to various factors of which climate change and the human action. Organic manure is one of the inputs that can be used to address poor soil fertility. This article analyzes the socio-economic factors which influence the use of the organic manure in the semi-arid area of Kibwezi in Kenya. *A Logit model* is used to isolate the variables affecting the use of the strategy. The results show a correlation between certain socio-economic variables and the use of the organic manure. Socio-economic variables such as matrimonial statute, local technical training, access to the resources, social relations in the village on one hand, and level of education of the heads of households on the other hand, have a significant influence on the probability of organic manure use to the thresholds of 5% and of 10% respectively. The other factors a priori relevant, present in the model, do not have any significant effect on the choice of the strategy. Lastly, to more increase the rate of adoption of this strategy, some strong actions must be implemented by development actors.

Key words: climate change, farmers, Kibwezi, logit model, organic manure, semi-arid zone.

Introduction

Climatic change and land degradation constitute some threats for the survival and the subsistence means of million people in sub-Saharan Africa (SSA). The strong dependence of the economies and the rural populations on rainfed agriculture, severe poverty and food insecurity, as well as the weak development of institutional and infrastructural capacities are such as that adaptation to climate natural variability remains always is a challenge (Sultan, 2011; Berg *and Al*, 2011).

Soil fertility is declining in many areas of SSA. Climate change should cause more extreme weather events like floods, drought and more unforeseeable weather. These changes will make probably only accentuate the problems encountered with soil fertility level. Soils fertility decline can be attributed to various reasons. The burning of crops residues causes in the soil some loss of its organic matter and its micro-organisms useful to its transformation. The abandonment and exposure of soils without protection against the sun and the wind, cause on one hand the oxidation of the organic matter, and on the other hand soil drying up and hydrous and wind erosion acceleration which conduct to soil loss of fertilizing matters. The excessive or insufficient use of fertilizers and inadequate crops rotations also involve a reduction in soils fertility (Oram, 1989; Hansen, 2002; UNDP, 2004).

In Kibwezi district, which belongs to the semi-arid area of Kenya, the drought generated by the climate change constitute a cyclic phenomena which belong to the normal life of the populations because well before those of 1970-1980 decades, they had endured years of drought in 1951-1953 and 1959-1962, with a painful procession of consequences (UNDP, 2004; MoA, 2009). Nevertheless, it was noted in this area which that it is from the 1970 decade that the droughts are more recurrent, with more catastrophic consequences (MoA, 2009). The poor populations like those of Kibwezi district, are particularly vulnerable to the effects of climate change because of their greater dependence to rainfed agriculture and their lower adaptation capacity (Abou, 2010).

However, there are many traditional and modern practices which can contribute to improve soil fertility and to help farmers making their farms more resilient and resistant to the changing climate. They include

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use of fertilizers, use of crops residues and other organic matters (organic manure, mineral manure, compost, green manures), plantation nitrogen fixing crops and trees, terraces, sowing under vegeTable cover, mulching, crops rotation. etc. Moreover, as Sultan (2011) announces it, the poverty of these populations does not allow them an access to technological adaptations (mechanization, manure, irrigation) and to the health care systems (vaccination, care curative), and often constitutes a worsening factor of the socio-economic impacts of climate change. In Kibwezi district, the principal adaptation strategies relating to the effects of climate change on the soils are the use of terraces and organic manure. Nevertheless, within the framework of this article, we choose an analysis of the determinants of organic manure use because there is a certain polarization on the use of terraces (87%). The aim of this study is to identify the socio-economic variables which influence the use of organic manure as regard to soil fertility declining, before making some technical and political recommendations.

Materials and methods

Study area and data-gathering

The study was carried out in in Kibwezi district, located in south-eastern Kenya. After having furrowed during two weeks the semi-arid areas of Kenya, our choice was made on this zone, because it belongs to the arid areas (250-500 mm) of sub-Saharan Africa where the populations, mainly farmers-grasers, are seriously affected by the effects of climate change (MoA, 2009; Kienken, 2007). A first field visit enabled us to carry out focus-groups in three villages, and to make field observations.

Thereafter, a structured questionnaire was adminstered to 186 household heads chosen randomly according to a transect materialized by the principal roads connecting the various villages. Only data from 111 questionnaires are used in this article because of certain irregularities detected. Lastly, some semi-directed interviews have been realized with some of the persons in charge for the public and private structures (Agriculture, Livestock, Water, Red Cross, USAID), and the data allowed us to complete the results.

Conceptual model

In this study, we make the assumption that the socio-economic variables influence organic manure use as regard to the declining soil fertility. One of the objectives of our study is to specify the behavior of the farmers vis-a-vis of the adaptation strategies by identifying the factors influencing their adoption, in the form of a probability. To achieve this goal, we chose a *Logit* modeling, facilitating results handling (Hurlin, 2003). This because on the empirical level, the analysis of the determinants of a strategy adoption by a farmer is based on a model of discrete choice (McFadden, 1973; Foster and Rosenzweig, 2010). Table 1 shows some statistics of the dependent variables used in the model.

Commented [LW40]: Is this from literature ? please insert reference.

And since terraces are mentioned in the objective, then the intro should give some background on this. That is set the scene

Commented [LW41]: meaning???

Commented [LW42]: Not clear.

Commented [LW43]: Thought the first visit could have been site selectio ?

Commented [LW44]:
Revise sentence. 'carry out focus group discusiions…' not 'carry out focus groups…'

'At the begining of the study, focus group discussions were held to…. In addition, field visits were made to collect data on…..

Commented [LW45]: Please state this more clearly

Commented [LW46]: 'the rest of the questionnaires had irregulariies' ?

Commented [LW47]: 'in addition, data from sem-direct interviews held with personnel from the ministry of agriculture…….have been used ' ?

Commented [LW48]: Meaning ?

The paper does not exsplore the link between use of manure and improved soil fertility

Commented [LW49]: Which are these ?

Table 1: Variables used in the model

Variables	Variables meaning and values	Mean	Std Dev	Min	Max	N
USMARASO	Use of the organic manure (1 if it uses and 0 if not)	1,61	0,489	0	1	111
AGE	Age of surveyed person (years)	45,42	12,77	25	90	111
GENDER	Sex of surveyed person (1=homme and 0=femme)	1,49	0,502	0	1	111
MARSTAT	Matrimonial status (1=marié and 0=autres)	1,16	0,564	0	1	111
LEVEDUC	Level of education (1=primaire and 0=autres)	1,67	1,02	0	1	111
NYCROPF	Number of years in agriculture	17,80	9,87	2	47	111
LABOAVAI	Labour Availability (1=oui, 0=non)	1,69	0,463	0	1	111
TECHSKIL	Local technical skills (1=oui, 0=non)	1,73	0,441	0	1	111
ACCESCRE	Access to credit (1=oui, 0=non)	1,67	0,470	0	1	111
ACCESRES	Access to resources (1=oui, 0=non)	1,07	0,259	0	1	111
LOCLINKS	Strong Local links in the village (1=oui, 0=non)	1,29	0,459	0	1	111
ACCMARKT	Access to markets (1=oui, 0=non)	1,24	0,430	0	1	111
ACCNEWS	Access to information (1=oui, 0=non)	1,090	0,287	0	1	111
CHILSCHO	Children going to school (1=oui, 0=non)	1,49	0,502	0	1	111

Results and discussions

Effects of climate change on soils

According to Sultan (2011) quoting the Intergovernmental Panel of experts on Climate Change (IPCC), the variations green house gases concentration as a whole, will lead, on a regional and global scale, to evolution of climatic parameters such as temperature, precipitations, soil moisture and sea level. Earth temperature increased by point three to point six degree approximately since the end of the XIXe century, and the sea level rose from ten to 25 cm during the last hundred years. It is thus seen that, climate change is obviousness. The rural populations of sub-Saharan Africa are particularly exposed to climatic risks insofar as they are narrowly dependent on the rainfed agriculture which represents nearly 93% of the cultivated lands. The perceived effects of climate change on agricultural resources are thus varied, but this section will present only those perceived by the farmers on soils (Table 2).

Table 2 : Direct or indirect effects of climate change on soils perceived by farmers

N°	Effects perceived by farmers	Frequency	Percentage (%)
1	Soil fertility declining	93	83,8
2	Hardening of soil surface	66	59,6
3	Soil color modification	12	10,8
4	Increase in soil erosion	10	9,0
5	Lightening of soil	3	2,7

All the effects perceived here by the farmers are dependent between them, leading all to soil fertility declining, and are directly or indirectly related to climate change. This known as, because of the stormy and torrential rains in summer, and of the violent and dry winds in dry season, hydrous and wind erosion involves the loss of organic matter of soils, making them hard and compact (clay soils) or light (sandy grounds). This organic matter loss is perceptible through the clear color of the soils, and fertility lowering which is the final result of all these effects, is perceptible by the populations through the continuous decreasing of crops yields. Indeed, according to Mapfumo *et al*. (2008), the results' from a study carried out in seven countries of three African zones (Western, East and Southern), show that the principal effect of

Commented [LW50]: Please translate the french words in this column to english

Commented [LW51]: For variables with max of one, values in this column should not be above 1 !!!!

Commented [LW52]: Which resources ?

Commented [LW53]: Which century?

Commented [LW54]: Is this in the objective ??

Commented [LW55]: Results to support this?

Commented [LW56]: In Africa ?

Commented [LW57]: Perceived ?

Commented [LW58]: Clear ?

Commented [LW59]: Meaning ?

climate change on soils raised by the peasants in each area is the declining of soil fertility. Apart from the declining of soil fertility and the hardening of soil surface which are the more easily perceivable phenomena by the farmers especially during sowing periods (hardening of soil surface) and harvests (soil fertility drops), the other effects are not easily perceivable. In the steeply sloping zones, hydrous erosion is strong and perceivable through the ravines and gullies.

Farmers' Adaptation Strategies to combat soil fertility declining

Climate change generates soil degradation, but accelerates also the degradation of those not protected and exposed to the bad weather on sloping lands like those of Kibwezi district; what compromises the capacity of the current soil management practices to maintain the productive potential of these soils. With an aim thus of ensuring their survival, the farmers of this area use various adaptation strategies (Table 3).

Commented [LW60]: revise

Table 3. Farmers' Adaptation Strategies

N	¶Adopted adaptation strategies	¶Frequency	¶Percentage (%) ¶
1	¶Terraces ¶	97 ¶	87,4 ¶
1	¶Organic manure	¶43	¶38,7 ¶
2	¶Plantation of trees	¶6	¶5,4 ¶
3	Soils' ¶Irrigation	¶5	¶4,5 ¶
4	¶Use of fertilizers	¶4	¶3,5 ¶
5	¶Use of the plough to break the hardened soils	¶1	¶0,9 ¶

Commented [LW61]: Meaning ?

Commented [LW62]: Irrigation ?

The massive use of the terraces by the populations indicates that it is about an area with sloping relief where hydrous erosion remains the principal cause of the of soil fertility loss. The true problem here is rather that of the quality of the terraces which as the majority is badly conceived and maintained. The significant use of the organic manure which is an interesting technique, could be explained by the strong association of agriculture and livestock in this area (80%), but the progressive abandonment of bovine breeding bovine to the profit of that of sheep and caprine, will limit its use to means or long terms.

It comes also from Table 3 that apart from terraces, adoption rate is weak for all the other adaptation strategies. Indeed, according to Leary., Kulkarmi., and Seipt (2009), in dry Africa, there exists a deficit of adaptation strategies adoption, and this deficit is likely to grow with time because the future climatic variations and their extremes will be apart from the limits to which the populations were exposed and adapted. This could be explained by the adaptation difficulties related to poverty, weak access to agricultural information, weak collaboration with the agricultural extension services, and by the enclosure of the majority of the villages.

Econometric model

We point out that the explained variable is represented by the use of the organic manure to adapt to the declining soil fertility generated or accelerated by climate change in the semi-arid area of Kibwezi in Kenya.

Commented [LW63]: In introduction, expound on how climate change has contributed to poor soil fertility.

Table 4: Determinants of organic manure use by the farmers (Logit model)

Variable	¶Estimate	¶Standard deviation	¶Wald	Sig.¶
Constant	¶-1,206	¶2,239	¶0,290	¶0,590 ¶
AGE	¶0,036	¶0,031	¶1,400	¶0,237 ¶
GENDER	¶-0,676	¶0,516	¶1,716	¶0,190 ¶
MARSTAT	¶1,505	¶0,670	¶5,044	¶0,025 ** ¶
LEVEDUC	¶-0,581	¶0,320	¶3,284	¶0,070 * ¶
NYCROPF	¶-0,043	¶0,035	¶1,553	¶0,213 ¶
EXTASSIS	¶0,841	¶0,805	¶1,092	¶0,296 ¶
LABOAVAI	¶0,787	¶0,687	¶1,311	¶0,252 ¶
TECHSKIL	¶-1,674	¶0,812	¶4,245	¶0,039 ** ¶
ACCESCRE	¶0,351	¶0,599	¶0,344	¶0,558 ¶
ACCESRES	¶-2,731	¶1,220	¶5,005	¶0,025 ** ¶
LOCLINKS	¶1,410	¶0,623	¶5,121	¶0,024 ** ¶
ACCMARKT	¶-0,751	¶0,683	¶1,210	¶0,271 ¶
ACCNEWS	¶1,564	¶1,164	¶1,806	¶0,179 ¶
CHILSCHO	¶-0,924	¶0,604	¶2,341	¶0,126 ¶
Numbers of observations		¶111 ¶		
Log-probability		¶-148,199 ¶		
Pseudo R2		¶0,266 ¶		
Khi 2		¶39,38 ¶		
Prob		¶0,000 ¶		

The levels of significativity are respectively:¶1% (***), 5% (* *) and 10% (*); Source: Data ¶analysis

The results highlight a correlation between some socio-economic factors and the use of the strategy. Thus, using *the Logit model*, one notes that the socio-economic variables such as the marital status, the local technical and skills, the access to resources, the social relations in the village have a significant influence on the probability of use of the organic manure to the threshold of five %, and the household heads level of education to the threshold of ten %. . Among these unquestionable variables some have positive effects on the probability organic manure use, in particular, the marital status and the social relations in the village, while, others affect the choice of the strategy negatively, in particular, the level of education, local technical skills and the access to the resources.

Commented [LW64]: State if effects are positive or negative

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Moreover, the analysis of the sensitivity of the probability of adoption compared to the explanatory variables shows that certain socioeconomic variables have the strongest marginal effects; moreover, certain variables negatively affect adoption propensity of the strategy. A singular analysis of the variables having significant effects on the probability of choice will enable us to highlight these effects.

Commented [LW66]: Which ones ?

The marital status (MARSTAT) is correlated positively with the probability of the farmers using this adaptation strategy to the threshold of five %. The married farmers are those who have children being used as labour for the animals' maintenance, collection and spreading of the organic manure to improve soil fertility and in order to increase their agricultural income and to satisfy the needs of the exploitation and the family. The marital status determines the needs and the expenditure of the producer, and conditions his decisions to improve its agricultural productivity.

Commented [LW67]: Not necessarily. 'tend to have children'. These children can be a source of labor….

Commented [LW68]: ?

Commented [LW69]: ??

The level of education (LEVEDUC) negatively influences the choice of this strategy to the threshold of 10%. The more the education level of the farmers is raised, the less they will tend to adopt this adaptation strategy to combat soil fertility decreasing. In this zone, the producers having a high level of education are generally civil servants who work elsewhere, and thus do not have enough time to devote themselves to a

Commented [LW70]: I think you mean 'the less the chance of using animal manure on their farms' ?

constraining technique. Even when they make agriculture, they have access to several sources of information which guide them to use other adaptation strategies to improve their agricultural production. They have also the financial capacity to use the chemical fertilisers. Education is a factor affecting the adoption and the application of the technological innovations in rural medium (Kienken, 2007).

The local technical skills (TECHSKIL) had significant effects on the probability of the choice of the strategy to the threshold of 5%. However, it is to be raised that with the negative sign of the coefficient, one notes that the more the farmers have local techniques, the more they will have tendency to less adopting this adaptation strategy which really is very forced (time, energy, labor). The use of chemical fertilizers or green manures for example, is less constraining and effective when one has financial means.

The access to resources (ACCESRES) (ground particularly) is a variable which had significant effects with the threshold of 5%. However, the negative sign observed makes believe that the farmers having more resources in will have tendency to less adopting this strategy. Because, the great landowners are not ready to use the organic manure because of the significant quantities required, especially that the availability of this manure poses problem due to the fact that bovine breeding is progressively abandoned following the past and current droughts.

Moreover, one observes positive significant effects (5%) of the variable local social relations in village (LOCLINKS) on the probability of the choice of the strategy. What stipulates that the farmers having solid social relations in the village will have tendency to adopting this adaptation strategy more. That consolidates our assumption which the individuals do not come in closed environment; they are influenced by their entourage. In the same way, the existence of solid local social relations facilitates the access to the organic manure and the labor during work periods.

Let us note finally that, other variables a priori relevant present in the model do not have any significant effect on the choice of the strategy by the farmers, although these variables influence its choice. It is in particular about the age of the household heads, the sex, the external assistance, the experience in agriculture, the availability of labor, the access to credit, the markets and information, and the sending of children to school.

Conclusion and recommendations

The *Logit* model used to determine the socio-economic variables which influence the use of the organic manure reveals the existence of a correlation between certain socio-economic factors and the use of the strategy. Thus, we notes that the socio-economic variables such as the marital status, the local technical skill, the access to resources, the social relations in the village have a significant influence on the probability of use of the organic manure to the threshold of 5%, and the level of education of the household heads to the threshold of 10%. Among these variables, some have positive effects on the probability of use of the strategy, in particular, the marital status and the local social relations in the village, while, others affect the choice of the strategy negatively, in particular, the level of education, local technical skills and the access to resources.

It is possible to reduce the vulnerability of the natural and human systems to climate change by implementing policies and adaptation measures which accompany the endogenous and local solutions practiced by the local populations. Thus, in order to increase the probability of adoption of the organic manure use to combat soil fertility, the following recommendations can be made:

- to reinforce the sensitizing of the farmers on the importance of the organic manure in the Figureht against soil fertility declining
- the social relations in the village are also significant, and in this case, the government through the qualified engineering departments (agriculture, breeding) must incite and support these farmers to militate in associative groupings
- to improve the access of the farmers to agricultural information through agricultural extension services

Commented [LW71]: ?

Commented [LW72]: The data in the paper suggests less than 4% of the farmers use fertilizer

Commented [LW73]: Positively or negatively ??

Commented [LW74]: Are farmers forced to use manure ? don't think so

Lack of labor could be a contraint to use of manure but the results don't support this arguement

Commented [LW75]: 'ownership of livestock should have been a variable.

The issue could be that livestock are few. So little manure availble

Commented [LW76]: Revise statement

Commented [LW77]: Good social networks ? or something like that

Commented [LW78]: Meaning ?

Commented [LW79]: Thought networks were good for information sharing.

- to solve the land problem by allocating some piece of land to the new immigrants in the various villages
- to encourage preparation and use of compost in the place of organic manure for which availability is a limiting factor.

Aknowlegment

At the end of this article, we want to thank the CRDI, the AAZ, the START and the DFID which give the opportunity to MR Salé Abou to carry out a research work at Egerton University of Njoro in Kenya within the framework of the African Climate Change Fellowship Program (ACCFP). We also thank the persons in charge for the START and the Egerton University of Njoro, particularly Pr Lenah Nakhone Wati, who gave us their unconditional support during his research period (May 2009 at May 2010) and especially during data-gathering, which enabled us to write this article.

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Factors affecting integrated water management practices in Mwania and Kalii watersheds in Machakos and Makindu Counties

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Abstract

Agriculture in Kenya continues to be the lifeline for the majority of the rural poor. The sector contributes up to 25 % of the total Gross Domestic Product (GDP) (World Bank, 2011). 80 % of the agricultural land in Kenya is under rain-fed agriculture, with generally low yield levels and high on-farm water losses. This problem led the KARI Katumani scientists to come up with this project which aimed at promoting Integrated Water Management (IWM) technologies, an effort geared towards increased food security in Mwania and Kalii watersheds. This pilot project was based in Machakos and Makindu Counties. To warrant up scaling of the technologies it was important to conduct this study which aimed at trying to establish whether there are constraints which affected the implementation of the technologies. Ethnographic research methods were applied in data collection which included: Focus group discussions, direct observation and documentary information. The result showed that there were many challenges that faced implementation of IWM practices. They included poverty, delay in delivering subsidized fertilizers and seeds to farmers, myths surrounding success stories, inadequate labor, lack credit facilities, limited information on early warning, limited extension services, poor transportation means, and inadequate information on policies guiding IWM practices. This study recommends that the farmers should be linked to banks and other micro finances which would assist them to get loans. The government to deliver farm in puts on time, farmers to be equipped with weather forecast information on time, and to consider constructing feeder roads.

Key words: IWM, farmers, watershed, Mwania and Kalii.

Introduction

According to Jaspers (2003), Integrated Water Management (IWM) is the management of surface and sub surface water in qualitative, quantitative and environmental sense from a multidisciplinary and participatory perspective. It focuses on the needs and requirements of the society at large with regard to water use for now and in the future and therefore aims at sustainability in all senses (*Ong'or 2005)*. The concept of integrated watershed conservation and management in Kenya emanates from the relationships between nature, people and culture. Rainwater is the primary source of water in agriculture. Agriculture in Kenya continues to be the lifeline for the majority of the rural poor. Despite its significance as a primary source of livelihoods, the sector is afflicted by several challenges which are especially predominant in the Arid and Semi-Arid Lands (ASALs). The level of crop productivity is below potential and in recent years, yield and value for some agricultural produce have either remained constant or are on the decline (GOK 2010). ASALs in Kenya exhibit erratic rainfall and weather conditions (frequent dry spells with occasional flooding), frequent crop failures and low crop and livestock productivity (GOK 2010).

Watershed management as an entry point acts as the beginning to address the issues of sustainable rainwater management for improving livelihood. KARI Katumani saw the need to come up with IWM technologies to promote food production among the farmers in Machakos and Makindu however these were only pilot projects which upon their success would be up scaled elsewhere. Therefore to warrant up scaling of the technologies it was important to conduct this study which aimed at trying to identify the constraints which affected the implementation of the IWM practices.

Objectives of the study

The main objective of the study was to assess the constraints facing implementation of IWM practices in Mwania and Kalii watersheds in Machakos and Makindu counties. The specific objectives were to

- To identify and document the constraints faced by the farmers while trying to implement IWM technologies
- To come up with recommendations for promotion of IWM practices

Materials and methods

Study area

This study took place in Machakos and Makindu counties in Eastern part of Kenya. The sites were chosen purposively because this is where KARI with the support of Association of Strengthening Agricultural Research in East and Central Africa (ASARECA) had established some pilot projects. In Machakos, the study took place in Mwania Watershed, while in Makindu it took place in Kalii watershed. In the study sites the population is homogeneous.

Data collection

Documentary data was acquired through literature search of published and non published work in order to give some background information of the project.

Primary data was gathered through focus group discussion. A focus group discussion guide was used to gather information from all the groups. Six focus groups were conducted three from each watershed.

Table 1: Groups that participated

Mwania watershed Focus groups	Venue	Kalii watershed Focus groups	Venue
Love & Kaathi	AIC Church Love	Kalii	Kalii catholic church
Mwania and Kilungu	Katumani - Resource Centre	Mtendeu	Kavete church
Kyamulu	AIC church Kyamulu	Nduluni	Nduluni catholic Church

Results and discussions

In total 134 people participated in focus group discussions. Kalii focus group had the highest (20.2%) number of participants, Kathi and love 19.4%, Kyamulu 18.6%, Mutendeu 17.1%, Mwania and Kilungu 16.4%. Finally, Nduluni had the lowest (8.2%) number of participants. The explanation given for low participation was that there was another meeting which was being held by the Lutheran church, where relief food was being given.

More than half (56%) of the focus group discussants were females, while 44% of the participants were males. The reason given for this was that most men the study sites usually move to urban towns to look for jobs. On the other hands, women are left in villages and they are the major providers of the much needed labour in the farms.

Some of the IWM Technologies introduced

This study indicated that these groups were working with KARI apart from Mtendeu. It came out clearly that these groups were implementing IWM technologies which they were introduced by KARI Katumani. Some of the technologies mentioned included use of composite manure, agro-forestry, *tumbukisha*, *Fanya juu*, tied ridges, early planting, spacing, digging benches among others. It also came out clearly that the groups had embraced the introduced technologies by KARI. This study reveals that they had formed Water Resource Users Associations (WRUAs) so as to protect the watersheds.

Organizations involved in assisting the communities in implementing IWM practices

Findings of this study indicated that there were few organizations and institutions which were involved in assisting the farmers in Mwania and Kalii watershed to implement IMW practices. Kenya Agricultural Research Institute (KARI) was ranked highly by all the groups in the two watersheds. KARI worked in collaboration with other government line ministries such as the Ministry of Agriculture (MoA), Kenya Forest Services (KFS), and Water Resources Management Authority (WRMA). The role of the church in promoting IWM practices was also highlighted although its contribution was not in a big scale, for instance groups in Mwania watershed mentioned Katoloni mission for having provided them with tree seedlings to plant in their farms. NGOs such as Child Community Fund (CCF), Catholic Relief Service, Lutherian Church Foundation were also mentioned to have promoted IWM practices.

Major constraints facing implementation of IWM practices

Poverty. The first problem mentioned by focus group discussants from Mwania and Kalii watershed that hindered the implementation use some IWM technologies. They indicated that some of the practices such as drip irrigation, green house, sand dams, tied ridges, *tumbukisha*, required a lot of money which they did not have. They said some of those technologies could not be implemented by people who had no sufficient resources. Therefore they indicated that since majority of them were poor they had to engage in those practices which were simple and affordable.

Delay in delivering subsidized fertilizers and seeds to farmers. Policies leading to liberalization and the removal of subsidies on farm inputs in the 1990s resulted in a rapid escalation of prices. As prices rose, farmers used less fertilizer or none at all, resulting in lower demand for the input. The government decided to promote agricultural production by subsidizing prices of fertilizers to farmers. These positive effects of government subsidies are felt by farmers in the country but in the study site they felt that the prices were still very high for them to buy. They also reported that the subsidized fertilizers and seeds were delayed and this affected planting which consequently affected production. The farmers also stated that sometimes the subsidized fertilizer was usually in small quantities and that sometimes it got out of stock before most of the farmers had acquired the inputs.

Inadequate labor. In the two study sites focus group discussions mentioned labour as a big problem which was affecting the implementation of IWM Practices. The reasons they gave for this was that their children were in schools and colleges. While those who had completed their collage education moved to urban areas in search of formal employment**.** Limited labour in Kenya is attributed to the education system which prepares young people for white collar jobs; a fact that contributes to the development of negative attitudes to agriculture and increased numbers of rural-urban migrants leaving behind the old, too young and women who are already over-burdened. Gender division of labor also impacted negatively on adoption and sustenance of watershed management measures since some of the duties such as land preparation, tillage and weeding are normally assigned to female while men provide their labor in activities which are income generating, such as in attending cash crops.

Lack of credit facilities. It was important to know whether the groups were having access to credit facilities as there was an assumption that they would get credits to implement some of the IWM practices. However, it came out clearly that the farmers had no access to credit facilities from the banking institutions. The most common source of credit was *Merry-go-round* in which members make monthly contribution to one another on rotational grounds. Limited access to credit can be explained by two factors. To smallholder farmers of semi-arid Mwania and Kalii watershed, borrowing money for farming does not make economic sense as the chances of crop failure are much higher than those of success. Secondly majority of them are poor and therefore lack collateral, including lack of land title deeds

Salty water. According to the findings of this study slightly less than half (45%) of the discussants reported that they depended on water from Kiboko river which they said was salty. This problem was highlighted by all focus group discussants from Kalii watershed. According to them salination affected the growth of some plants. They gave a case of tree nurseries which they had established but they all dried up. This argument is in agreement with Rhodes and Loveday (1990) which indicates that salination reduced rates

of plant growth, reduced yields, and in severe cases, total crop failure. The problem mentioned have serious implications on the technologies introduced to enhance soil and water management**.**

Soil erosion. Soil erosion as a result of quarrying, sand harvesting and charcoal burning activities was also mentioned by all participants from Mwania and Kalii watershed. They indicated that despite the fact that these activities contributed positively to generating income to the locals they impacted negatively to their environment especially sand harvesting for building houses, road constructions and sand as harvesters dig deeper, they leaving behind a series of gaping holes that make the stream water stagnate affecting the flow of water downstream. The study indicated that sand scooping has led to collapse of river banks.

Limited information on early warning. Focus group from Kalii Watershed indicated that weather forecast information provided was not always reliable. They indicated that sometimes the information provided about the onset and amount of the rains was misleading. They gave a case In point where by, they were informed that the rains would come earlier but it came very late and was poorly distributed as a result their crops were affected. In some cases the meteorological announces that there would be plenty of rains but it ends up being little. According to them the meteorological department is not supposed to give generalized information of a whole county but would be better if weather forecast information would be specified according to regions.

Limited **extension services.** According to the findings of this study focus group discussants stated that extension officers were rare. Some groups said that they have never seen extension officers, others revealed that they started having interactions with extension officers during the implementation of ASARECA project which was introduced to them through KARI. It was important to understand how they were getting information before KARIs interventions and they indicated that they used to get from exchanging ideas with other farmers. The agricultural sector extension service plays a key role in disseminating knowledge, technologies and agricultural information, and in linking farmers with other actors in the economy. However limited access to extension services hinders most farmers from keeping pace with introduced watershed management technologies.

Poor transportation means. Focus group discussants reported that poor roads made it almost impossible to take the needed inputs such as fertilizers to their farms. They also stated that poor roads led to increased prices of goods from the farms to the markets and vice versa. In addition it also led to spoilage of perishable commodities as they wait for the available transport and during transportation. They also indicated that in some cases they do not get transport at all especially during the rainy season since most of the roads are not tarmacked which makes them impassable during the rainy season hence if there farm inputs to be transported they are delayed until the rain stops. This complicates planting and harvesting of some farm commodities.

Discussions, conclusions and recommendations

The findings of this study indicated that the communities of Mwania and Kalii watershed had been taught IWM technologies. According to the focus group discussants there were some institutions and organizations which were involved in introduction of IWM practices. They included government departments, NGOs and faith-based organizations. However, the discussants indicated that KARI had contributed significantly to the implementation of IWM technologies as compared to the other stakeholders. The study indicated that there were various constraints which hindered the full implementation of some of the introduced technologies. The constraints included poverty, the focus group discussants indicated that some IWM practices required a lot of capital and since the members were subsistence farmers they did not have capital to fund heavy investments. The other constraint mentioned was delay in delivering subsidized fertilizers and seeds to farmers by the agriculture departments and as a result farmers planted without fertilizers and also planting seeds which are not certified leading to low yields. Inadequate labour was also highlighted and this was attributed to children having been taken to learning institutions and rural urban migration. Limited access to credit facilities was also mentioned as the discussants indicated that their only source was *Merry-go-round.* Soil salination was

mentioned as a big problem by Kalii focus groups. Other problems reported included inadequate weather forecast information, extension services and transportation.

Conclusion

This list of challenges facing IWM implementation in Mwania and Makindu watershed can be solved if effective extension and advisory services would be accorded to farmers especially. Those relating to poverty, labour and lack of credit facilities would be solved by the farmers being linked to banks who give credit to farmers.

Recommendations

This study recommends that the farmers should be linked to banks and other micro finances which would assist them to get loans. There is also need for the government to make sure that subsidized fertilizers and seeds are delivered to the farmers on time. A study of the degree and necessary remedial measures on saline soils is required. In addition there is also need for the farmers to be well equipped with weather forecast information as this will assist them to plant at the right time and suiTable crops depending on the information given. There is also need for the government to consider constructing feeder roads and also to recruit extension officers.

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Farmers' risk perceptions and adaptation to climate change in Lichinga and Sussundenga in Mozambique

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Abstract

A study was carried in two villages of Lichinga and Sussundenga Districts in Mozambique to assess the perceptions of smallholder farmers to climate change and adaptation strategies. Using data obtained from a farmer survey, descriptive statistics analysis was undertaken using SPSS Version 16. Results indicate that farmers from both districts cited rainfall variability and higher temperatures to have severely affected maize production. Due to the late onset of rains, in Lichinga, the planting period has changed from November (47.5%) to December (70%), while in Sussundenga the planting period has changed from September-October (40%) to November (62.5%). The rain seasons have become shorter and dry seasons longer. It is concluded that differences in perceptions of climate events differ within the two districts and diversification through raising adapted crops and having off-farm income significantly reduce climate risk perceptions. It is also recommended that adaptation strategies should support farmers' livelihood diversification and off-farm farm income risk management strategies.

Key words: climate variability, farmers' perceptions, adaptation strategies.

Background

Climate variability and droughts are important stress factors in Africa, where rural households have adapted to such factors for decades (Mortimore and Adams, 2001). Historical data shows that the continent is already undergoing climate change. The continent is becoming warmer and drier. Rainfall is becoming less predictable. Meanwhile, storms, droughts and floods are becoming more common and intense (Ehrhart and Twena, 2006). In Mali, Lacy *et al.* (2006) revealed a tendency for a shortening of the rainy season to induce farmers to shift some of their sorghum production to a variety with a shorter cycle than the traditional one. In Burkina Faso, Nielsen and Reenberg (2010) found rainfed cereal production to be declining due to a change in climate and a shift towards a higher level of dependence on migration, livestock, small-scale commerce and gardens. Recent events, such as the poor rains in Southern Africa 2001-2013, demonstrate that communities may already be suffering the consequences of less predicTable weather patterns (Wiggins, 2005).

As the poorest country in Southern Africa – a region that is projected to become substantially hotter and drier – Mozambique is likely to feel the impacts of climate change more than most countries in the southern Africa (Ehrhart and Twena, 2006). The most striking impacts of climate change over southeastern Africa are expected to be an increase in the frequency and severity of extreme events such as droughts, floods, and cyclones (Ribeiro and Chaúque, 2010); all of which are expected to become more frequent, intense and unpredicTable (IPCC, 2001).

Climate variability directly affects agricultural production since agriculture is inherently sensitive to climatic conditions and is one of the most vulnerable sectors to the risks and impacts of global climate change. Climate change will affect food security by reducing livelihood productivity and opportunities in Mozambique (Ehrhart and Twena, 2006). Research by the Government of Mozambique suggests that mean air temperatures will rise by at least 1.8-3.2° C nationwide by 2075 (MICOA, 2007). Precipitations are predicted to fall by 2-9%, which will take greatest effect between November and May. As this coincides with the growing season, it will have an especially pronounced impact on crop yields (Ehrhart and Twena,

2006). Harvest failure and incidents of food insecurity in Africa have become regular events occurring at least once or twice every decade (Eriksen, 2005).

Over time, rural households develop various coping strategies as a buffer against uncertainties in their rural production induced by annual variations in rainfall combined with socioeconomic drivers of change (Cooper *et al.,* 2008). Coping strategies may be preventive strategies such as altering planting dates, introducing other crops and making investments of water equipment, or may be in-season adjustments in the form of management responses (Trærup, 2010). Farmers can adapt to climate change by modifying the set of crops planted and their agronomic practices (Blanc, 2011). The latter most often include consumption smoothing, sale of assets such as livestock, remittances from family members outside the households and income from casual employment (Niimi *et al.,* 2009).

While extensive research on the impacts of climate change has tended to focus on impacts on country level, less effort has been directed at developing adaptation strategies at individual households and little has been done on the farmer risk perception. There is, thus, need to investigate the farmer risk perception and adaptation to climate change on agriculture in Mozambique at the individual household level, considering that agriculture remains the backbone of the country's economy. This study seeks to contribute to the body of research on climate change by investigating the vulnerability of smallholder farmers in Mozambique.

Methodology

Study site

The study was conducted at Lichinga and Sussundenga Research Stations in Mozambique (12º 30′ to 13º 27′ S; 34°50' to 35°30' E at 1000 m). The agricultural production in two is predominantly rainfed and receives unimodal rainfall (MAE, 2005a,b). Lichinga Research Station is located in Lichinga District to the West of the Niassa province and lies along. The rains occur between November and April ranging from 900-2000 mm per annum. The temperature ranges from 16.1-32.9º C with an annual average of 22.9ºC (MAE, 2005a). The soils are ferralsols according to FAO (2006) soil classification system.

Sussundenga Agrarian Research Station is located in Manica province, central Mozambique and lies on 19º20′ S; 33º14′ E, with an altitude of 620 m. The rains occur between November and April with average annual of 1,155 mm (MAE, 2005b). The average minimum temperature is 9.5º C in the month of July and average maximum is 29.1º C in the month of January, giving an annual average of 23.0º C (MAE, 2005b). The soils consist of ferralsols, lixisols and acrisols according to FAO (2006) soil classification system.

Data collection procedures

A household survey was conducted in Lichinga and Sussundenga Districts of Mozambique to evaluate the farmers' risk perception and adaptation to climate change. Two villages were randomly sampled from each of the selected Districts. The survey was carried out at Lichinga District from 16-17 February and at Sussundenga from 20-21 February 2012 using questionnaires with open-ended and closed-ended questions. The survey included face-to-face interviews of 80 farmers. Forty farmers were selected in each district of which 20 came from one village. Selection of respondents was based on farmer's willingness to participate in the research. During the data collection process, participants were explained the objective of the study as well as its confidentiality. Interviews were done at farmers' homesteads. Respondents were household heads and in their absence, any member of the household was interviewed. In each district, a lead farmer was identified, contacted and met to make arrangements to meet other farmers and interpreters were used where necessary.

Analytical procedures

The data were analysed using the Statistical Package for Social Sciences (SPSS) version 16 (SPSS 16.0 for Windows, Release 16.0.0.2007. Chicago: SPSS Inc).

Results and discussion

Perceptions about climate change

Most (87.5%) of the respondents in Lichinga and in Sussundenga (90%)were aware of climate variability and change (Table 1). Farmers reported to have noticed significant changes in rainfall and temperature over the past 10 years. There was higher likelihood of insights on climate change with increasing age of the head of the household, which is associated with experience in which farmers observe changes over time and compare such changes with current climatic conditions. Maddison (2006) reported farmer perceptions of climate change through noticing an increase in temperature and a decrease in precipitation. Mubaya *et al*. (2008) also reported that most farmers across southern Africa perceive warming and drying of climate and low unpredicTable rainfall as indicators of climate change. Studies by McSweeney *et al*. (2012), Queface and Tadross (2009) and INGC (2009) indicated that in Mozambique, the mean annual temperature have increased by 0.6° C and the mean annual rainfall decreased at an average rate of 2.5 mm per month between 1960 and 2006.

Table 1: Farmers' awareness of climate change over the past 10 years

District	Rainfall		Temp	Unusual weather conditions experienced		Noted changes	
	Changed (%)	Un-changed (%)	Changed (hot) (%)	Drought (%)	Heavy rains (%)	Longer rain periods (%)	Shorter rain periods (%)
Lichinga	87.5	12.5	100	0	40	42.5	57.5
Sussundenga	90	10	100	45	0	0	100

N=40

Many (40%) of respondents in Lichinga have noticed heavy rains, while 45% of respondents in Sussundenga have noticed drought in the past 10 years. Most (57.5%) of the respondents in Lichinga and 100% in Sussundenga believe that there is a shift in the beginning of the short and long rains. Rains that would normally start in October and stretch up to April are now starting late in November and in most cases ending in February (Table 2). These results are supported by Usman and Reason (2004) who reported that in different parts of southern Africa, a significant increase in the number of heavy rainfall events have been observed. MICOA (2007) and INGCC (2009) also noted that farmers in the central Mozambique (Sussundenga) are the most likely to experience increased risk of droughts. A study by Ribeiro and Chaúque (2010) revealed that farmers in Mozambique faced prolonged droughts over the last few years causing a decrease in agricultural productivity.

Table 2: Changes in planting dates in the last 10 years in percentage

District	Farm operations dates changed (%)		Planting date for maize 10 years ago (%)				Planting date for maize now (%)			
	Yes	No	Sept	Oct	Nov	Dec	Sept	Oct	Nov	Dec
Lichinga	90	10	0	22.5	47.5	30	0	7.5	22.5	70
Sussundenga	75	25	5	30	40	25	2.5	12.5	62.5	22.5

N=40

The findings of this study showed that in the past 10 years 40% of smallholder farmers used to plant in November and but presently over 63% of farmers plant in November. This increase may be explained by the shift in the start of the rains from October to November. These results are in agreement with those of

Mary and Majule (2009), and Mortimore and Adams (2001) who found that the onset of rainfall has shifted from October to November.

Adaptation to climate change

Coping strategies to climate change employed by most households include change of crop variety, kitchen gardening and seeking for off-farm jobs (Table 3). Due to increased frequency of droughts, changing crops varieties was a strategy in which 15% of respondents in Lichinga and 35% in Sussundenga were growing drought tolerant crops. These results are similar to those of Mutsvangwa (2009) who indicated that planting drought tolerant crops was the most common adaptive strategy in Gweru and Lupane Districts in Zimbabwe. Similarly, 47.5 of the respondents in Lichinga and 65% in Sussundenga were planting cassava and sweetpotato as an adaptation strategy. However, 90 of the respondents in Lichinga and 82.5% in Sussndenga were reported not to be using drought-tolerant maize varieties. This result are similar to those of Cavane (2011) who reported that improved maize varieties, whose traits have been selected for drought-tolerance were not yet widely adopted. International Fertiliser Development Center (IFDC) (2012) reported that in Mozambique only 5% of smallholders use improved seed varieties. The results confirms those reported in Zambia by Mubaya *et al*. (2008) that farmers do crop diversification to cope with low rainfall.

Table 3: Mitigation strategies to climate change effects

District	Mitigation strategies (%)			Mitigations crops (%)		
	Change crop varieties	Kitchen garden	Off-farm jobs	Cassava & sweetpotato	Cabbage, Onion Tomatoes	Adopting improved maize varieties
Lichinga	15	75	10	47.5	2.5	10
Sussundenga	35	32.5	32.5	65	5	17.5

N=40

Results in Table 3 also indicate that Most (75%) of the respondents in Lichinga and 32.5% in Sussundenga are engaged in kitchen gardening. This could be because the farmers take advantage of the wetlands remain charged for a long time after the rains and they therefore grow crops throughout the year. This finding are consistent with those by (Mubaya *et al*, 2008; Oxfam, 2011) which indicate kitchen gardening is a strategy adopted in Zambia and Mozambique to cope with climate change. The results further indicate that farmers in Lichinga (10%) and Sussundenga (32.5%) concentrated more on off-farm activities in times of low rains than in times of high rains. Oxfam (2011) and Maddison (2007) indicated that due to low rains, farmers have moved towards non-farming activities. The workers mentioned that off-farm activities were considered to contribute significantly to the income of rural households.

The results also indicated that 47.5% farmers in Lichinga and 65% in Sussundenga cultivate cassava and sweetpotato as mitigation crop to cope with the effects of climate change. It is also shown that use of horticultural crops such as cabbages, onions and tomatoes is now common. Studies by Maddison (2007) suggested that changes in temperatures and precipitation call for changes in crop varieties more-adapted to mitigate the effects of climate. Studies conducted in Ghana by Acquah (2011) showed that farmers were using different crop varieties as methods to cope with climate change. Respondents in Lichinga (10%) and Sussundenga (17.5%) reported not using improved varieties tolerant to drought because of high costs of seeds. Enete and Achike (2008) and Cavane (2011) indicated that undercapitalised farmers fail to adopt the required level of agricultural technologies that will ensure profiTable return.

Conclusion and recommendation

There is a consensus among sampled farmers that under climate change, sustainable agriculture development and livelihoods in Mozambique is one of the greatest problems. This study established that rainfall has been decreasing and the temperature increasing, thus negatively affecting the production and management of crops. Different forms of changes on rainfall have been identified including shrinking of rain seasons due to late onset of rains, shifting from October to November or even December.

A combination of strategies to adapt, such as proper timing of agricultural operations, crop diversification, use of different crop and diversifying from farm to non-farm activities were applied.

Consequently the following recommendations have been proposed on the basis of the study:

- Farmers should be encouraged and enabled to use crop diversification as adaptation coping strategy to guard against crop failure in times of adverse climatic conditions
- All effective adaptation options that farmers have applied in the study area should be widely disseminated to others farmers
- Authorities should formulate sound policies that can strengthen capacity of smallholder farmer to adapt to climate change
- More research should be done in assessing the capabilities of the farmers through in-depth assessment of how they are currently adapting to current climate change impacts. This would help also inform how best they can deal with future challenges of climate change

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Food security: A case of maize production in Kandara District, Muranga County

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Abstract

A maize agronomic study was conducted between May and August 2012 in a 10 x 10 km block in Kandara District. The objectives of the study were to determine factors affecting maize production in the County and actual maize production under farmers' practices and management. A questionnaire was used to collect information on maize growing, management practices and actual yields under farmers' practices. Questionnaires were administered to farmers in 16 clusters of 15-20 farmers separated by 2.5 km within the block. A total of 302 farmers were interviewed between May and July 2012. Maize yields from 238 farms were measured in August 2012 from replicate plots measuring 2 x 3 m within a 5 x 5-m plot. Soil analysis for available nutrients was carried out at the Kenya Agricultural Researc Institute (KAR) at Kabete. Most (30.5%) of the farms produced 1-2 t ha^{-1} of maize grain. Only 6.4% of the farms produced more than 5 t ha^{-1}. Most (87%) of the farmers used their own unique maize spacing. The use of improved maize varieties was widespread. Only 20.5% of the farmers planted a local maize variety Most (62%) of the farms had Nitrogen deficiency while 25% had phosphorus deficiency. Soil pH on most farms was within the satisfactory range for crop growth except in 18.4% of the farms where it was 4.27-4.99. Fertiliser (NPK) was the most popular followed by DAP. On average, 89% of the farmers were using inorganic fertilisers while 91% used manure. Fertiliser application rates in Kandara are low. Since plot sizes in Kandara are small (0.01-0.5 ha) food security can only be improved by increasing maize production per unit area.

Key words: maize yields, spacing, maize varieties, nutrient deficiency, fertiliser, manure.

Introduction

Many factors limit crop production on smallholder farms in Kenya. These include low and declining soil fertility, pests and diseases, lack of inputs, farmers inability to purchase inputs in sufficient quantities, low quality of inputs such as manure, fertilisers and seeds and farmers knowhow. Past research has generated numerous soil fertility technologies that can increase rural incomes and food production. However, the gap between research and application of best nutrient management practices is wide. The proportion of small-scale farmers using fertiliser varies from 10% in the dry lowlands to over 85% in central and northwestern Kenya. Mineral fertilisers are an important entry point to increasing crop productivity, and substantial increases in crop yields have been demonstrated using modest amounts of fertiliser. Combining mineral fertilisers with organic resources such as manure leads to improved nutrient use efficiencies than when used separately (Esilaba and Kibunja, 2010).

A maize agronomic study was conducted between May and August 2012 in a 10 × 10-km block in Kandara County. The work was conducted jointly by the Kenya Soil Survey (KSS) and the Plant Nutrition Programme of the Kenya Agricultural Research Institute (KARI), Kabete. The soils of the area are described as well drained, extremely deep, dusky red to dark reddish brown, friable clay, with an acid humic topsoil classified as humic Nitosols (Sombroek *et al.,* 1982). Plot sizes are small (90% of the plots are 0.01-0.05 ha). Crops grown under rainfed are maize and bananas while sweetpotatoes, kales, sugarcane and cut flowers are grown under irrigation. The livestock in the farms consist of dairy cattle and goats under zero-grazing with Napier grass as the main fodder.

The objectives of the study were to (a) determine factors affecting maize production in Kandara County and (b) assess actual maize production under farmers' practices and management.

Materials and methods

Study site

The 10 × 10 km Kandara block (36˚ 57′ 08′′E and 36˚ 02′ 31′′E; 0˚ 51′ 02′′S and 0˚ 51′ 02′′S) lies within four agroecological zones (lower highland zone one [LH1], Upper midland zones 1, 2 and 3 [UM1, UM2 and UM3] (Jaetzold *et al.,* 2006) while the Kandara 10 x 10 km block site lies within UM1 and UM2. Zone UM1 covers 2570 ha while UM2 covers 7430 ha. It receives bimodal average annual rainfall of 1200-1600 mm. Rainfall in the first rainy season (March-August) ranges from 500-700 mm and 300-400 mm in the secondrainy season (October-February) (Jaetzold *et al.,* 2006). The mean annual temperature is 18.0-19.7° C. The mean annual potential evaporation (Eo) is 1200-2100 mm (Jaetzold *et al.,* 2006).

The soils of the area are described as well drained, extremely deep, dusky red to dark reddish brown, friable clay, with an acid humic topsoil classified as humic Nitosols (Sombroek *et al.,* 1982). Plot sizes are small (90% of the plots measure 0.01-0.05 ha). Crops grown under rainfed are maize and bananas while sweetpotatoes, kales, sugarcane and cut flowers are under irrigation. Other rain-fed crops and fruits include tea, coffee, beans, mangoes, avocados and macadamia nuts. Livestock consist of dairy cattle and goats under zero-grazing with Napier grass as the main fodder.

Data collection

A structured questionnaire was used to collect information on maize growing, management practices and harvests under farmers' practices. Data were taken on name of farmer, location, crops planted, row and hill spacing, (number of plants in the 5 x 5-m plots, planting dates, whether thinning was done or not, weeding and timing, estimate of weed cover, pests and diseases, soil quality, soil conservation measures, GPS coordinates of whole farm and plots under maize and maize yields. Questionnaires were administered to farmers in 16 clusters, 2.5 km from each other in the block. Each cluster had 15-20 farmers. A total of 302 farmers were interviewed between May and July 2012 and soil samples from a depth of 0-30 cm collected from each farm for fertility analysis. Maize was harvested from 238 farms in August 2012 from replicate plots measuring 2 × 3 m within a 5 × 5 m-plot.

Soil analysis

The soil samples collected from the field were air-dried and sieved through a 2-mm sieve before analysis. Soil pH and electrical conductivity (EC) were measured using the analytical procedure described by Hinga *et al*. (1980). Organic carbon was determined using the procedure described byAnderson and Ingram (1993). Total nitrogen (N) was determined using the procedure described by Okalebo *et al*. (2002). Potassium (K) and sodium (Na) and calcium (Ca) were determined with a flame photometer. magnesium (Mg) and manganese (Mn) were determined calorimetrically and P was determined using Olsen method (Hinga *et al.,* 1980). Iron, copper and zinc were determined using Atomic Absorption Spectrophotometer (AAS).

Data analysis

The data collected using the questionnaires were entered into the Census and Survey Processing System (CSPro) software using pre-designed templates after first verifying and correcting any errors. The data were then exported to an Excel spreadsheet for analysis.

Results

Maize grain and dry matter yields under farmer's practice

Table 1 shows the maize yields from 236 farms within the 10 × 10 km block. Most farms (30.5%) produced 1-2 t of maize grain and only 6.4% of the farms produced more than 5 t ha^{-1} while 9.3% had less than one tonne per hectare.

Farmers' crop management practices

Maize spacing. Table 2 shows the measured maize inter-row and intra-row spacings from the 231 farms. Two hundred and one households used their own spacing. Thirty had a form of shared spacing.

Table 1: Maize grain yield in Kandara 10 × 10 km block under farmers' practice, August 2012

Mean maize yields (t ha^{-1})	No. of harvested farms	Total farms harvested (%)
0-1	22	9.3
1-2	72	30.5
2-3	70	29.7
3-4	41	17.4
4-5	16	6.8
> 5000	15	6.4
Total	236	

Table 2: Shared maize inter- and intra-row spacings in the Kandara10 × 10 km block

Inter-row x intrarow spacing (cm)	No. of farmers using the spacing
80 × 40	5
80 × 42	2
85 × 42	2
87 × 50	2
90 × 40	4
95 × 40	2
97 × 46	2
100 × 40	4
100 × 41	2
100 × 50	3
100 × 55	2
Total	**30**

The wide variation in inter-row and intra-row spacing had no significant effect on maize yield ($F(10, 27) = 0.657$, p, 0.748). The arrows in the Figure are error bars. The arrows in the Figure are error bars.

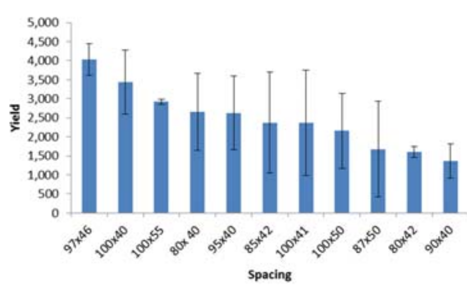

Figure 2. Effect of inter- and intra-row spacing on maize yield in the Kandara 10 × 10-km block

Maize varieties

Some (20.5%) of the farmers plant a local varieties while another 20.5% prefer using more than one variety per farm per season. Variety H513 was planted by 12.5% while Pioneer was planted by 11.2% of the farmers. Each of the other hybrids like Dk, Duma, H512, H514 and H516 were planted by less than 9% of the farmers.

Popular varieties include local, Pan, H513, Pioneer, Dk, Duma and H614. Figure 3 shows the effect of maize varieties used on grain yields for farmers who obtained more than 5000 kg ha^{-1} of grain maize.The varieties had a significant effect on maize yield (F(9,27) = 4.479, p, 0.003).

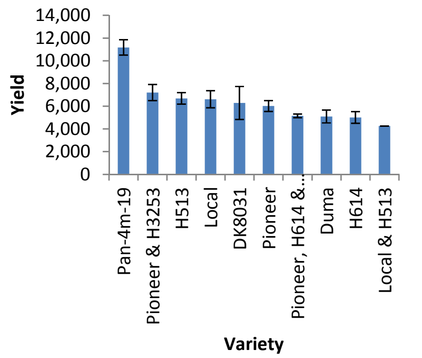

Figure 3: Maize yields of over 5000 kg ha^{-1} matched with the variety used in Kandara 10 × 10 km block

Soil fertility status

Table 3 shows percentage of farms which were deficient in nitrogen, phosphorus, calcium and manganese. Sixty-two percent of the farms were deficient in N (< 0.2 % total N) while 25% of the farms were deficient in P (< 30 % ppm of P). Eleven percent were deficient in Ca (< 2 me %) while 3% were deficient in manganese (< 0.11 me %). Potassium, magnesium, copper, iron and zinc were in adequate quantities.

Table 3 : Nutrient deficiency in the Kandara 10 × 10 km block

Element	Farms with deficiency (%)
Total nitrogen	62
Phosphorus	25
Calcium (me %)	11
Manganese	3

pH status

Twenty-one out of 228 farms (9.2%) had a pH of 6.0-7.13. Many (35.5%) of the farms had pH of 5.50-5.99, 36.8% had 5.48-5.0 and 18.4% had 4.99-4.27%. Maize require a pH of 5.5-8.0 (Jaetzold *et al.*, 2006) indicating that pH was outside the suiTable range in 55.2% of the farms.

Application of fertiliser and manure

Fertiliser NPK is the most popular for planting followed by DAP (Tables 4, 5 and 6). Eighty-one farmers used the wrong fertiliser (CAN) for planting in long rains 2012 (Table 4). A few farmers use NPK and DAP for topdressing instead of CAN or urea.

Table 4: Fertiliser application by farmers during the 2012 long rains

Planting	No of farmers	Quantity (kg)			
		0-10	10.1-25	25.1-50	>50
CAN	81	20	35	21	5
DAP and NPK	30	10	11	7	2
NPK	114	33	44	31	6
None	26	26	0	0	0
Others[1]	12	3	7	2	0
Totals	263	92	97	61	13
% users	90.1	25.1	36.9	23.2	4.9
Topdressing					
CAN	132	56	33	37	6
Urea	15	12	3	0	0
CANandUrea	9	8	0	1	0
None	38	38	0	0	0
Others[2]	10	8	1	1	1
Totals	204	122	37	38	7
% users	81.4	41.2	18.1	18.6	3.4

Table 5: Fertiliser application by farmers during the 2011 short rains

Planting	No of farmers	Quantity (kg)			
		0-10	10.1-25	25.1-50	>50
DAP	69	21	28	17	3
DAP and NPK	28	9	11	6	2
NPK	122	33	49	32	8
None	26	26	0	0	0
Others[1]	17	7	9	1	0
Totals	262	96	97	56	13
% users	90.1	26.7	37.0	21.4	5.0
Topdressing					
CAN	160	64	63	27	6
CAN and Urea	10	8	1	1	0
Urea	16	12	2	2	0
None	28	28	0	0	0
Others[2]	14	10	3	0	1
Totals	228	122	69	30	7
% users	87.7	41.2	30.3	13.2	3.1

For the three seasons, 37%of the farmers who used fertilisers applied between 10 and 25 kg ha^{-1} with 26.3% applying less than 10 kg ha^{-1} and 26.1% applying more than 25 kg ha^{-1} at planting (Table 9). During topdressing, 41% of the farmers applied less than 10 kg ha^{-1} while 25.4% applied between 10 and 25 kg ha^{-1} and 28.7% applied more than 25 kg ha^{-1}. Overall, 90.7% and 86.9% of the farmers said they use fertilisers at planting and topdressing, respectively.

Table 6: Fertiliser application by farmers during the 2011 long rains

Planting	No of farmers	Quantity (kg)			
		0-10	10.1-25	25.1-50	>50
DAP	76	22	33	18	3
DAP and NPK	27	9	11	7	2
NPK	114	33	44	29	7
None	24	24			
Others[1]	16	6	8	1	0
Totals	257	94	96	55	12
% users	90.7	27.2	37.4	21.4	4.7
Topdressing					
CAN	159	64	61	27	7
CAN and Urea	12	9	2	1	0
Urea	14	10	2	2	0
None	30	30			
Others[2]	14	10	3	0	1
Totals	229	123	68	30	8
% Users	86.9	40.6	27.9	13.1	3.5

Table 9: Summarised fertiliser application quantities and percentage of farmers involved per category during the 2012 long rains, the 2011 short rains and the 2011 long rains

Season	Quantity (kg ha^{-1})			
	0-10	10.1-25	25.1-50	>50
Percentages at planting stage				
LR 2012	25.1	36.9	23.2	4.9
SR 2011	26.5	36.7	21.2	4.9
LR 2011	27.2	37.4	21.4	4.7
Mean	26.3	37.0	21.9	4.8
Percentages at topdressing stage				
LR 2012	41.2	41.2	18.1	3.4
SR 2011	41.2	41.2	30.3	3.1
LR 2011	40.6	40.6	27.9	3.5
Mean	41	41.0	25.4	3.3

On average, 91 % of the farmers said they applied manure at planting during the 2012 long rains, the 2011 short rains and the 2011 long rains. The quantities applied ranged from 0 to more than 40 t ha^{-1} with 57.5 %, 30.4 %, 5.8 %, 3.4 % and 2.9 % applying 0-2.5, 2.5-10, 10-20, 20-40 t ha^{-1} and more than 40 t ha^{-1}, respectively. Farmers who attained yields of over 5000 kg ha^{-1} reported that they applied 24-462 t ha^{-1} of manure at planting (Table 10). Most (82%) of these farmers applied 132-522 kg ha^{-1} fertiliser at planting during the 2012 long rains while 67% applied 200-694 kg ha^{-1} fertiliser for topdressing . The amounts of manure and fertiliser applied by some farmers were too high, indicating that their estimates were probably wrong.

Other crop management information

Maize was intercropped with beans in 84.2% of the farms. Other intercrop crops were bananas, cassava, coffee, irish potatoes, kales and water melons. Data for the 2012 long rains indicate that 56.4% of the farmers planted between 1st ando 7th April, 22% between 22nd and 31st March, and 14.3% between 15th and 22nd March. The rest (2.8% and 4.5%) planted earlier and after these dates, respectively. Most (74.6%) of the farmers said they thinned while 25.4 did not. Some (58.3%) weeded once and 41.7% twice in a season, 65.4% of the farmers plots had no weeds, 29.1% were moderately weedy, 5.2% had severe weed investation and 0.3 had very severe weed investation. 85% of the farmers said they had experienced maize crop diseases in 2011 while 96.5 % said they had experienced pest problems. Treatments included proper weeding, applying soil and ash to the top of the maize stock to kill stalk borers, roguing, maintaining high fertility by use of fertilisers and manure, use of chemicals such as herbicides, Dimekil for stalk borers, Actellic and Melathion for weevils, scaring squirrels and monkeys and trapping moles. Some other faremrs (78.3%) reported mild erosion on their farms, severe and very severe erosion was experienced in 13.2 and 2.6% of the farms, respectively, 5.9% of the farms had no erosion problems. Erosion control methods included grass strips, bench terraces, Fanya juu/Fanya chini, ridges, unploughed strips and drainage trenches.

Table 10: Fertiliser and manure application as reported by farmers who attained yields of over 5000 kg ha^{-1} during the 2012 long rains

HH	Yield (kg ha^{-1})	Fert type planting	Fert qty planting kg ha^{-1}	qty-P (kg N and P_2O_5 or N only	Fert type TD	Fert qty TD (kg ha^{-1})	Fert qty (kg N ha^{-1})	Manure (t ha^{-1})	Soil pH (early season)
116	11174	NPK	522	120*	CAN	260	70	Amount not given	5.52
112	8837	NPK	360	83*	None			40	5.57
284	7516	CAN	132	36	CAN	211	57	No manure	5.51
155	7204	NPK	142	33*	None			14	5.27
142	6593	CAN	4167	1125	None			1666	5.82
051	6289	None			CAN	128	35	462	4.95
246	5883	DAP and NPK	150	31 N, and 52 P O_5**	None			30	5.85
030	5861	Unknown						32	5.15
063	5443	CAN	200	54	CAN	200	54	24	4.70
204	5331	NPK	600	138*	CAN	500	135	5	5.36
179	5146	DAP and NPK	115	24 N and 40 P_2O_5**	CAN and urea	51	14	Amount not given	5.59
156	5117	NPK	69	16	CAN	694	187	83	5.66
256	5093	None			CAN	85	23	Amount not given	5.93
247	5060	DAP and NPK	142	29 (N), and 49 P_2O_5**	CAN	38	11	1.5	5.84
033	5009		None				None	1053	

It was assumed 10 wheel barrows = one ton and one bag = 4 wheel barrows, *it was assumed 23:23:0 was used, **it was assumed DAP and NPK were applied in ratio of 50:50, QTY-P= Quantity at planting, QTY-TD = Quatity at topdressing

Discussion

There were more than 5 t ha^{-1} in 6.4% of the farms while 6.8% had 4-5t ha^{-1}. It is therefore clear that higher yields can be achieved through intensification of fertiliser and manure use, use of proper variety, inputs and management. The wide range of maize inter- and intra-row spacing used by the farmers means this issue need to be addressed. There a lot of variation in maize varieties used in the area. Some farmers use the wrong fertilisers for planting or topdressing, case in point is the 81 farmers who said they applied CAN at planting during the 2012 long rains and others who used NPK and DAP for topdressing. Applying CAN would be a waste because it is easily leached by the time the maize develops roots to utilise the fertiliser. Some farms had high levels of phosphorus, so such farmers can plant without fertilisers and topdress with CAN at the 11th leaf stage. The African Fertiliser Summit conducted in Abuja, Nigeria in 2006 recommended that current fertiliser use in Africa be increased from the current 8 to 50 kg nutrients per hectare by 2015 (Sanginga and Woomer, 2009). Thus fertiliser applications in Kandara are low considering the application amounts given are in kilogrammes per hectare and not nutrients per hectare. For those farmers who attained more than 5000 kg ha^{-1}, 9 out of 15 (60 %) satisfied the 50 kg nutrient per hectare. A lesson can be learned from the Kandara farmer who attained the highest maize yield of 11 t ha^{-1} by applying an equivalent of 120 kg N ha^{-1} and 120 kg P_2O_5 ha^{-1} at planting, 70 kg N ha^{-1} at topdressing and Pan 4m-19 hybrid maize (Table 10).

Farmers in Kandara understand the usefulness of applying manure and mmost apply it at planting. A pH of less than 5 in 18.4% of the sites. This can interfere with nutrient availability to the maize crop (London, 1984). Kihanda (2012) in their research on acid ando-humic Nitosols with initial pHs of 4.1-4.3 in Manyatta Division, Embu District observed that there was a significant increase in soil pH by 1.0-1.4 units in plots that had been treated with lime annually at 1.0 t ha^{-1} between start and end of the eight years' experiment. Smaller increases of 0.3-0.5 pH units were recorded in plots that had received FYM at 5.0 t ha^{-1} in the absence of added lime during the same period. The aluminium saturation at the start of the experiment was above 70% in all the plots but annual application of agricultural lime at 1.0 t ha^{-1} within the eight years reduced the Al saturation to zero or near zero, irrespective of the NP or FYM treatments. There was also a small reduction in Al saturation of 10% in plots that had received FYM at 5.0 t ha^{-1} in the absence of applied lime. Their highest maize grain yield of 4.5 t ha^{-1} was obtained by a combination of NP at 50 kg ha^{-1} N and 50 kg ha^{-1} P_2O_5, respectively, lime at one tonne per hectare applied annually and FYM applied at the rate of 5 t ha^{-1}.

Conclusions and recommendations

- Maize production in Kandara is low at 1-2 t ha^{-1}
- Maize varieties significantly affect grain yield in Kandara
- Nitrogen deficiency is widespread in the area. Low pH of below 5.0 experienced in 18.4% of the farms can cause low maize grain production
- The fertiliser and manure applications as given by some farmers were too high and did not match the low maize grain yields obtained
- There was wide variation in planting dates. This could have contributed to the low maize yields
- Since plot sizes in Kandara are small, food security can only be improved by increasing maize production per unit area (agricultural intensification)
- Farmers need to be educated on the correct maize varieties
- Information on proper maize spacing should be given to the farmers
- Farmers should be educated on the right fertilisers and quantities to apply at planting and topdressing
- Information on disease and pest control is lacking and need to be availed
- Agricultural intensification will require farmers who attained maize yields lower than 3 t ha^{-1} to at least double their fertiliser and manure inputs
- Farmers should be encouraged to continue applying manure and to increase input to 5 t ha^{-1} per season (50 wheel barrows) or 12 bags ha^{-1} or more in combination with the fertilisers. These amounts should be devided with the area of their fields to get the amount to apply. This is a preliminary

recommendation that will be confirmed by results of the ongoing Kandara fertiliser trials by KARI (Kibunja *et al*.)

- Besides high dose of manure, liming is recommended for farms with pH below 5.5. A combination of NP, FYM and liming will give best results. The soil fertility trials being conducted in Kandara by KARI (Kibunja *et al*) will give more insight on the appropriate fertiliser, manure and lime rates.

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Gender dynamics influencing adoption of integrated watershed management technologies: The case of lower eastern Kenya

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Abstract

Women play a critical role in the agricultural sector. Any intervention focusing on improving agricultural productivity must take into account gender differences (needs and preferences) as a major factor likely to influence success of the development intervention. This case study paper analyzes gendered needs and preferences influencing adoption of identified integrated watershed management (IWM) technologies among targeted male and female beneficiaries during the early stages of project implementation in lower Eastern Kenya. Focus group discussions (FGDs) were conducted among 171 male and female smallholder farmers randomly selected from Mwania and Kalii watersheds in Machakos and Makindu districts respectively. Among other results, the study revealed higher adoption rates among male farmers as compared to female farmers despite higher proportions of female than male farmers participating in project activities. The paper derives important policy implications for enhanced adoption of IWM technologies in lower eastern Kenya.

Introduction

The 'Integrated Management of Water for Productivity and Livelihood Security under Variable and Changing Climatic Conditions Project in Kenya' focuses on increasing farm productivity and incomes at household and watershed levels through an integrated approach of promoting adoption of proven water management and associated interventions at production, post-harvest (value addition) and marketing stages of agricultural and livestock enterprises. The aim of promoting appropriate technologies along the agricultural value chains is to maximize returns from farming in order to transform subsistence to commercial agriculture in the semi-arid Eastern Kenya.

Women play a critical role in the agricultural sector. According to USG (2011), women are responsible for 80% of paid and unpaid labour in food production. Thus, any intervention focusing on improving agricultural productivity must take into account gender differences (needs and preferences) as a major factor likely to influence success of the development intervention. Addressing gender practices, needs and preferences during project implementation is likely to lead to empowerment of women. A study conducted by Hallman *et al*. (2007) revealed how implementing gender-blind fish pond programs benefited wealthy men, whereas those targeted at poor women led to their empowerment. Implementing gender-responsive programs is likely to result in greater sustainability of development projects and the environment because women often hold local knowledge of low-cost coping strategies that can prove vital to making farming systems more resilient to climate change (Meinzen-Dick *et al*., 2010).

Within the on-going water productivity project, several proven technologies have been selected and capacity building of farmers to enhance adoption is in progress. The project has an explicit goal to enhance gender impact, hence improving participation by women farmers in project activities is one of the main activities targeting achievement of this impact. Despite the technologies' potential in improving productivity, there is limited engendered information on how target beneficiaries perceive the technologies. Based on the technologies' attributes, specific gender categories could develop unfavourable attitude towards some technologies which may result in negative implications on adoption of those technologies. In an attempt to fill this knowledge gap, this case study paper analyzes awareness and adoption of selected technologies under promotion within the project. It is expected that an understanding

of gendered needs and preferences influencing adoption of identified technologies among targeted male and female beneficiaries during the early stages of project implementation will lead to implementation of complementary interventions to ensure equiTable sharing of project benefits.

Materials and methods

The study was conducted in Machakos and Makindu districts in semi-arid Eastern Kenya. Agriculture is the main economic activity in the region with heavy reliance on erratic and unreliable rainfall. The distribution pattern is bi-modal with two distinct seasons {short and long rains falling in October-December and March-May respectively}, with an annual rainfall ranging from 500-1300mm.

Focus group discussions (FGDs) were conducted among 171 male and female project participants randomly selected from two project sites – Mwania and Kalii watersheds in Machakos and Makindu districts respectively, during a project activity - participatory evaluation of trials in July 2012. The farmers comprised of 75 male and 96 female farmers drawn from different sites as shown in Table 1.

Table 1: Participating farmers per site

Name of watershed	Male farmers	Female farmers
Mwania	27	37
Kalii	48	59
Total	75	96

The disproportionate numbers of participants from each watershed may be attributed to the expansive nature of Kalii watershed (17,811.2ha) as compared with Mwania watershed (889.9ha). Separate FGDs were conducted for each gender category (male and female farmers) in different project sites.

Data coding, entry and cleaning was done using Statistical Package for Social Sciences (SPSS) software Version 15.0. Descriptive statistics which included frequencies and cross-tabulations were generated with SPSS and used to analyze farmers' characteristics and practices.

Results and discussions

Respondents' characteristics

Respondents comprised of farmers from Mwania (37%) and Kalii (63%) watersheds. There were more female farmers (56%) participating in the FGDs than men (44%), with 21% of the females representing female-headed households. Female farmers from female-headed households tend to be more vulnerable and marginalized than those with spouses hence their presence in project activities was a good indication of their inclusion and participation. Almost all respondents (99%) represented different households except 1% who comprised of couples (husband and wife).

Technology awareness and adoption

According to Rogers (1995), a farmer's decision about an innovation is not an instantaneous act, but a process that occurs over time and consists of the following series of actions. In the presence of a new technology, a farmer is exposed to the technology's existence and gains some understanding of how it functions. Rogers (1995) argues that one does not actively seek an innovation without awareness of its existence; hence one becomes aware of the innovation by chance. The farmer becomes aware of an innovation through change agents or mass-media channels. At the persuasion stage, the farmer forms a favourable or unfavourable attitude towards the innovation/technology, where a general perception of the technology is developed, mainly of the technology attributes. Based on the perceived attributes, the farmer applies the idea to his/her present or future situation before deciding whether or not to try it. At the decision stage, the farmer engages in activities that lead to a choice to try out the idea or to reject the innovation. Farmers who choose to try the innovation will move to the implementation stage where they will put the innovation into use. At this stage, the farmer still has some degree of uncertainty about the

expected consequences of the innovation. Based on the expectations and the actual outcomes as a result of testing the innovation, a farmer will then choose either to continue (adoption) or discontinue (abandon) use of the innovation.

Within the Integrated Watershed Management project, promotion was underway of seed priming, tied ridging, micro-dosing, composting and terracing technologies for adoption at farm level. Farmers empowerment was conducted through various capacity building activities and participation in technology evaluation . An engendered assessment of awareness and adoption of technologies shown in Table 2 was deemed necessary to guide project activities likely to influence adoption hence conducted.

Table 2: Awareness and adoption of IWM technologies among farmers

	Technology	Proportion of farmers (%) N=171			
		Technology awareness		Technology adoption	
		Male	Female	Male	Female
1.	Seed priming	99	68	55	22
2.	Composting	97	78	48	0
3.	Terracing	99	91	97	43
4.	Microdosing at planting	99	66	41	6
5.	Microdosing at topdressing	99	77	40	25
6.	Tied ridging	99	82	81	5
7.	Tumbukiza	51	65	21	0
8.	Improved seed varieties	100	90	99	50
9.	Pasture establishment	88	85	75	5
10.	Preservation of vegeTables	81	95	39	13
11.	Tree nursery establishment and management	71	5	39	1
12.	Agroforestry	64	64	64	8

Although more female than male farmers participated in the evaluation of field trials, an assessment of technology awareness showed higher awareness levels of 75% of the technologies promoted by the project among male farmers as compared with their female counterparts. In addition, a higher adoption rate among male farmers as compared with female farmers was also evident.

Composting

Despite awareness on how to produce farm yard manure (FYM) at household level by majority of the female farmers (78%), there was no adoption of the technology by these farmers. They indicated that it was an expensive technology hence could not afford to do it, but instead continued using the traditional composting techniques.

Terracing

It was encouraging to note that 43% of female farmers had adopted terracing in their farms, which they attributed to labour provision by male household members in previous years. Notwithstanding, the female farmers reported that the terracing technology was not gender-friendly because it was labour intensive, especially during initial terrace construction which could only be done by men. According to Meinzen-Dick *et al* (2010), women have less access to the labor-saving technologies and hired labor that is necessary for adoption of labour-intensive technologies. However, it was interesting to note that female farmers from Kalii watershed did not consider terracing as a technology suiTable for men and participated in the construction of the terraces.

Micro-dosing

Micro-dosing is targeted application of small fertilizer quantities close to the seed at planting or close to the plant at top-dressing stage to enhance its efficiency (ICRISAT, 2009). Most farmers (99% and 66% male and female farmers respectively) were aware on how to carry out micro-dosing at planting. However, adoption rates especially by female farmers were low (6%), which they attributed to lack of finances to purchase fertilizer. This finding was congruent with the observations of Peterman *et al*. (2010) who concluded that accessibility of inputs is a key issue for female farmers because technology inputs such as fertilizer and improved seed have a cost implication during acquisition.

More farmers (40% male and 25% female farmers) applied micro-dosing at the top dressing stage as compared to planting stage. They attributed this to the use of a plough at planting time, which made it difficult to apply fertilizers. They indicated that fertilizer application at top dressing stage was easier to manage than during planting.

Tied ridging

Adoption of tied ridges by female farmers was very low (5%) despite knowledge on how to do it. The farmers explained that tied ridging was labour-intensive and many households were labour-constrained. The common practice was use of a plough for land preparation while tied ridging requires hand-driven tools like *jembes*, which is drudgerous and time-consuming. Adopting female farmers (5%) indicated that they only tested the technology on a small piece of land and used a plough for the rest of the farm.

Tumbukiza

There was no adoption of tumbukiza technology by female farmers. They likened this technology to construction of terraces, which required hard menial labour that they are not able to provide. It is therefore of paramount importance for the project team to identify alternative IWM options targeting implementation by female farmers.

Improved seed varieties

It was encouraging to note that almost all of the sampled male farmers (99%) were testing improved seed varieties. However, only 50% of the sampled female farmers were using the technology, which they attributed to lack of finances to purchase improved seed. Those using improved seed varieties indicated that they were doing it on minimal scales. The sampled female farmers indicated willingness to adopt the technology if their spouses could provide cash to purchase the seeds or if the improved seeds would be provided by the project. This finding was congruent with the common notion that women face persistent economic constraints, which limit their production potential in agriculture.

Other technologies

There was notably low adoption of other technologies such as pasture establishment, preservation of vegeTables, tree nursery establishment and management, and agroforestry among female farmers. They attributed this to the fact that they had learnt about these technologies during the season when the study was conducted hence would test them in their farms the following season.

It is worthwhile to note that male farmers were leading in adopting IWM technologies introduced to them. This may be attributed to their relatively higher economic empowerment levels as compared with their female counterparts; hence the ability to acquire and test the technologies.

The low rates of adoption among female farmers may also be attributed to their risk-averse nature where a technology has to be proven beyond reasonable doubt in delivering the purported benefits before they can adopt it. This was evidenced by low adoption rates among female farmers (13%) as compared to higher awareness rates in which a higher proportion of female farmers (95%) than that of their male counterparts (81%) on the technology for preservation of vegeTables was reported. This is notably expected given that technologies on vegeTable preservation are perceived to be in the domain of women. Additionally, despite an indication by female farmers of sensitization and training on the technologies, they requested to have repeated trainings on the same aspects which they referred to as 'refresher training'. Thus, it is important for training sessions for most of the technologies to be organized every season to enhance adoption.

The low rates of technology adoption may also be attributed to limited control of land, which requires consent by their spouses before they can implement new techniques on the farm. Male farmers indicated that they were the ones likely to adopt the technologies since decision-making on how land will be used is in their domain, hence they would not allow their spouses to 'experiment' on the family farm unless they (men) have also been sensitized on the technology potential. Notably, long-term technologies (likely to be used over several seasons) e.g. terracing, tied ridging, tumbukiza, pasture establishment, tree nursery establishment and management, and agroforestry had low adoption rates among female farmers, thus signifying the effects of lack of control over the family land.

Thus, despite encouraging participation in project activities by female farmers it is important to include their spouses if the project has to achieve the intended impact on household food security and incomes. In addition, since women are responsible for 80% of paid and unpaid labour in food production (USG, 2011), it is important to sensitize and train spouses of participating male farmers to ensure proper application of the technologies especially when the men are away. In order to achieve household food security and increased household incomes sustainably, strategies for participation of more than one household member (preferably the head of the household and the spouse) in project activities are vital. Quisumbing and Maluccio (2003) challenge the assumption that the household is a unified entity that works together to pool common resources towards a common end, hence involvement of one household member may not yield optimal results.

Conclusions and recommendations

The study revealed that women participants were more than men. Almost all (99%) project participants represented different households, while only one household was represented by bothhusband and wife. While this ensures that information on technologies under promotion is acquired by more households, it may not necessarily imply adoption by all households since a household head and spouse play complementary roles in adoption of agricultural technologies.

The study revealed higher adoption rates among male farmers as compared to female farmers. This is a clear indication that despite emphasizing participation of female farmers in project activities, it is important to develop strategies to involve their spouses (men) who are likely to complement their efforts by providing financial and labour support to enhance adoption. In addition, considering the role played by women in the family farm, capacity building of spouses of male participants would be vital in ensuring implementation of proper practices at farm level in the event of the man's absence. Organizing a sensitization and training schedule for participants' spouses would be a vital outreach strategy.

Terracing, tied ridging and tumbukiza technologies were envisaged by female farmers as not being gender-friendly despite acknowledging their potential in increasing productivity. In order to ensure equity in benefits attributed to the project for both male and female farmers, it is important to identify alternative IWM technologies that suit female farmers' needs and preferences to supplement those regarded as 'not favourable for women' to ensure equiTable sharing of benefits among project participants. In addition, the research team recommends modification of tied ridging technology to make it compatible with the ox-ploughing practice adopted by the community in circumventing labour intensiveness and time constraints.

Adoption of improved seed and fertilizer use was low among female farmers due to financial constraints. Identification of credit schemes supporting agricultural activities should be explored and linkages with project participants established to address financial constraints in input acquisition. It would also be important for the project team to consider providing initial improved seed of varieties whose production potential is not significantly affected when seed recycling is done (e.g. open pollinated varieties), which would be provided to female farmers and a revolving model developed to ensure seed access by all project participants. In addition, it is important for the project to develop strategies for improving market linkages with sTable and sustainable markets to ensure good returns after produce marketing, thus providing capital for acquisition of inputs.

Despite women farmers acknowledging previous training on some of the technologies at group level, they indicated that they were not confident in implementing the technologies and requested for more training on the same aspects which they referred to as 'refresher training'. The inadequacy of few training sessions may be attributed to lower education levels that usually characterize female members in most communities. Thus, in order to enhance adoption among female farmers, it would be important for project implementers to organize multiple training sessions covering the same aspects, which may include conducting demonstrations at group level and organizing exchange visits to areas where successful adoption by female farmers has been realized.

Collecting gender-disaggregated information at group level is a resourceful way of rapidly generating a general representation of needs and preferences. It would therefore be important to conduct a lesson-learning in-depth analysis of households where female farmers have: successfully adopted some of the technologies cited as 'not favourable for women' The applicability of factors positively influencing adoption will be evaluated and recommended to enhance adoption of IWM technologies among female farmers.

Acknowledgement

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Smallholder farmers decision to adopt and utilize ISFM technologies in Tororo District, Uganda

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Abstract

Soils in Tororo district like in other parts of Uganda are of low inherent fertility, which is declining due to low use of external inputs by farmers and poor management. Integrated Soil Fertility Management (ISFM) offers considerable promise for increasing food production. However it is unclear whether ISFM techniques are easily adopted by smallholder farmers. The study focus was on smallholder farmers' adoption and utilization of ISFM technologies in Tororo district. Soil management technologies were introduced, fine-tuned and disseminated in the study area using participatory approaches by the National Agricultural Research Laboratories of the National Agricultural Research Organization, Africa 2000 Network and government extension. The objectives of the study were to examine household factors that influence adoption of ISFM; to assess the methodologies used to disseminate ISFM technologies; to establish the level and nature of adoption of ISFM by smallholder farmers; and to examine the effects of structural and ecological factors on farmers' decision to adopt ISFM technologies. Research results indicated that farmer wanted the price for ISFM technologies to be reduced; farmers lacked enough training for efficient use of ISFM. Technology use was affected by farm size, farmer educational knowledge and age, economic and institutional support characteristics and farmer's perceptions. The three most effective dissemination methodologies/approaches in descending order were trainings, farmer field schools and demonstration farms. Respondents revealed that trainings played a greater role in teaching farmers about fertilizer use. The major problematic aspects were technology accessibility and labour constraints. Strengthening of advisory services and facilitation of inputs delivery by the government through private sector supply would play a critical role in soil fertility replenishment in Uganda. These findings raise important questions as to whether ISFM and related techniques are really affordable to smallholder farmers, so the government should encourage input facilitation such as credit and microfinance to farmers through the private sector in order to facilitate the use of soil management inputs.

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Key words?

Introduction

Agricultural sector in African economy is the most important sector because of its contribution towards economic development of the region. First, the agricultural sector in sub-Saharan Africa employs more than seventy percent of the active population in the region. Second, it contributes more than forty-six percent to the gross domestic product (GDP). Third, it remains the main source of foreign exchange earnings. In Uganda, the contributions of the agricultural sector are as follows: the agricultural sector is the main export revenue earner; it contributes ninety percent of the export earnings (World Bank 1994). Agriculture is the largest employer of most Ugandans employing over seventy-three percent of the labor force as compared to manufacturing at four percent and services at twenty three percent (Ministry of Agriculture, Animal, Industry and Fisheries (MAAIF) 2010/11). It is the source of raw materials for the industrial sector through forward and backward linkages with the service and industrial sector (World Bank 1994). Therefore, development programs need to put into consideration the agricultural sector it being the backbone of the Ugandan economy.

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Despite the contributions of the agricultural sector, agricultural development remains a challenge in Uganda with little attention to the challenges facing agricultural sector. There has been a noTable decline

in food production, increase in poverty levels, high malnutrition levels and vulnerability to shocks (Mugwe, Thomas, Isaac, and Minde 2009). The above challenges can therefore be attributed to the following reasons: limited land for cultivation due to high population pressure (Arellane and lee 2003, FAO 2001), insecure land tenure system that has limited farmers from acquiring land for cultivation (MAAIF 2010/2011), poor climatic conditions (Ajayi, Oluyedde Clifford 2009), low soil fertility (Mugwe, Thomas, Isaac, and Minde 2009).

Low soil fertility has become a matter of concern by development workers, researchers and soil scientists and it has been identified as a major constraint to food production in Uganda (Matata, Oluyedde, Ajayi, Oduol and Agumya 2010). Adoption of integrated soil fertility technologies then appear to be the most appropriate way of responding to declining soil fertility in Uganda (National Agricultural Research Laboratories- Kawanda 2009). Integrated soil fertility management (ISFM) refers to making best use of inherent soil nutrient stocks, locally available soil amendments, and inorganic fertilizers to increase land productivity whilst maintaining and enhancing soil fertility and improving efficiency and nutrient and water use (Ajayi oluyedde Clifford, 2009). The agro ecological zones (AEZ) of eastern Uganda are characterized with low organic matter and nutrient contents (NARL 2009). The problem of low organic matter in the soil and declining soil fertility has been worsened by limited or no use of external inputs such as use of organic and inorganic fertilizers, nutrient mining, soil erosion and land fragmentation in some parts of Uganda.

To solve the problem of declining soil fertility in Eastern Uganda, association for strengthening agricultural research in east and central Africa (ASARECA) project in collaboration with national agricultural research organization (NARO) has taken part in encouraging farmers in Tororo district to adopt integrated soil fertility management technologies (ISFM). This project was introduced in Tororo district in 2009; one of the project main objectives is to develop appropriate methodologies for uptake and scaling up of soil fertility management technologies among smallholder farmers. In order to enhance declining soil fertility and increase crop production among smallholder farmers, NARO Uganda developed a number of soil fertility management technologies in Tororo district. Some of the types of technologies developed by NARO include inorganic fertilizers such as Triple super phosphate (TSP), dis-amonium phosphate (DAP), Urea) and organic fertilizers such as animal manure and Green manure. Smallholder farmers have provided a number of dissemination methodologies to promote the use of the technologies. Examples of the methodologies include, farmer field schools, farmer groups, field days and trainings, mother baby trials and demonstration farms (learning centers), and knowledge sharing products like brochures and posters (NARO 2009). However, there is still need for further information on how effective such techniques are in changing farmers' traditional practices and attitudes and whether or not there is local farmers' participation in the program.

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Significance of the Study

Adoption and utilization of integrated soil fertility management technologies is believed to be the best solution in arresting declining soil fertility. However, adoption and utilization of soil fertility management technologies has been problematic by smallholder farmers yet little research has been done on this problem and there is an information gap on the factors that influence smallholder farmers' decision to adopt and utilize ISFM technologies. The study findings will help cover the gaps in the previous research done on soil fertility technologies. Study findings will also guide policy makers to formulate appropriate policies on agricultural based activities for smallholder farmers. The findings will also help in enhancing soil fertility, increased crop production and reduction of poverty levels among smallholder farmers. The findings will help ASARECA project and other international organizations to identify an appropriate approach for disseminating the technologies to smallholder farmers.

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Scope of the study

The study was conducted in Tororo district. Tororo district was chosen because according to NARL-NARO, Progress report January to May 2010, there was a noticeable decline of the fertility of the soil in Tororo district which is the main reason for low crop production in the area. The study was carried out in

three sub-counties of Kisoko, Usukuru and Petta sub-counties. Two parishes were selected from each sub-county. The study populations were the smallholder farmers and other key stakeholders such as the district agricultural officer and extension workers in the implementation of the project. Tororo district is one of the most densely populated, maize producing districts bordering western Kenya. Extensive research has been conducted in western Kenya on the use and profitability of soil improvement strategies. It is likely that there are spillover effects to neighboring Eastern Uganda. Furthermore, soils in Tororo have been characterized as poor in nutrient status. The study was confined on factors influencing small holder farmer's decision to adopt and adapt soil fertility management technologies. The key themes under this study are: smallholder characteristics and needs, IISFM project implementation methodology, the nature of technology structural and ecological set up. The data collection exercise was carried out in a period of one month, during which the researcher collected enough data that was used to provide answer the study objectives.

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Materials and methods

Study design

The research mainly used a cross sectional design and was implemented for the purpose of assessing the process of smallholder farmer's decision to adopt and utilize integrated soil fertility management technologies. The cross sectional study research design was selected because allows one to conduct in-depth investigations on the study in question. The study employed both qualitative and quantitative research methods. Qualitative method was used to establish in-depth issues that smallholder farmers consider important to adopt and utilize ISFM technologies. These issues included farmer's attitudes and the reasons behind farmer's attitudes and perceptions, reasons why farmers are limited to utilizing recommended fertilizer technologies and recommendations for such challenges. Qualitative method was also used to get key people's views in the study like extension workers who have participated in the implementation of the ASARECA project in Tororo district

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Description of the study area

The study was conducted in Tororo district (Eastern Uganda) located between latitudes 33°45′ -34°15′ East and 0°30′ - 1°00′ North. Tororo is bordered to the southeast by Kenya, northeast by Mbale, the northwest by Pallisa, and Bugiri, southwest by Iganga and to the south by Busia. The district has a population of 555,574 people, 88.5% of who reside in the rural areas (Rwabwoogo, 1996). Eighty percent of this population derives their livelihood from agriculture. Annual crops such as cassava, finger millet, sorghum, maize, beans, and other crops are grown in this area with cotton grown as the major cash crop. The animals kept are cattle, goats and sheep. Industrial activity includes the manufacture of corrugated iron sheets, inorganic fertilizers, fungicides, cassava starch, cotton ginning, and oil milling.

Sample selection

According to Amin (2005), sample selection is the process of choosing elements from a population in such a way that the sample elements represent the population. Two types of sampling procedures were employed in this study namely; stratified random and purposive sampling. Stratified random sampling was used to select smallholder farmers who acted as study respondents and one farmer introduced the researcher to the next farmer after the interview. Purposive sampling was used in the selection of key informants respondents based on their role in the project, in society, and their experience in the area of study. The respondents under purposive sampling were extension workers and the agricultural officers in Tororo district. The type of respondents, methods and instruments that were used are summarized in the Table 1 below.

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Sampling procedure

These included Osukuru, Kisoko and Petta sub-counties purposively selected because they host project activities in the district and 3 villages randomly selected per sub-county. From these villages both adopters and non-adopters were interviewed with only one household member from each household interviewed.

The activities that have been conducted include training of farmers through farmer groups, farmer field schools and demonstration farms. During the trainings, different technologies were identified, tested and recommended as best bet technologies by farmers. It was upon this that farmers considered the best bet technologies for increased crop production.

Data collection

The study used both primary and secondary data. Primary data were collected using a pre-tested structured questionnaire that was administered to individual farmers to determine the level of acceptance and the farmer's perceptions of soil improvement practices. The variables that were captured to characterize the determinants of acceptance included socio-economic data such as household size, farm and family size, educational status of the household, participation in farmer organizations, extension-farmer contact, perception of the soil fertility problem and labor requirements of different farming stages. The farmer perceptions and ideas to adopt and utilize ISFM technologies preferred were established from Focus Group Discussions (FGD's). Secondary data was extracted from text books, agricultural related reports, newspapers and internet related information on agriculture and adoption of soil fertility technologies. However, given the gaps in the literature in terms of time and space, the researcher also collected first hand information from the contact respondents using Interview guides and a review guide that were accompanied by observation and photography. The approach was useful in a way that allowed the researcher to come up with firsthand information about factors that influence smallholder farmers' decision to adopt and utilize ISFM technologies.

Data analysis

Quantitative data was analyzed using SPSS (version 11.0). This computer program was used because it gives simple descriptive statistics easy for interpretation. Data analysis was done through relative frequencies and percentages and cross tabulations at a significance level of 0.05 percent. Descriptive statistics and Logit regression model were used.

Results and discussion

Table 4.1 shows that majority 52.1 percent of the respondents who participated in the study were men while 47.9 percent were female, also majority (42.2 percent) of the respondents were less than 35 years, majority (54.3 percent) were married, 12.9 percent were widowers or widows and 28.6 percent were cohabiting. 10.1 percent of the respondents who were interviewed had not attained education at all, 20.9 percent attained lower primary, 35.3 percent attained upper primary, 27.3 attained O-level, 5 percent attained A-level and only 1.4 percent of the respondents attained other educational levels. Farmers with more years of education are likely to have lower probability of adopting ISFM like agro forestry technologies than less educated farmers. This was not expected as educated farmers are likely to be better informed about the improved soil conservation technologies and the adverse effects of land degradation. The likely explanation for these results may be related to higher cost of labor for more educated farmers, which reduces the probability to adopt labor-intensive soil conservation methods.

Table 1: Social characteristics of Respondents

Characteristic	Category	Frequency (n=140)	Percentage
Sex	Male	67	47.9
	Female	73	52.1
Age		Frequency (n=135)	
	< 35	57	42.2
	36-50	39	28.9
	>50	39	28.9
Marital Status		Frequency (n=135)	
	Single	5	3.6
	Married	76	54.3
	Widower/widow	18	12.9
	Separated	1	7
	Cohibititing	40	28.6
Education Level		Frequency(n=139)	
	Never attained	14	10.1
	Lower primary	29	20.9
	Upper primary	49	35.3
	O'level	38	27.3
	A level	7	5
	Others	2	1.4

Increase of farmers' age has been found to decrease the probability of adoption. It may be that older farmers who have more experience in the use of available soil fertility management technologies are in a better position to assess characteristics of new technologies than younger farmers Michael M. Odera., Kimani, S.K. and Musembi, F.,(2000). However it could be that older farmers are more risk averse than younger farmers and have a lesser likelihood of adopting new technologies (Adesina and Zinnah, 1993). The likely explanation for this is the opportunity cost of labor. Younger farmers are likely to be more educated and with more nonfarm activities (Abdulai and Delgado, 1999), implying that the opportunity cost of the labor is higher. The farmers that had attained above secondary level of education were very few which showed a negative impact of education of household head on probability to adopt ISFM and was also unexpected. Since educated farmers were expected to have a good knowledge of the importance of ISFM technologies and hence the need to adopt the technologies. The reason for these results is the cost of farmers' labor, which is likely to increase with years of formal education. This would make the labor intensive ISFM technologies too expensive to implement.

Sex of respondent versus application of fertilizers

Hypothesis

H_o: Application of fertilizers depends on the gender of the farmer

H_a: Application of fertilizers does not depend on the gender of the farmer

∗Significant at $\alpha = 0.05$.

When I checked from cross tabulation, the critical value of χ^2 when α=0.05 was 0.231. Therefore the chi-square is significant at the 5% level, and therefore this suggests that application of fertilizers does not depend on the sex of the farmer.

Age of respondent versus application of fertilizers

Hypothesis

H_o: Application of fertilizers depends on the age of the farmer

H_a: Application of fertilizers does not depend on the age of the farmer

∗Significant at $\alpha = 0.05$.

When I checked from cross tabulation of age and application of fertilizers, the critical value of χ^2 when α=0.05 was 0.786. Therefore the chi-square was significant at the 5% level, and therefore this suggests that application of fertilizers does not depend on the age of the farmer.

Marital status of respondent versus application of fertilizers

It is hypothesized that

- H_o: Application of fertilizers depends on the marital status of the farmer
- H_a: Application of fertilizers does not depend on the marital status of the farmer

∗Significant at $\alpha = 0.05$.

When I checked from cross tabulation of age and application of fertilizers, the critical value of χ^2 when α=0.05 was 0.190. Therefore the chi-square was significant at the 5% level, and therefore this suggests that application of fertilizers does not depend on the marital status of the farmer.

Education level of respondent versus application of fertilizers

Hypothesis

H_o: Application of fertilizers depends on the education level of the farmer

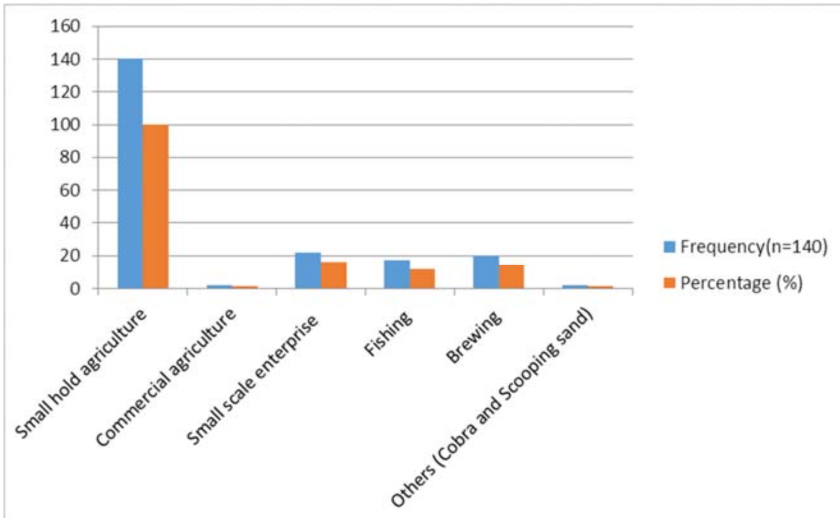
H_a: Application of fertilizers does not depend on the education level of the farmer

∗Significant at $\alpha = 0.05$.

When checked from cross tabulation of age and application of fertilizers, the critical value of χ^2 when α=0.05 was 0.275. Therefore the chi-square was significant at the 5% level, and therefore this suggests that application of fertilizers does not depend on the level of education of the farmer.

Economic activities undertaken in the community

The economic activities undertaken in the community are presented in the bar chart below. It is observed from the chart below that smallholder agriculture is the main economic activity in the study area. This implies that addressing factors that affect smallholder agriculture will have significant benefit to the livelihoods of the communities.



Source of income per household

According to Table 4.8 it shows that almost all (99.3 percent) of the respondents who were interviewed got their income from agriculture activities, 29.9 percent of the respondents also got income from salaries as salary earners, 24.6 percent were wage earners, 23.6 percent got their incomes from loans, 4.9 percent were pension earners, 3.4 percent got incomes from their assets like buildings they rented out and got interest while only 0.7 percent of the respondents got their incomes from other activities like mining. Wealth, as indicated by some households that got revenues from more than one avenue had a positive impact on probability to adopt improved land management technologies. Wealth was observed to increase the probability to adopt SFM technologies in Tororo and Uganda at large, probably due to its role in increasing the possibility of hiring labor to implement ISFM practices. Wealthy farmers may also have more land than poor farmers, hence would afford to adopt technologies that compete for land space with crops. As expected, wealth is also predicted to increase the probability to adopt inorganic fertilizer in Uganda.

Land access and utilization

Study findings shows that 93.6 percent of the people in Tororo have enough access to land while only 6.4 percent of the people have no access to enough land. The households that are found not to have enough access to land are the families that were observed to be extended families and yet family size is found to reduce the probability to adopt ISFM most especially agroforestry technologies in Tororo district. The reason for this observation is likely to be related to land scarcity, which is more severe with larger families.

Source of information about ISFM

Study findings shows that 30.5 percent of the respondents got information about ISFM from farmer groups, 37.1 percent got it from farmer field schools, 51.4 percent got it from trainings, 35.2 percent got it from demonstration farms, 19.7 percent got it from posters/brochures or leaflets while 9.3 percent got it from other sources like other farmers, radios and TV talk shows. As indicated in the literature review and the background of the study, there are a number of implementation methodologies that most researchers have developed to disseminate information to farmers

Fertilizer application

According to the study findings 65.7 percent of the respondents have ever applied fertilizers in their gardens while only 34.3 of the respondents have never applied fertilizers in their gardens.

Beneficiaries of ISFM technologies

According to the study results, it shows that 91.3 percent of the farmers who were interviewed and use fertilizers have benefited in using fertilizers while only 8.7 percent of the farmers have not benefited. The farmers who have managed to benefit are the farmers who have been able to use the required amounts of fertilizers in their farms and have managed to get increased crop yield. While the farmers who have not managed to get benefits ever since they started using fertilizers are those who are occasional farmers and have very many others off farm activities that reduce their time on the farms.

Furthermore study findings indicate that there is limited access to agricultural extension services on ISFM. The proportion of households reporting to have received agricultural training in the Tororo district is low (39.7 percent) because Tororo district has just started getting programs and organizations that train on ISFM. This could be the reason for limited knowledge of soil fertility technologies by farmers in Tororo district.

According to findings most of the farmers (37.7 percent) get extension services through trainings. As expected the number of visits by extension agents positively affects the probability to use SFM technologies in Tororo. Study findings show that majority of the respondents (65.1 percent) get extension services once in three months. In addition the results indicate that there is limited satisfaction with the extension services provided to farmers about ISFM. The findings shows 41 percent of the respondents are satisfied with the nature of extension services. This is because majority of the services given to the people of Tororo do not come in time because of the long distances from the suppliers and the weather roads that link to these farmers. And some extension service agents do segregate between the farmers leading to hatred between the farmers

From the cross tabulation findings it can be noted the p-value =0.45 is greater than 0.05 it implies that there was no a significant relationship between extension services and application and adoption of fertilizers at the 5 percent level, and therefore this suggests that application and adoption of fertilizers doesn't depend on the extension services received by farmers on SFM. This implies that extension services have no relationship with farmer's decision to adopt and utilize soil fertility management technologies. Farmers with or without extension services have the ability to adopt and utilize soil fertility technologies.

Type of extension service received versus application of fertilizers

Study results in the Table 2 indicate that a big number of the respondents (82.6 percent) who received fertilizers from the extension workers applied the fertilizers in their gardens and a relatively smaller number of respondents (68.2 percent) who had only received trainings on soil fertility had not applied any fertilizers in their gardens. The likely explanation could be related to the fact that provision of fertilizers reduces on the costs of applying fertilizers hence encouraging farmers to apply fertilizers.

Table 2: Type of extension service received versus application of fertilizers

Category	Ever applied fertilizers	Never applied fertilizers	Number of farmers (n)
Training	68.2%	31.8%	44
Fertilizers	82.6%	17.4%	23
Farm visits	76.5%	23.5%	34
Provision of seeds	77.8%	22.2%	18

Markets

Study findings shows that low market prices for the produce is the major constraint affecting marketing of farmers produce. This is in addition to poor transport due to lack of feeder roads in the villages yet it over rains during the rainy seasons cutting off the farmers from the town areas meaning they are not able to get farm requirements and linking to the market places during the rainy seasons.

Access to credit

Study result show that most of respondents interviewed lack collateral security to present to financial institutions to access loans to invest in their farming activities with a 61.9 percent, while others face problems with the procedures involved in getting bank accounts and processing loans. Access to credit may help to reduce poverty and hence land degradation and also increases the probability to adopt agro forestry technologies in Uganda. This is consistent with the findings of Pender, Gebremedlin, Benin and Etui (2001) who observed that access to credit increased the probability to plant trees and live fences

Study results shows that, SACCO'S are the major (81.8 percent) sources of loans for the farmers in Tororo district. The findings also reveal that there is limited access of funds from commercial banks by smallholder farmers. The high proportion of respondents receiving credit from Microfinance Institutions (MFIs) may be related to the success of microfinance institutions (MFI) in Uganda. It is estimated that there are about 500 MFIs in Uganda with 550,000 active customers who save about pound 370 million.

Conclusion and recommendations

It can be concluded that the variables that significantly increased the adoption of ISFM were group membership, in form of farmer groups and farmer field schools, access to off-farm income, access to fertilizers, fertilizer knowledge in terms of types of fertilizers and knowledge on fertilizer measurements and access to practical knowledge through participating in technology evaluation on demonstration farms or learning centers. Adoption of organic fertilizers like manure was more associated with the farmers who expressed limited sources of income.

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However it should also be noted that the major constraints to usage of fertilizers were the high prices of the fertilizers and lack of enough fertilizers in the region, though other factors like low incomes, low producer prices and others also constrained fertilizer usage while lack of security also mainly contributed to failure to acquire loans from micro-finance institutions.

The adoption and utilization of soil fertility management technologies is likely to increase with higher levels of education to farmers, secured farm ownership, profiTable crops, availability of information, availability and affordable technologies. There is a need to identify and integrate socio-economic characteristics of farmers and integrate in plans to promote the uptake and utilization of soil fertility management technologies. Important characteristics are personal characteristics, resources availability and institution factors.

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References – Where are the list of references used in the text?

An integrated approach to food security, ecosystem management and sustainable livelihood in arid and semi-arid lands

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Abstract

Kenya is expected to feed 30 million more people, between 2013 and the year 2030 when her population is estimated to reach 73 Million people. The role of agriculture, in supplying enough food, creating industries and attendant services among others is critical for transforming Kenya into middle income status. The high population growth, coupled with sub-division of land and over exploitation of the natural resources often lead to land degradation in the high potential areas and outright desertification in the ASALs. Land degradation, the temporary or permanent lowering of the productive capacity of land, covers the various forms of soil degradation, adverse human impacts on water resources, deforestation and lowering of the productive capacity of rangelands. It is also defined as the long term loss of ecosystem function and productivity caused by disturbances from which the land cannot recover unaided. An integrated approach that seeks to improve food security, ecosystem management and sustainable livelihoods should be considered in building capacity among communities, particularly those living in ASALs, in land and water management. Integration requires leveraging on mixed farming practices that most rural communities have adopted while introducing new methods and technologies that will increase production, productivity and the capacity to better manage the natural resource base. Africa Harvest has implemented this approach in the ASAL areas of Makueni and Kitui Counties, since July 2010 to date.

Introduction

Kenya is expected to feed 30 million more people, between 2013and the year 2030 when her population is estimated to reach 73 million people. This calls for intensified production of staple food crops such as maize. With the per capita consumption of maize, the staple food in Kenya, currently standing at 100 kg per annum, this translates to an additional 176 million bags (100-kg each) of maize per year. The current production is well below the required 40 million bags, with the estimated shortfall being around 10million bags per years.

The high population growth rate, land sub-division of land and, over exploitation of the natural resources often leads to land degradation in the high potential areas and outright desertification in the ASALs. Land degradation is defined as the temporary or permanent lowering of the productive capacity of land (UNEP, 1992b). It has also defined as the long term loss of ecosystem function and productivity caused by disturbances from which the land cannot recover unaided. The process covers various forms of soil degradation, adverse human impacts on water resources, deforestation and lowering of the productive capacity of rangelands. Use conventional citation systems.

Kenya’s arid and semi-arid lands (ASALs) support about 25% of the human population, 60% of the livestock population and some reasonable degree of cropping. The ASALs also provides a wide variety of useful products such as timber, fuel-wood, charcoal, fruits, gums, resins, honey, and herbal medicines. The rapid population growth in the country implies it is imperative to support the communities in ASAL whose livelihoods are limited by a number of ecological constraints such as erratic rainfall run-off; high rate of potential evapo-transpiration; and low organic matter levels.

Over the past two decades, ASALs in Kenya assumed more prominence as alternatives for food production. The challenge of land degradation in the ASALs is further complicated by deeply seated or cultural notions on soil fertility which militate against use of fertilizers. The belief is that soils in these areas require no

fertilizers and that use of inorganic fertilizers leads to low soil fertility. In addition, traditional methods of conserving soil fertility- crop rotation, terracing and on-farm water harvesting have been neglected over the years.

One option to help mitigate the adverse effects of degradation while building resilience in the target communities-living in ASALs through knowledge and skills transfer, is to utilize alternative methods of soil fertility enhancement that complement traditional/cultural knowledge and farming systems. The integrated farming systems approach-which combines both agricultural as well as livestock activities can be leveraged to achieve this goal. This approach seeks to enhance the resilience in smallholder farmers living in ASALs of Kenya through imparting skills and knowledge needed to conserve and improve soil fertility as well as manage water resources to increase food production, productivity and overall economic well being.

The goal of this project was to investigate how this approach can be used to enhance household food security, incomes and nutrition while enhancing coping mechanisms in the face of climate change, for sustainable rural livelihoods in the ASAL areas.

The project had five specific objectives namely;

- To map out, the status in production of horticultural and high value traditional food crops, short cycle livestock, status of soil and water management as well as the corresponding technologies,
- To determine the potential for improving food security by supporting and facilitating the adoption and production of adapTable and fast maturing horticultural and traditional food crops
- To evaluate alternative approaches to enhancing soil fertility including harnessing livestock manure use for improved agricultural productivity,
- To assess the community's ability to sustain the ecosystem by promoting water conservation, harvesting and management practices and
- To evaluate alternative means of diversifying incomes and nutrition by promoting the adoption and the rapid improvement of short cycle livestock

Materials and methods

Site description

Consultative and participatory methodologies that give local/target communities the opportunity to develop their capacities while allowing them a choice in the selection of suiTable interventions were used in implementing this project. The Whole value chain approach which seeks to streamline barriers and bottlenecks and link downstream activities to surplus markets was the guiding strategy, during project implementation. 10,596 Household representatives were organized in 80 farmer groups were identified for support and participation in project activities, over the course of 3 years, in the three divisions of Mulala, Wote (in Makueni County) and Central Kitui (Kitui County). Most (73%) of these household representatives were women and 27% were men. Diversity of participants as was promoted through an inclusive approach targetting the bottom of the pyramid including participation by vulnerable members of the community 5 groups of people living with HIV/AIDs, 6 Youth groups, 21 Women only groups, 2 (two) Widows and Orphans support groups, One rehabilitation group, One men only group and 44 groups of mixed gender (Women and Men).

A three pronged implementation strategy was adopted namely; 1) Organizing beneficiaries into groups and building their capacity to participate in the interventions- group dynamics, group governance and leadership trainings, 2) facilitating access to improved technologies and 3) building the capacity of target beneficiaries to exploit the full potential in these technologies as well as establishing sustainability measures.

These groups were facilitated to access the improved varieties of Sorghum (Gadam and Seredo) and Cowpeas (K80), Agro-forestry species (*Calliandra callothyrsus* and *Leucena leucocephala*), improved

Toggenburg goats and Kenbro chicken. Capacity building to improve skills in terracing as well as on-farm water harvesting structures (retention ditches) was undertaken in partnership with The World Agro-forestry Center and Ministry of Agriculture. Training on nursery establishment and management, animal husbandry, good agronomic practices and water conservation- through kitchen gardens, were also carried out among the target community. In matters of water management, the communities were involved in prioritizing their need in matters of water resources and they opted for sand dams.

Results

- Adoption of improved food crop technologies by smallholders coupled with the training package on improved agronomic practices geared towards better management of natural resources-especially soil
- Increased production of drought tolerant crops that are best suited to the ASAL ecologies
- Use of cowpea technology to improve nitrogen fixation was also enhanced through establishment of the crop in 1822 acres within the target regions. This is a cumulative area
- Enhanced awareness and knowledge on agroforestry practices as well as skills in composting and the use of these practices in soil improvement
- Enhanced skills and knowledge in terrace laying and use of terraces in conserving soils. Any numbers of farmers trained
- Enhanced skills and knowledge as well as the use of animal manure (chicken and goat) in composting and farm yard manure used to improve soil fertility and enhance productivity
- Enhanced skills and knowledge on water harvesting- roof as well as road surface run off, leading to improvement in soil water retention
- Improved the recharge of ground water Table through sand dams and enhanced the knowledge among target community on water management, conserving the environment and reducing sand harvesting along river lines.

Discussion

Beginning in July 2010 and running until June 2013, Africa Harvest biotech foundation International implemented a grant project targeting 8000 smallholder households in the Arid and Semi Arid Lands of Makueni and Kitui County. The project was funded by IFAD with funds from the Italian Development Cooperation and sought enhance food security, ecosystem management and sustainable livelihoods in Mulala, Wote and Central Kitui divisions of Makueni and Kitui Counties. The project used an integrated approach with four components, namely: traditional food crops, Soil fertility management (agro-forestry and composting), Water (Conservation, harvesting and management) and Shortcycle livestock (Improved chicken and goats). These components are self reinforcing in a loop that ensures improved production of food crops, nutritional enhancement(human), enhancement of soil fertility (cowpea for nitrogen fixation, agro-forestry and composting), water conservation, water harvesting and construction of water structures(sand dams) and finally incomes, nutrition and soil fertility management through promotion of shortcycle livestock (chicken and goats). The agroforestry tree species promoted played a dual role- that supporting goat production- as fodder crops as well as providing a sustainable source for domestic woodfuel. The approach sought to build the capacity of beneficiary households through training and enhancing access to improved technologies as well skills and knowledge needed to improve production and productivity. Sorghum and Cowpea were promoted as traditional food crops best suited to the target ASALs- fast maturing, drought tolerant and nutrition enhancing (especially Cowpea). Soil fertility management was promoted through training on composting, use of agroforestry tree species, use of cowpea-for nitrogen fixation and establishment of terraces in addition to crop rotation practices. Kitchen garden technology was promoted to enhance domestic water conservation, harvesting of roof water and road surface run-off for on farm water harvesting were also promoted. Sand dams were constructed to enhance water access and recharge of water Tables in the target areas. Improved breeds of Chicken and Goats were introduced in the target community to improve local breeds, increase egg and milk production

and enhance household nutrition and incomes through consumption of these products, as well as the sale of surplus products, respectively.

The main take away lesson from this investigative grant is that the introduction of new technologies and methods requires a well thought out strategy on how to bridge the knowledge gap while leveraging local/indigenous knowledge. Where conflict presents, between new methods and indigenous knowledge and practices, the community will need time and positive reinforcement that provides a reference and learning point. This can be achieved through champion farmers, farmer field schools and other adult learning and participatory approaches. Secondly, access to end user markets for produce and products generate through the value chain is necessary to enhance sustainability and spur scalability. Lastly, the cost of new technologies and methods may limit adoption and therefore, alternative avenues to ease access should also be factored into the program design. Cost and sustainable access to these new methods/technologies requires due attention too.

Conclusion

While the over arching goal of the integrated approach to food security, ecosystem management and sustainable livelihoods is to improve food security, incomes and nutrition at the household level, adoption of the approach has positive and far reaching spill-over benefits for smallholder farmers. The approach leverages on local knowledge and practices in improving soil fertility while introducing iterations (composting and terracing) that further reinforce the system. The system also consolidates skills and knowledge base among smallholder farmers in land, water and other natural resource management through training, demonstration and participation by the local community.

Providing such communities with access to information and walking with them to convince, demonstrate and empower them to make informed choices from a position of knowledge, is critical to success. In addition, the mode of transmission and packaging of new information, ideas, practices and technologies can potentially derail a noble idea. It is therefore important to tailor make the information dissemination pathways to the target audience if one is to catalyze a desire to change for the better, among rural communities. Ultimately, the intervention should make it easier for the target community to economically achieve their goals in a cost effective, efficient and sustainable manner.

However the challenge here is one of changing or altering the mindset of the community given prior knowledge and experience. Community involvement is critical to success and therefore participatory and consultative approaches should be encouraged.

The cost of accessing technologies should be easy to afford if farmers/communities living in these areas are to adopt and sustain the practices over a long time.

Recommendations

- By leveraging the mixed farming practices that most rural communities know and trust, while introducing new methods and technologies that will increase production, productivity and the capacity to better manage natural resource base, this approach compliments what is on the ground and is not overly disruptive
- A skill, knowledge management and transfer component is critical to success and should be designed with the needs of the target community in mind. Dissemination of information should also be done in participatory and consultative manner to enhance ownership and ensure sustainability

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- Africa Harvest Biotech Foundation International

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Farmers perception on changes in natural resource base at Kathekakai settlement scheme, Machakos County, Kenya

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Abstract

This study analyzed changes in natural resources in Kathakakai settlement scheme, Machakos County using participatory resource mapping and attempted to discuss possible effects. The area, which was a ranching enterprise for nearly a hundred years, was sub divided in 1995 into individual farm holdings with average farm size of 2.5 hectares per household. Individual farmers opened-up the land for agricultural activities and other land developments. The results show that natural resources had decreased since the ranch became a settlement scheme in 1995. Farmers indicated that the natural forests decreased and have been replaced by exotic trees, vast land was cleared for cultivation, rivers, and dams have since dried-up while soil erosion has increased. A majority of farmers (98%) said they had observed a general change in the climate of the area. They cited declining crop production (29%), increased drought (15%), and increased temperatures (10%) as some of the major pointers to climate change. However, farmers adopted various adapting and coping strategies. Drought tolerant crops (25%), early maturing crops (17%), and water harvesting (14%) were some of the strategies adopted by farmers in response to cope with the emerging changes. The results also show that resource base management at the community level is still a challenge and a lot of investment needs to be done in this field for sustainable management.

Key words: land subdivision, human settlement, population growth, agricultural activities

Introduction

Participatory Mapping is the creation of maps by local communities usually with the guidance of organizations e.g. government agencies, non-governmental organizations, universities, and actors interested in development and land planning. The activity provides a platform for a community to represent in visual terms a place and significant features within it. These features may range from natural physical features, resource and social cultural features known by the community.

Participatory Mapping is a powerful tool to good governance and this has led to increased use of this initiative for the last 20 years throughout the world (IFAD, 2009). It is a useful medium for communities to communicate land related information at present and future needs to government to better understand the community and environment (McCall, 2004). The exercise facilitates management of land, resources, and supports community advocacy on land related issues (Di Gessa, 2008). This is one of the best ways to 'empower' community, as participation prioritizes local decision-making and reinforces responsibilities. The ability of individual citizens and communities to share their understanding of the past, present and visions for the future is an important pre-requisite to informed planning and, through this, to building a consensus on complex issues such as sustainable development (Curwell and Hamilton, 2003). Through maps, communities are able to communicate long but invisible history of managing resources. The process hence assists the community to articulate and communicate desired management plans to local or regional planners, which could enable the community to access productive natural resources and promote decentralized management of resources (Aberley, 1993). Participatory Mapping therefore contributes to planning and management of local resources by enabling the community information to be incorporated and compared with government planning information and processes (IFAD, 2009).

In a number of cases worldwide, communities have succeeded to demand for legal recognition resource rights through maps. For instance; in Guyana, Amerindian people claimed ancestral land titles (Griffiths,

2002) as a result of Participatory Mapping of resources through Participatory Geographical Information Systems (PGIS); the Zuni pueblo of New Mexico prepared digital maps of 'non-graphic descriptions' of their appropriated lands to receive a quarter of a million acres as compensation (Marozas, 1991). In the Philippines, claiming Ancestral Domain Title is conditional on preparing a resource management map for the area (Rambaldi and Callosa-Tarr, 2002); and in Indonesia, through Participatory Mapping it was possible to identify traditional village territories and competing rights claims (Sirait *et al*. 1994), that were crucial for planning. Futherstill, the Ogeik, Sengwer and Yaiku indigenous communities in Kenya were able to initiate their own ancestral land rights, cultural rights and natural land resource management projects after a participatory resource mapping exercise carried out in 2006 (Muchemi et.al. 2009).

This study sought to use farmers' knowledge to determine changes in natural resources including land, water, forests and soil and, assess strategies used by community to cope with these changes.

Methods of study

Study site

The study was carried out at Katheka-kai Settlement Scheme, in Machakos County of Kenya The area, which was a ranch for nearly a hundred years, was sub divided in 1995 into individual farm holdings with average farm size of 2.5 ha per household. The total population as per 2009 census was about 15000 individual farmers opened-up the land (cutting trees and shrubs) for agricultural activities and other land developments. The climate in Machakos County is typically semi-arid with mean annual temperatures of 15-25^{o}C and mean annual rainfall of 700 mm. Rainfall distribution is bimodal with the long rains starting from March and ending in May, and short rains from November/December to early January, recording average seasonal rainfall of between 300-400mm and 310mm respectively. Short rains are more reliable than the long rains and therefore most important for agricultural production.

Study methodology

Data was collected through focus group discussion (FGDs) during which a resource mapping exercise was also carried out. The discussions were conducted in a free environment where the participants gave their comments and asked questions.. Mulwa and Nguluu (2003) have recommended a similar approach of collecting information using FGDs. Most of the studies on social economic dynamics as well as natural resource management employ FGDs (Odimegwu, 2000). In this study, FDGs were used to establish changes that have taken place since the first people settled in Kathekaka in 1995. A Participatory Rapid Appraisal exercise involving 30 farmers (13 men and 17 women) from Kathekakai location was conducted through FGDsand resource mapping. Based on the objective of the study, two FGDs consisting of 12 members each were formed. The first group consisted of farmers who settled before year 2000 and who drew the map of Kathekakai as they found it when they first settled. The second group had farmers who settled after year 2000 and they drew a map showing the current resource situation of the area. Household interviews were carried out, with 62 farmers (36% men and 64% women) who expressed their views on changes that have taken place and the coping strategies used. A comparison of the two sketch maps drawn was made based on resource availability.

Results

Farmers' characteristics

According to the farmers, the farm was initially a co-operative society. The enterprise was poorly managed and divided to individual share holders and hence, the land is now under private ownership. About 71% of the land is owned by men. Women own 8% mostly through succession after death of the husband. The rest (21%) is under family ownership. Although this is a farming community (92%), most households derive their income from casual labor (37%), business (25%), formal employment (18%), sale of farm produce (11%) and remittances (9%).

Resource availability at the time of settlement

Different types of old natural and traditional trees and shrubs were available at the time of settlement. A range of Acacia tree varieties was common in the area. The rivers that passed through the area had clean, safe drinking water and that the rivers flowed throughout the year. Big earth dams for water harvesting had been constructed and wind vanes were used to pump water into well established water tanks throughout the ranch, both for livestock and human drinking. The roads, though not many were well maintained during that time.

Resource changes

Presently, the scenario has changed as most of the resources are no longer in existence, and even where they exist, they are in poor condition. The number of people settling is increasing year after year, a situation farmers associated to its proximity to Nairobi, the capital of Kenya.

This has led to more land being cleared to pave way for cultivation and other developments. Natural trees have also been cut down to cater for various uses including building, firewood and charcoal, and have been replaced by exotic trees such as grevillea. Farmers reported the opening of new land and cutting down of trees as major contributing factors to increased soil erosion that has led to declining land productivity, a situation that has increased food insecurity and poverty in the area. This was observed this during household interviews between september and october, 2009 where school going children stayed at home due to hunger. This was later confirmed when during one of the meetings, the Ministry of Agriculture staff was seen distributing food and planting seeds to the farmers.

Rivers that used to be annual had become seasonal and anymore. Most households either went a long distance to draw water or bought from people who have either dug boreholes or constructed dams. The trend, according to the residents was worrying as the ever increasing population had forced people to settle on mountains, hills and cultivate along the riverines which essentially interfered with river water source and flow. This, according to residents had accelerated the rate of soil erosion and s caused most of the river water to be unfit for consumption. The activities had also affected the transport system as most roads got filled up with mud from soils eroded from the hills rendering them impassable.

Farming systems

Farmers in this area practiced mixed farming with about 45% of them practicing crop production. However, farming systems had changed with time. Although a larger number of farmers grew traditional crops the traditional crops such as sweet popato (19%), cassava (16%) , sorghum (15%), green grams (9%), millet (8%), a few able were abandoning them for modern and high value crops fruits and vegTables mostly for economic purposes.

Livestock about 31% and hence an important component of the farming systems in this area, highly contributing to food (40.2%), income (33.5%), manure (12.3%) and family labour (7.9%). Inorder of importance farmers p poultry (mostly local chicken), cows, sheep, goats bulls and oxen. From an area that was 100% free range grazing system, other systems since come to play semi- grazing (33.9%) and zero-grazing (19%). Residents identified land and subdivision as the main cause of these changes. However, free range and semi-grazing systems also accounts for increased soil erosion as large numbers of livestock usually on land with very low vegetation.

Farm agroforestry (14%) is also an important farming practice system in Katheka-kai. About 64% of farmers planted different trees agroforestry trees such as *Grevillea robusta* and *Melia volkensii* (34%), fruit trees mangos, citrus and tree tomatoes (4.9%), and leguminous trees such as *Calliandra calothyrsus* (2.4%). The trees planted for various reasons including windbreaking (12%), shade (11%) and firewood (10%). Fruits are planted for household use as well as income generation.

Coping strategies

Most (98%) of the farmers believed that climate had changed with time. Some factors identified as contributing to change include cutting trees, clearing land for cultivation, sand harvesting, increased popultation, increased fuelwood demand and lack of planting trees,. They agreed that this change had

decreased crop production (29%), increased drought and temperatures (15% and 10% respectively). However, farmers have adopted measures to adapt and cope with climate change (Table 1).

Table 1: Coping strategies to change

Coping strategy	% of respondents
Drought resistant crops	25
Early maturing crops	17
Water harvesting	14
De-stocking	10
Conservation agriculture	6
Irrigation	5
Off-farm employment	8
Change of livestock breeds	3

Discussions

Changes in resources have been observed at Kathekakai location, Machakos District since 1995 when land was subdivided to private owners. The new settlers were at liberty to use the land in a way to get maximum benefits. It has been reported that when individual members acquire private land with title deeds, they get rights to make land use decisions based on the returns (Mundia and Muranyan, 2009; Serneels S. and Lambin E. (2001). According to Mundia and Muranyan (2009), changing land tenure policy results in expansion of agricultual land. Due to its proximity to Nairobi, the capital city of Kenya, the area has continued to attract a big population as a periurban area. Farmers at Katheka-kai location have continued to clear more land and cut down trees to pave way for agricultural land to meet demands for the households as well as for the ever increasing population. Therefore, small farmers are forced to work harder, often on shrinking farm sizes on marginal land, to maintain household incomes. A study carried out by Laukkonen *et al*, 2009 reported population growth as a major driver of environmental change in Africa, causing significant impacts on the natural resource base with the primary and most direct impact as land cover change mainly through opening of new land for agriculture, and other developments. Work carried out in the same area also confirms this (Gathaara et.al. 2010).

The area has witnessed changes in farming systems. Only a few able farmers have abandoned local and traditional crops and adopted those deemed to have high returns and preferred by the swelling population. The very few wealthy farmers embarked on irrigated agriculture and green house farming. It has been reported that population growth shapes patterns of production and consumption in the world usually by increasing demand for food, water, arable land, fuel wood, and other amenities (UNEP, 2008), and hence determines the farming systems in an area. However, the increased agricultural activities lead to increased encroachment into forests and woodlands, soil erosion and infertility and ultimately food insecurity and increased poverty levels (MOA, 2008). As good as these activities are in sustaining household livelihoods in the short-run, if poorly managed they may have detrimental impacts on environmental resources. For example felling of trees for agricultural land and timber products, settlement on mountain have left watersheds bare, threatening the water catchment functions of forested watersheds (MOA, 2009). Extensive economic activities and population congestion has increased pressure on water for various uses including domestic, livestock and industrial use, among others, causing water allocation and use conflicts. This may result in natural resource base degradation, which in turn impinges on the livelihoods, with most of the consequences more pronounced in the rural communities (Laukkonen *et al*, 2009).

With climate change setting in, diversification in the agricultural activities becomes paramount to cushion against adverse effects. It has been indicated that in the absence of alternative opportunities, lack of sustainable management of natural resource and alternative opportunities to meet the needs of the

increasing population results in environmental degradation and resource depletion (Laukkonen *et al*, 2009). Farmers in this area are taking a precaution by adopting some of the coping strategies drought tolerant crops, early maturing crops, water harvesting, and de-stocking. However, a lot of advocacy on mitigation and adaptation strategies should be done for increased adoption rate.

Conclusion and recommendations

The process of resource mapping seemed to open the mind of farmers to understand the past, present and future situation, and the problems facing the community. Decreasing trend in natural resource base after settlement was witnessed and associated with increased population and poor management especially of communal resources. Farmers in this area are aware of environmental change though issues on mitigation and coping strategies need to be addressed. Most of the farmers still rely on their past farming experience and this poses a great challenge to sustainable development of the study area.

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The role of agro-input dealers in dissemination and communication of soil fertility management knowledge: the case of Siaya and Trans Nzoia Counties in Kenya

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Abstract

Lack of access to necessary agro-inputs contributes to low agricultural productivity and slows the overall economic growth and development in most parts of sub-Saharan Africa. Agro-input dealers make inputs more easily accessible to rural-based smallholder farmers. This study assessed the role played by agro-input dealers in disseminating and communicating ISFM practices and information to smallholder farmers. The study was conducted in Siaya and Trans Nzoia counties in Kenya, and looked at agro-input dealers' awareness of ISFM practices. The study interviewed 144 agro-input dealers randomly selected across the study area. The field surveys were conducted where agro input dealers were the main respondents. The result from logit regression model estimates showed that gender, age, educational level, experience in agro-input business and visit by extension staff significantly influenced the agro-input dealers' awareness of ISFM technologies.The study findings suggest the need to improve the provision of extension services to agro-input dealers to enable them effectively communicate information about ISFM technologies to farmers. Such initiatives on capacity building should take into consideration gender of the agro-input dealers.

Key words: ISFM, agro-input dealers, smallholder farmers, knowledge, communicating, disseminating.

Introduction

Limited access to necessary agro-inputs has been the main cause of low agricultural productivity and the overall poor economic growth and development in most parts of sub Saharan Africa (SSA) (Sanchez and Jama, 2002). Agro-input dealers play a significant role of guaranteeing that farmers have access to some of the essential agricultural inputs that contribute to boosting the agricultural productivity (Ayieko and Tschirly, 2006; *Chianu et al.*, 2008). Despite this importance, the strategic role and position of the agro-input dealers has not been fully exploited especially in dissemination and communication of the key agricultural development technologies such as Integrated Soil Fertility Management (ISFM).

In 2006, the plight of African farmers was highlighted when the African policymakers met during the Africa Fertilizer Summit held in Abuja, Nigeria in June 2006 (IFDC, 2010). The meeting highlighted the gap in agricultural productivity caused by limited use of agricultural inputs. From the meeting and subsequent follow up summits, the role of agro-input dealers and agro-input business started receiving serious attention both in agricultural development discussions and policy-making (COMESA, 2009).

This study explored the knowledge among the agro-input dealers on various soil fertility management practices. The soil fertility management components that were looked at in this study included the use of improved seeds and fertilizers in maize production. These inputs are by far the most widely used ISFM practices by farmers for tackling maize productivity problems in Kenya. Maize was chosen because it is the

most widely grown and the most important staple crop in Kenya. The other components of integrated soil fertility management practices that were studied include use of inorganic fertilizers, micro dosing or precise fertilization, nitrogen fixations by legumes, biomass transfer, agro-forestry, improved fallow, composting, crop rotation , animal manure, agrochemicals, farm machinery, seed treatment chemicals, pesticides and storage chemicals.

The main objective of the study was to assess the role agro-input dealer's play in dissemination and communication of the ISFM practices and agricultural information in Siaya and Trans Nzoia Counties in Kenya. Specifically, the study assessed the agro input dealer's awareness of soil fertility management practices.

Methodology and materials

Description of study area

This study was conducted in Siaya and Trans Nzoia counties in western Kenya. Western Kenya is among the most densely populated regions in the SSA (Titonell *et al*, 2005). The high population is attributed to the earlier settlements that were motivated by the high agro ecological potential of the area making it conducive for crop production and high fertility of the soils in the region (Titonell *et al*, 2005). Despite the high potential exhibited by the region, the area has remained highly under-developed.

Siaya County lies between latitude 0°30' North and longitude 34°30' East at 1,141-1,400 m on the shores of Lake Victoria in the south and southwest, to 1,400 m in the North and East.

Trans Nzoia County is located between the Nzoia River and Mount Elgon. Its centre is the Kitale town and it is the continuation of the fertile Uasin Gishu plateau beyond ("Trans") the Nzoia river. It is the best zone in the country for maize and sunflower production. The altitude varies between 1,800-1,900 m.

Sampling and data collection

The study involved agro-input dealers as the main respondents. The agro-input dealers were drawn from the prior participants in the Kenya Agro-dealers Strengthening Program (KASP) projects. The sampling frame consisted of 288 agro-input dealers that had participated in the KASP project: 140 agro-input dealers in Trans Nzoia and 148 agro-input dealers in Siaya County. A total of 144 agro-input dealers were selected. The distribution of the respondents in the two counties is presented in Table 1.

Table 2: Sampling scheme for agro-input dealers in Siaya and Trans Nzoia Counties

County	Sampling frame	Proportion (%)	Sample agro-input dealers
Siaya	148	50	74
Trans Nzoia	140	50	70
Total	288	100	144

Empirical methods

This study used a detailed questionnaire to collect data from 144 agro-input dealers from 2 counties (*Siaya* and *Trans Nzoia*) covering 33 market centers. The questions covered in the questionnaire were organized into 2 sections. These included general characteristics of agro-input dealers (gender, age, years in school, main and secondary occupation, year started agro-input business, etc.), assessment of ISFM awareness by agro-input dealers. Following training of enumerators, actual data collection was carried out between November and December 2011. Data entry was done in Census and Survey Processing System (CSPro). Data cleaning and analysis was carried out Statistical Package for Social Sciences version 20 (SPSS 20) and MS Excel office 2007.

Two null hypotheses were being verified in this study. Foremost the level of education of the agro-input dealer has no effect on the awareness of ISFM technologies. Secondly the period of engagement in agribusiness has no effect on the awareness of ISFM technologies among agro input dealers.

Data analysis

Data was analyzed using the SPSS version 20. Frequencies, descriptives, correlations and cross-tabulations were generated to derive summary statistics. Regressions (Logistic regressions) and ANOVA's were undertaken to determine causal relationships between variables. Logistic regression was selected due to the fact that the responses are binary i.e. aware or not aware. The methods also allows for combination of numeric and non-numeric data to compute binary response (Smith and Moffat, 1999).

To address the objective on the factors that influenced agro-input dealer awareness of various ISFM technologies a logistic regression was used (Smith and Moffat, 1999). Following Gujarati (1999), and Hardin and Hilbe (2001), the logistic regression model characterizing awareness by the sample agro-input dealer can be specified as:

$$Pi = F(\alpha + \beta Xi) = \frac{e^{(\alpha+\beta Xi)}}{1+e^{(\alpha+\beta Xi)}} \quad (2)$$

Where:

- *Pi* is the probability that an individual agro-input dealer is aware of the ISFM technology given Xi, and *i* denote i-th observation in the sample
- X*i* is the random variable
- F (.) is the accumulative distribution function of the Logit model
- e is the base of natural logarithm
- α and β are the coefficients associated with each explanatory variable

Awareness is defined as whether the agro input dealer has heard of the various ISFM components such as inorganic fertilizers, precise fertilization (micro-dosing), nitrogen fixation by legumes, improved germplasm (seeds), biomass transfer, agro-forestry, improved fallow, compositing, crop rotation, animal manure, farm machinery, seed treatment chemicals, pesticides or storage chemicals. The variables used in the logistic model are gender, age, level of education, experience in agro business, visit by extensions and researchers, participation in famer field days and education days.

Results and discussions

Socio-demographic characteristics of agro-input dealers

The summary statistics of the variables used in this study are presented in Table 2. Most of the agro-input dealers (65%) were men. The age of agro-input dealers ranged from 19 to 68 years, with a mean and standard deviation of 37.3 and 9.68 years, respectively. About 119 of the 144 of the agro-input dealers interviewed were specialized agro-input shops. The remaining combined agro-input dealer business with other business lines.

Agro-input dealer's awareness of ISFM technologies

This study assessed whether the agro-input dealers were aware of ISFM technologies. Awareness was defined as whether the agro-input dealer ever heard of ISFM technologies such as use of inorganic fertilizers, precise fertilization or micro dosing, nitrogen fixations by legumes, use of improved seeds or germplasm, biomass transfer, agro-forestry, use of improved fallows, composting, crop rotation, use of animal manure, use of farm machinery, seed treatment chemicals, pesticides and storage chemicals. Results indicated that 58% of the agro-input dealers were aware of various ISFM technologies.

Table 3: Socio-demographic characteristics of surveyed agro-input dealers in Trans-Nzioa and Siaya Counties in Kenya

Gender		Frequency	Percentage
Male		94	65.3
Female		50	34.7
Siaya		73	50.7
Trans Nzoia		71	49.3
Agro-input dealer		119	82.6
Farmer		19	13.2
Veterinary officer		4	2.8
Teacher		2	1.4
Agro-dealer experience		Gender	
		Male	Female
Age (years)	Minimum	19.0	20.0
	Maximum	68.0	50.0
	Mean	39.2	33.7
	Std. Deviation	10.34	7.09
Duration in business (years)	Minimum	1.0	2.0
	Maximum	16.0	15.0
	Mean	5.6	5.2
	Std. Deviation	3.18	3.07
Agro-dealer-interaction		Year	
		2010	2011
Number of times agro-input dealers interacted with extension staff	Minimum	1.0	1.0
	Maximum	20.0	12.0
	Mean	2.0	1.9
	Std. Deviation	3.71	1.61
Number of times agro-input dealers interacted with researchers	Minimum	1.0	1.0
	Maximum	5.0	9.0
	Mean	1.5	1.5
	Std. Deviation	1.08	1.06
Number of field days /shows/fairs attended	Minimum	1.0	1.0
	Maximum	15.0	11.0
	Mean	3.0	2.1
	Std. Deviation	1.92	1.73

Logit regression of factors influencing awareness of ISFM by agro-input dealers in Siaya and Trans Nzoia Counties in Kenya

A logistic regression was fitted to assess the effects of various variables on ISFM awareness by 144 agro-input dealers is shown in Table 3. Five variables: gender, age, formal educational level, experience in agro business and visit by extension of agro-input dealers substantially contributed to agro-input dealer's awareness of ISFM knowledge.

Results from the logistic regression analysis show that agro-input dealers with primary level education or lower were less likely to be aware of some of the ISFM technologies compared with those with secondary or post-secondary education. From the logit regression model, holding other variables constant, an increase

in the formal level of education by one unit such as from primary level to secondary level increased the chances of ISFM awareness by 0.91 (p=0.000). This finding highlights the importance of education in the dissemination and communication of ISFM technologies and knowledge to the agro input dealers.

Holding other factors constant, increasing the number of years of engagement in agro businesses increased the chances of agro-input dealer awareness of ISFM technologies by 0.08 (p=0.000). This implies that agro-input dealers who have been in business for longer periods were more likely to be aware of ISFM technologies than those who have been in agro business for a shorter period. This further means that agro-input dealers who have been in business for a longer period would have higher chances of learning or interacting with other agro-input dealers and agents in this field.

Age of agro-input dealer was also statistically significant. Holding other factors constant, the model indicated that with an increase in the age of the agro-input dealer by one year increased the chances of agro-input dealer awareness of ISFM by 0.036 (p=0.000). This meant that agro-input dealer awareness of the various ISFM components is determined by the age and level of education. Table 3 shows the logit model of the factors influencing agro-input dealer's awareness of ISFM technologies.

Table 4: Logit regression of factors influencing awareness of ISFM by agro-dealers in Siaya and Trans Nzoia Counties in Kenya

Variables	Co- efficient	S.E.	P value	Marginal effects
Gender of agro-input dealer	-0.395	0.117	0.001	1.335
Age of agro-input dealer (years)	0.036	0.007	0.000	37.213
Formal education level	0.906	0.109	0.000	3.696
Experience in agro business (years)	0.076	0.021	0.000	5.587
Visit by extension	0.569	0.264	0.031	0.931
Visit by researcher	0.038	0.23	0.869	0.916
Farmer field days/shows	-0.442	0.415	0.287	0.991
Engagement in farmer education	0.127	0.287	0.657	0.958
Constant	-4.042	0.669		

Overall percentage predicted correct (86.7%),
Model Summary (-2 Log likelihood =1927.42, Cox & Snell R Square (0.11), Nagelkerke R Square (0.16), N=142.

Examining Table 3 further, gender was also statistically significant in influencing the agro-input dealers' awareness. Holding other variables constant female agro-input dealers were less likely to be aware of ISFM technology compared with male agro-input dealers. This indicated that farmers who rely on male agro-input dealers were more likely to benefit from the awareness advantage compared with farmers who rely on female agro-input dealers. Though the statistics show this result, the application of this result should be treated with caution because the numbers of male respondents were higher than the female making it important for further analysis using the same number of male and females in the analysis.

Visits by extension staff was another variable that affects the agro-input dealer's awareness of ISFM technologies. Holding other variables constant, an additional visit by extension staff, increased the probability of agro-input dealer awareness of ISFM by 0.57% (p=0.031). This indicates that extension service has a role to play in the knowledge of ISFM dissemination and or communication.

Several variables had no significant influence on the awareness of ISFM knowledge by agro-input dealers; visitation by researchers, farmer field days and involvement in farmer education were found to have no significant influence on the ISFM awareness.

Based on the above findings, the level of education of the agro-input dealer contributes to the agro-input dealer's awareness of the ISFM and the results further show that the years of engagement in agro-input business also raises the awareness of the ISFM technologies by agro-input dealers. Therefore the null

hypothesis that the level of education of the agro-input dealer has no effect on the awareness of ISFM technologies was rejected. Subsequently, the null hypothesis that the period of engagement in agro-input business has no effect on the awareness of ISFM technologies was likewise rejected.

Conclusions

Foremost, the level of formal education of the agro-input dealer plays a vital role in the agro-input dealer's awareness of the ISFM technologies. The period of engagement in agro-input business has an influence on the agro-input dealer's awareness of the ISFM technologies.

The findings of this study suggest the need to improve the provision of extension services to agro-input dealers to enable them effectively communicate information about ISFM technologies to farmers. There is need to address the existing knowledge gap among agro-input dealers to enable them effectively communicate ISFM technologies to farmers. There is need for all stakeholders to be encouraged to engage in awareness creation and capacity building of the agro-input dealers to effectively equip them with skills and knowledge essential in dissemination and communication of ISFM technology. There is need for the empowerment of female agro-input dealers to be able to participate in awareness creation of the agricultural technologies being developed; the results indicate the existing systems do not favor them much.

The government agencies engagement in training of agro-input dealers has been minimal, there is need for more resources in terms of human capital and infrastructure to be invested in national research centers so that agro-input dealers and farmers are able to benefit from basic services like soil analysis and thus be able to effectively know which agronomic practices to adopt for optimum returns.

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Land and water resources management in Nkambe highlands of Cameroon: Challenges and perspectives

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Abstract

In Africa, access to land and fresh water is becoming crucial in most rural and urban centres. This is evident as several rivers and lakes have undergone marked reduction in flow rates and surface area while land is available only to a few. Land and water resources are constantly threatened by inappropriate land use and climate variability. In the western highlands of Cameroon and Nkambe highlands in particular, this situation has accelerated the migration of agropastoralists into marginal lands and agricultural production, most especially market gardening is highly affected. In the face of persistent water stress and land degradation challenges for agropastoralist in the study area, the objective of this study was to assess how effective is the socioeconomic and policy options adopted by the government, councils, the local population and civil society organisations to ensure sustainable land and water resources management .To attain the objective of the study, the hypothesis considered was that the government, councils and civil society organisations have been playing an important major role to enhance the sustainable management of land and water resources. To verify the validity of the above hypothesis, semi-structured and structured questionnaires were used to sample the opinion of 200 respondents on the effectiveness of land and water resources management options adopted by the State and stakeholders. From data analysis, the main results were as follows; the government, council and civil society organisations have been doing their best to ensure the sustainable management of land and water resources through the application of institutional and legal provisions, appropriate technology, private sector participation, community participation, partnerships and, fund raising and agroforestry techniques. However, the efforts of the State and stakeholders are limited by political, institutional, socioeconomic and climatic constraints.

Key words: Cameroon, Nkambe highlands, water resources, management.

Introduction

Land and water resources management is becoming a serious challenge to policy makers in the western highlands of Cameroon and particularly in Nkambe highlands because the land and water resources here are threatened by high demographic growth, climate variability and inappropriate land use (Mbabwop, 1991; Amawa, 1999). There has been, among others, an increase of mean temperature and modification of the precipitation regime (Ngakfumbe, 1984; Tsalefac, 1999). These changes are prone to affect human and natural systems with high water dependence (Kuate, 1991). Amongst them is the agropastoral sector which is very strategic in the economy of many highlands of Cameroon and Nkambe highlands in particular (Dongmo, 1984).

Materials and methods

The Nkambe highlands (6° 20'and 6º 41' N and 10°23' and 11°25' E) are within the humid tropic and at the eastern foot of Mount Oku watershed. In recent years, the region is facing acute water shortages, especially during the dry seasons, and land degradation (Tchawa, 1991). It is under this background that the government, civil society organisations and councils have adopted socioeconomic and policy options to address the problem of land and water resources degradation.

To realise this study, literature review was done on the existing information on climate variability, land use and water resources degradation from both private and public libraries. Electronic search was conducted to identify published articles on global environmental change, poor land use and water resource

management and its effects on agro pastoral production. Data were also collected through semi-structured and structured questionnaires to sample the opinion of family households on the effectiveness of land and water resources management options adopted by the State and stakeholders. A total of 200 respondents (100 men and 100 women) were investigated and interviewed. Women are particularly attached to land and water resources for livelihoods. Data on land and water resources degradation, consequences on agro pastoral production and food security in the region were also collected.

Results and discussion

Socioeconomic and policy options to address land and water resources degradation

Institutional reforms. Cameroon's commitment to the protection of the environment dates back to 1972 when the country featured among other African countries who attended the Stockholm Conference on environment. A few years later in 1977 this led to the creation of the National Committee on Man and the Biosphere as the beginning of the systematic handling of environmental issues in Cameroon (Semuyeh, 1986; Fonteh, 2003). In 1984, the sub-Department of Rural Development and Environment was created in the Ministry of Planning and Regional Development as testimony of the government's awareness of the interaction between the environment and development (Semuyeh, 1986). The sixth five-year Development Plan of 1986-1991 provided a rational environmental management plan and appropriate legislation to protect the environment, but this was not realised because of the introduction of the Structural Adjustment Program that resulted from the economic crisis and the devaluation of the CFA Francs in the country in the early 1990s (Bessong and Ngwasiri, 1995). However, the government's concern for environmental problems was still a priority; thus the creation of the Ministry of the Environment and Forestry in April 1992, today the Ministries of Forestry and Wildlife, and Environment, Nature Protection and Sustainable Development. This was a logical continuation of the long internal process corresponding to the country's response to the call for international solidarity in the protection of the environment most especially land and water resources.

Implementation and/or reinforcement of legal Provisions. Since 1972, Cameroon has ratified many international conventions (Ramsar Convention on Wetlands; Iran, 1971) and put in place a series of legal instruments to protect and assure the constant availability of water resources. This is contained in:

- Law No 94/01 of 20 January 1994 relating to the conservation of forestry, wildlife, fisheries and biodiversity and law No 96/12 of 5 August 1996 relating to environmental management which according to section II article 25 is based on the protection of continental waters and flood plains which; states that "continental waters constitute public property whose use, management and protection shall be subject to the provisions of this law and those of the laws and regulations in force. Article 29 pending the provisions of article 30 insist on the fact that any act likely to provoke surface or underground water degradation through the modification of their physical, chemical, biological or bacteriological characteristics shall be prohibited"(Bessong and Ngwasiri, 1995)
- Law No 90/016 of 10 August 1990 on spring and mineral waters which states that the exploitation of mineral waters is subject to authorisation by the Ministry of Energy and Water Resources (MINEE). Such authorisation determines the zone of protection of the catchment
- Law No 98/005 of 14 April 1998 which focused on the respect of the norms of environmental protection and the protection of public health. It states that "water is a national resource and that the state assures its protection, administration and facilitates its access to all either by itself or any other person by delegation of authority". Concerning protection, the following are forbidden
  - Any act likely to pollute water, change its quality negatively, retard or put into question the development of this resource and threatens public health both faunal and floral
  - Anybody intending to provide water to the general public on a large scale must obtain authorisation to do so
  - Article 6(3) it is forbidden to wash, repair vehicles and any other engines or any material in or near water resources

- Article 7(1) In order to assure the quality of water for public use, a perimeter of protection has been created around the catchment zone; treatment works and storage installations
- Article 7(2) the perimeter of protection is declared public utility (100 m) around water sources and 50 m around catchment areas

Networking with Environmental Stakeholders. Considering that the society of Nkambe is subsistence-based, it needs forest cover for a better conservation of soil and water resources. Degradation of the forest resources has increased due to commercial logging and inappropriate land use systems (Evans, 2004). This is why some non-govermental organistions (NGOs) operating in the region assist the government on sustainable integrated development. Developing long-term and sustainable natural resource management strategies for the country is therefore, a priority for the Cameroon government. The implementation of government policy in the landscape of Nkambe is seen through the holistic actions of the Ministries of Environment, Nature Protection and Sustainable Development (MINEPD), Forestry and Wildlife (MINFOF), Livestock, Fisheries and Animal Husbandry, Agriculture and Rural Development (MINADER), State Property and Land Tenure, Economy, Planning and Regional Development (MINEPAT) and other related departments. The above ministries have been given the main responsibility for developing and implementing appropriate policies and approaches aimed at protecting and managing land, forest and water resources (Tanto, 2000). Some of the key elements of the current government policy that is under implementation in the Nkambe highlands to ensure sustainable water resources management are as follows:

- Ensuring food security, promoting and diversifying crop and livestock production
- Reducing slash and burn/shifting cultivation
- Emphasis on integrated rural development at the community level through prompt financial, material and technical assistance and organisation of seminars and workshops to farmers which could go a long way to alleviate poverty which is considered a prerequisite of environmental degradation in the area

Common Interest Groups (CIGs) working within the framework of environmental protection and sustainable agriculture has been encouraged and today about 100 of such associations do exist. In developing a legal and institutional framework for land and water resource management, the Cameroon government seems to be making sincere effort to ensure that right of local communities are recognised and protected (Kemche, 1991). This is very encouraging. Several NGOs are working with MINEPD, the Ministries of Environment, Nature Protection and Sustainable Development, Forestry and Wildlife, Livestock, Fisheries and Animal Husbandry, Agriculture and Rural Development, and related services to implement activities aimed at supporting community-based natural resource management.

Mobilisation for funding sources. To mobilise for material and financial support in order to sustainably manage watersheds and water catchment areas in Nkambe highlands, the technical service of Ministry of Water and Energy Resources in collaboration with MINEPD and MINFOF have been writing project proposals to present the state of the problem to donors for funding. There is political will and commitment of the services. The Divisional Delegate of the former Forestry and Environment (MINEF) Donga Mantung in collaboration with colleagues of Water and Energy Resources wrote a project entitled: *The Nkambe Water Catchment Protection Project* estimated at 17,195,650 Francs for five years. The global objective of the project was to protect the Nkambe water catchments to ensure sustainable water supply to the municipality in the short- and long-term. Recently, the local administration in collaboration with the technical services and other stakeholders has been very pragmatic in their activities. However, there is lack of field staff to monitor forest fires, the growth of the trees from destruction until maturity. It is evident that the government could have addressed water shortages if the political will and commitment was reinforced such that paper works were transform to actions.

Role of the Councils. The Nkambe and Ndu councils play a major role at ensuring sustainable management of land and water resources within the Nkambe highlands despite some limitations observed in the field. This is illustrated by series of municipal decisions signed by the councils. The municipal decisions forbids farming and planting of Eucalyptus trees on the water banks of Magha-Bontor-Chuachua streams and its tributaries (Semuyeh, 1986). This was in the same line with the municipal order by Ndu council of 3rd March 1999. In 1998, the councils of Nkambe and Ndu in collaboration with the Administration, traditional rulers and the local population embarked on the operation "No Eucalyptus at water sources" and about 5000 Eucalyptus were eradicated from principal valleys but today most of the trees have regenerated.

The persistence of drought prompted the Senior Divisional Officer for Donga Mantung to sign a Prefectural order in collaboration with the Mayor of Nkambe Council forbidding Eucalyptus planting around water sources and Valleys, declaring areas of radius 100 m to water sources "No man's land" as stipulated in the provision of 1996 law on Environmental management in Cameroon which unfortunately was not respected by the local population and today the situation has not change.

However, considering Law No 74/23 of 5th December 1974 organising the municipal councils in Cameroon modified by law No 92/003 of 14th August 1992 and the 2004 law on decentralisation which define the role of municipal authorities in Environmental Management, most especially land and water resources, the councils in this region have given less priority to this burning issue of land and water resources degradation and there is need to change or reinforced their strategies from municipal decisions, seminars, workshops to the action or implementation phase.

The role of civil society orgranisations

The role of the traditional rulers, secret societies and the local population. Community participation in resource management is not a recent issue in the history of human society and in Africa specifically. Long before imperialism, local communities had been managing sustainably, the natural resources on which they have been custodians for long period. Empirical evidence has shown that resource based communities' still poses vast local knowledge and experience in natural resource management that cannot be underrated. Although pre-colonial regulations sought to exclude local people from natural resource management via top –down policies and State nationalism of resources, experience has shown that decentralising resource management by involving the local people, is not only sustainable but profoundly improves the socioeconomic wellbeing of these communities.

The traditional rulers in collaboration with their subjects and the secret societies (kwifon etc.) through the traditional council and local village water maintenance committees have been very instrumental in the Figureht to sustain water catchment management schemes in the landscape of Nkambe. A good example is the Fon of Nkambe, Binshua, Ntundip, Tabenken, to name the few which during the onset of drought in the early 1990s mobilised the population to fell down about 30,000 Eucalyptus found on the watersheds, and water sources of their areas of jurisdiction. Their own municipal gendarmes were the "Kwifon" that went from door-to-door escorting the population to the disaster sites and defaulters were judged by the traditional council under the customs of the area for disobeying the orders of the palace. Community participation in water projects management is promoted in the region by NGOs and Cultural Groups such as Heifer International, Swiss Association for Development and Cooperation (HELVETAS), YDETPA, Organisation for Rural Infrastructure Community Animation and Afforestation (ORICAA), SHUMAS, Nkambe Cultural and Development Association (NKACUDA) which since 1997 have ensure the extension of water points, construction and rehabilitation of watersheds, catchment chambers, eradication of Eucalyptus from water sources at a global cost estimate of 26.588,000 France. The modest financial and materials contribution of the beneficiary localities was 4.410.000 France, unskilled labour and local materials respectively. The localities who benefited from these technical and financial assistance are Kakar, Ndu, Mbipgo Nkambe, Binju, Moh, Njap and Jirt (Kanfon, 1999).

Role of voluntary groups and associations. Voluntary groups and associations have not been indifferent in the struggle of Eucalyptus replacement projects and water conservation in the Nkambe highlands.

Among such Associations that have been collaborating with the administration, technical services, councils and NGOs is the dynamic Nkambe Highland's Youths for Environmental Sustainability (NHYES), and Save Your Future Association (SYFA), JMBC Ndu Water Catchment Protection Association, Agroforestry and Development Organisation (ACADEO), Tabenken Agroforestry Group and Union Earth Cameroon (UNEC). They have so far organised sensitisation talk, drama on the importance of replacing *Eucalyptus* with indigenous trees for the sake of water conservation. However, for most of these youths, mastering of environmental literacy education is a big handicap for the sensitisation campaign as they lack the concept and vocabulary to convince the population on the reason d'être of their movement. All the same, their role has raised serious awareness in the community on the impact of planting *Eucalyptus* near the water sources and the resulting socioeconomic consequences (Ngala, 1992).

Role of non-governmental organisations. NGOs have been preoccupied with land and water management in Nkambe highlands since the late 1990s with only one legalised organisation such as Youth, Development, Environmental Training and Protection Association (YDETPA). At present, there are five NGOs operating in the region, YDETPA included. The other four NGOs are Society for Initiative in Rural Development and Environmental Protection (SIRDEP), Strategic Humanitarian Services (SHUMAS), Swiss Association for Development and Cooperation (HELVETAS), and Organisation for Rural Infrastructure Community Animation and Afforestation (ORICAA).The NGO's global objectives are to promote integrated land and water resources management (Ngoufo,. Tazo et Djongand, 2005). For instance, in line with the municipal order of 13th April 1998 prohibiting the planting Eucalyptus on watersheds and water catchment areas in Nkambe highlands, the NGO YDETPA in collaboration with Nkambe council, and the administration launched a giant Eucalyptus replacement project of which about 18,000 Eucalyptus trees on the Magha Bontor –Chua –Chua catchment area were replaced with about 1,500 species of trees such as Acacia, Filanthus altissima, Alnus acciminate though follow up or monitoring of trees planted around the water sources, and the project was far fetch as the trees were abandoned on their own to survive .

Another NGO which has been very pragmatic in its activities is SHUMAS. It was legalised in 1997 with headquarter in Nkwen Bamenda and with areas of jurisdiction being Bui and Donga Mantung and intervene principally in the domain of agriculture, social and environmental protection with emphasis on planting environmental friendly trees, protection of water basins, watersheds and agro-forestry (Tedonkeng *et al.,* 2003). They did organised consultation meetings for all environmental stakeholders in the Nkambe highlands to inform them on the Eucalyptus Replacement Project Phase II which was intended to nurse about 2,500,000 local tree species from 2007-2009 to replace Eucalyptus which covers about 1,500 ha. The major targeted project site was the Magha-Bontor-Chua-chua water catchment which supplies the Cameroon National Water Utility (CAMWATER) reservoir downstream.

Constraints to smooth implimentation of land and water resouces management options

Political constraints

Lack of collaboration from some with diverse political ideologist has retarded progress in the conservation strategies adopted so far by environmental stakeholders.Most council staffs have not been trained on environmental management issues and they are more interested in infrastructural development of short term benefits, since most of them are appointed on political basis and are answerable to their electorates and not on intellectual basis.

Institutional difficulties

There exists several technical services and NGOs in Nkambe highlands working within the framework of water resource conservation or related activities such as MINFOF, MINEP, MINEE MINPLADAT, MINDAF,MINUH, YDETPA, NHYES, SYFA, SNEC, Councils and Public Security. These institutions are always at conflicts on who does what, when, and how? Most often some of these institutions do not want to assume their responsibilities in terms of water conservation and its development.

Insufficient logistics in terms of material, technical and financial means.

Most of the technical services in the highland have inadequate technical staff to adequately patrol the water catchments sites and book all defaulters to the law. The technical services and environmental stakeholders operating within this region equally have insufficient material and financial motivation to multiply the organisation of seminars, educational talks, round Table conferences and green concerts to thoroughly sensitise the population on the techniques and importance of water resource management.

Corruption and Lack of a Master Plan

Corruption has equally retarded the development strategies designed to do away with *Eucalyptus* plantations found on water sources. Here, it is common to find people with land certificate of land of 100m close to water sources and 50 m into the water catchment which according to the 1996 Environmental Management law is considered public utility. This situation is worsened by the creation of the administrative units of Donga Mantung by the colonial administration which has fostered urbanisation. Nkambe highlands do not have a Master Plan to clearly define the settlement pattern of its major towns like Ndu and Nkambe. Hence, urbanisation has taken place without any planning and sanctions from the Delegations of State Property and Land Tenure (MINDAF) and that of Urban Development and Housing (MINDUH) respectively, making it very cumbersome for the councils to control illegal settlements. Most often, the council authorities are dragged to court by the population for attempting to restrict them from constructing on the watersheds or in proximity to water catchments.

No-participatory approach in the conservation strategies

The non-participation of the local population in the conception, execution and evaluation of water catchment conservation strategies have always led to the contestation of resolutions taken by MINEP, MINEE and the administration. It is under this background that the traditional councils in the region are claiming for a clear text that defines their involvement in the execution of action to better sanction defaulters planting Eucalyptus on water sheds and catchment areas without any impunity. The problem here is who does what for whose interest, how and when? So, the challenge is to define the responsibility of each stakeholder involved in the watershed management so as to avoid conflicting approaches.

Conclusion and recommendations

In recent times, the Nkambe highlands is witnessing serious land and water resources management challenges which is attributed inappropriate land use dominated by the indiscriminate planting of *Eucalyptus* and to a lesser extent deforestation, overgrazing, settlement and climate variability. So from the field observations, it could be concluded without any reservation (bias) that faced with the recent environmental challenges, the state, councils and civil society organisations have adopted strategies which is far from effective to resolve land and water resources degradation in the study area.

Considering the need for a sustainable watershed management for steady water supply on the Nkambe highlands for the sake of the present and future generations as illustrated by our result findings, the following recommendations are made to the community, the councils, the government, the scientific world and various development agencies operating in Nkambe highlands.

Training and Research

Recommend to the government, Nkambe and Ndu councils to envisage the training of Council staffs on special domain such as Integrated Water Resource Management and Environmental Management. This will go a long way to improve their capacities on aspects of environmental literacy education which is a process of creating environmental awareness for the purpose of seeking an change of values and attitudes among the people.

Legal frameworks

The promulgation and/or reinforcement of national regulations and ratifications of other related legal instruments related to land and water resource management like the 1996 Environmental law, 1994

Forestry, Wildlife, Fisheries and Biodiversity law should be strictly applied and any defaulter be sanctioned indiscriminately according to the text. Declaration of watershed zones and water catchment areas (50 m on the upper courses and radius between 100 and 300 m) as "No man's land" as stated in the 1996 Environmental law should be implemented without any impunity. On the other hand, the text defining the settlement pattern (Master Plan) of major towns like Ndu, Nwa and Nkambe should be reviewed and strictly respected when issuing land certificate to potential applicants.

Participatory approaches in water resources management

For a successful water catchment management to be achieved, the different component of the population (local population, business community, councils, government, influential people in the community (Elites), NGO and Common Initiative Groups, youth and women) should be integrated in the conception, valuation, policy and institutional design making and realising of any project aimed at conserving the water catchment and watersheds within the region

Constructions of dams and reinforcement of partnerships

The municipal authorities in collaboration with the colleague of Cameroon National Water Utility Company (CAMWATER) should construct a dam on most principal water catchments areas like Chua-chua to help retained much of the water that comes during the rainy season. This could create a municipal lake; provide enough water throughout the year to foster sustainable fish farming, market gardening domestic usage, livestock breeding, and tourism. The council authorities and SHUMAS should equally intensified their campaign of Eucalyptus replacement around water sources with less water consuming trees such as *Acacia maarnsi*, *Filanthus altissima, Alnus acciminata, Amnus nepaleusis* and *Alnus rubra, Prunus Africana, Raffia vinifera, Sorindeia* spp., *Albizia* spp., *Croton macro Ztachryus, Halea ciliate,* Calliandra, Cordia (Tedonkeng *et al.,* 2003) which could also provide firewood, timber and medicine to the local population while at the same time protecting water sources from drying and contributing to soil fertility.

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Stakeholders' diverging interests and emerging resource use conflicts in apiculture in West Usambara Mountains, Tanzania

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Abstract

A study was conducted in West Usambara Mountains, Tanzania to assess stakeholders diverging interests and emerging resource use conflicts in apiculture with respect to natural resource management (NRM) by local communities. The study aimed at generating knowledge base for effective governance of NRM by farmers from which lessons could be drawn for guiding appropriate NRM. Participatory Rural Appraisal (PRA) tools including focused group discussion, questionnaire survey and participant observation were used for data collection from 98 respondents randomly selected. Data collected were analysed using descriptive and inferential statistical analyses. Results show that majority of individual small scale farmers (73%) were driven by social economic interests than NRM. On the other hand, farmers' groups (10%) showed high interest in both economic and conservation of natural resources followed by faith based organisations (FBOs) (7%). Stakeholders' diverging interests in apiculture were significantly influenced by educational level (p=0.010); household size (p=0.006); marital status (p=0.011) and major economic activities (p=0.029). The most prevalent conflicts in the study area were between farmers practising apiculture and fellow farmers (74%) followed by neighbours (16%). The study demonstrated that for small scale farmers to engage in NRM, economic interest is vital. Recommendations on areas of further intervention are given.

Key words: diverging interests, resource use conflicts, apiculture, Usambara Mountains, Tanzania.

Introduction

Farming in the mountainous areas of East Africa is the major source of income for the majority of households both for income generation and subsistence. However, with increasing population and land scarcity, of recent there has been an increase in farming on fragile lands including the valley bottoms and wetlands. Bush fires are common in villages surrounding the mountainous areas of East Africa. The main sources of bush fires are land preparation, hunters, firewood collection and honey gatherers (Kimaro *et al.*, 2010).

Over the past decades, increased population and stakeholders' divergent interests have put excessive pressure on natural resources (NRs) leading to over exploitation, degradation and resource use conflicts. Degradation of NRs has contributed to progressive decline in resource productivity. For effective conservation of NRs, the link between rural livelihoods and natural resource management is of fundamental importance to national prospects for economic growth and poverty reduction. Natural resource management, in turn, is principally a function of environmental governance. However, stakeholders diverging interests, perceptions and the emerging conflicts are key challenges that need to be addressed if the situation of land degradation is to be reversed. This study was conducted to provide critical analysis of stakeholders' divergent interests with respect to apiculture at local level in order to generate

knowledge base for effective governance of NRM by farmers and to draw lessons for guiding conservation of NRs efforts in hot spot areas.

Materials and methods

Description of the study area

The study was conducted in West Usambara Mountains (4^o 24′ and 5^o 00′ S and 38^o 10′ - 38^o 36′ E) in three agroecological zones, covering about 184 km^2. The surveyed zones include warm dry (Mwangoi village), cold dry (Lukozi and Malindi villages), and cold humid comprising the villages of Migambo and Lushoto suburbs. These areas are potential for production of honey and other bee's products due to their favourable climatic conditions and presence of various vegetations (fruits plants and natural vegetations) which are best forages for honey bees (Msita *et al.*, 2010).

Data collection

The study employed a cross sectional design which allows data to be collected at one point in time from a selected sample of respondents using standard survey techniques including household questionnaire survey, focused group discussions, participant observation and key informants. Purposive sampling procedure was applied where the study area was stratified into three agro-ecological zones as indicated in Table 1. The sampling frames were the lists of beekeepers and non beekeepers respectively in each zone. The beekeepers that belonged to groups were randomly sampled from the group lists while individuals practicing apiculture were randomly sampled from a separately prepared list. Non -beekeepers were selected at random from a list of farmers that are not involved in beekeeping. A total of 98 respondents were interviewed using questionnaires to obtain primary data of the study area.

Table 1: Household sampling

S/N	Zone	No. of households	Population	Sample size
1	Cold Humid (Lushoto suburbs/ Migambo)	4781	23236	36
2	Cold and dry (Lukozi/Malindi)	3133	14100	32
3	Warm dry (Mwangoi)	1086	4890	30
Total		9000	42226	98

Both male and female households were eligible for interview. The data collected included, socio-economic data of households, identification of stakeholders and their interests, major economic activities undertaken by households, type and nature of resource use conflicts, and socio-economic factors (age, household size, level of education, marital status, duration of residence in the area, level of interest in apiculture and land size).

Data analysis

Content analysis (Singleton *et al.*, 1993) was used to analyse the information collected through verbal discussions with the key informants. The data collected through structured questionnaire was analysed using both descriptive and inferential statistical analyses carried out in Statistical Package for Social Sciences (SPSS 16.0) and Excel. Frequencies and percentages, Tables and Figures were used to summarize the data. Cross-tabulations involving Chi-Square tests were also employed in testing association between variables in the different agro-ecological zones. Inferential statistical analyses were carried out to provide an idea about whether the patterns described in the sample are likely to apply to the population from which the sample was taken. Logistic regression models were developed and used to establish the relationships between dependent and independent variables.

Results and discussion

Stakeholders interests in apiculture and NRM in the study area

Table 2 presents the list of various stakeholders and their respective interests in apiculture. The results show that the majority of small scale farmers who constitute 73% were involved in apiculture with economic focus as their primary interest. On the other hand beekeeping groups constituting 10% of the stakeholders in apiculture showed high interest in both economic and conservation of natural resources followed by faith based organizations (7%). MWAMBOA and TAMILWAI beekeeping groups in Mwangoi and Migambo villages were practising beekeeping with the central objective of conserving river banks and water sources respectively while at the same time aiming at income generation. These results were similar to those described by Woodcock (2002) in the Eastern Arc Mountains, Tanzania, who noted that stakeholders' interests in natural resource management were influenced by economic demands, livelihood needs, institutional mandate and geographical proximity (adjacency) to the natural resources.

Table 2: Types of interests by various stakeholders in apiculture in the study area

Stakeholder	No.	(%)	Type of Interest	Nature of beekeeping	
				Traditional	Improved
Small-scale individual beekeepers	30	73	Economic (Income generation)	Traditional	Improved
Beekeeping groups Mwamboa, Tamilwai, Asali Yetu Mtumbi, Wafungaji Wanyuki	4	10	Economic (Income generation); conservation of natural resources (Conservation of catchments, water sources); food security; economic (Beehive making, harvesting gears); capacity building (ToTs)	Traditional	Improved
FBOs (Catholic and Lutheran [Irente Farm] churches	3	7	Conservation of natural forest; biodiversity conservation; economic (Income generation)	Traditional	Improved
TAFORI, SEKUCO, ASARECA and Kwemaranba Sec. School	4	10	Capacity building (ToTs); research and Development of innovative technologies; conservation of natural forest		
Beehive makers	-		Economic (income generation through beehive sells)		
Total	41	100			

TAFORI = Tanzania Forest Research Institute, SEKUCO = Sebastian Kolowe University College and ASARECA = Association for Strengthening Agricultural Research in Eastern and Central Africa

Apiculture in developing countries is commonly viewed as a pro poor income generating activity (Lietaer, 2009; FAO, 2009). This fact is attributed to its low start-up capital and labour requirements. It is apparent from this study that organizing small scale farmers into beekeeping groups tend to enhance their interests in apiculture so as to conservation of natural resources while at the same time providing sustainable alternative livelihood (Ranthore and Jain, 2005).

Factors Influencing stakeholders' diverging interests in Apiculture in the study area

Table 3 presents the results on key factors influencing stakeholders' diverging interests in apiculture in the study area. The results indicate that household size, level of education, marital status and major economic activities had significant ($p < 0.05$) influence on stakeholders' diverging interests in apiculture while age, sex and ethnicity were not significant ($p > 0.05$).

Household size

The results show that household size is statistically significant and positively correlated with stakeholders' diverging interests in apiculture. The result implies that the larger the household size the higher the chances that members of the household would develop diverse interests in various livelihood strategies. This factor is thus likely to contribute positively to apiculture and hence natural resource management due to the fact that apiculture has an economic incentive (Lalika and Machangu, 2008).

Table 3: Factors influencing stakeholders' diverging interests in apiculture in the study area

Variable	B	S.E.	Wald	df	Sig.	Exp(B)
Household size	1.573	0.567	7.692	1	0.006*	4.821
Level of education	0.344	0.134	6.576	1	0.010*	1.411
Marital status	3.097	1.219	6.460	1	0.011*	22.133
Major economic activities	2.440	1.117	4.768	1	0.029*	11.471
Age	0.411	0.256	2.578	1	0.108ns	1.509
Sex	0.632	0.530	1.422	1	0.233ns	1.881
Land size	-0.183	0.175	1.091	1	0.296ns	0.833
Ethnicity	-0.964	0.669	2.079	1	0.149ns	0.381
Constant	-7.097	1.813	15.328	1	0.000*	0.001

* Significant at $p < 0.05$; Ns Not significant at $p < 0.05$

Level of education

Table 3 shows that level of education was positively correlated with stakeholders' diverging interests in apiculture and statistically significant at $p < 0.05$. Increase in the level of education of the communities has been reported in many studies to be associated with increase in the awareness of the communities' on natural resource management attributed to the development of diverse interests in livelihood activities that have positive outcome to natural resource management (Kajembe, 1994; Mbwilo, 2002). For example, Katani (1999) in his study in Mwanza District, Tanzania demonstrated that increase in level of education increases the interest and willingness of local communities to participate in natural resource management such as tree planting and contour farming.

Marital status

The results in Table 3 show that marital status of the respondents was positively correlated with stakeholders' diverging interests and was statistically significant at $p < 0.05$. The plausible explanation is that married households have larger families which call for household heads to look for more basic needs (Kessy, 1998). This in turn calls for households to explore and expand their interests in diverse livelihood activities which may include apiculture. Mayeta (2004) reported that marital status influences decision making at the household level, including the use of natural resources.

Major economic activities

The results in Table 3 show that major economic activities were positively correlated to stakeholders' diverging interests and were statistically significant at $p < 0.05$. In the study area, given the nature of major economic activities include annual cropping, vegeTable production and livestock farming and apiculture and the land scarcity increased multiple interests is likely to exert pressure on natural resources including land, water and forests (Mowo *et al.*, 2002). Introduction of modern beekeeping by SUA–ASARECA project is an innovative technological intervention that is likely to influence communities' multiple interests in major economic activities towards conservation of natural resources (Kimaro *et al.*, 2010).

Types of resource use conflicts prevalent in apiculture in the study area

Resource use conflicts. Table 4 present the types of resource use conflicts prevalent in apiculture in various agroecological zones in the study area. The results show that the conflict between beekeepers and other

farmers was the most prevalent accounting for 74.2 and 57.4% out of 98 respondents interviewed and 54 interviewed beekeepers, respectively.

Table 4: Types of resource use conflicts in apiculture in various agroecological zones in the study area

AEZ	Type of resource use conflicts				Total
	Beekeepers and fellow farmers	Individuals and beekeeping groups	Beekeepers and neighbors	Beekeepers and middle men	
Cold humid	7(58.3)	1(8.3)	4(33.3)	-	12(100)
Cold dry	14(93.3)	-	1(6.7)	-	15(100)
Warm dry	2(50)	1(25)	-	1(25)	4(100)
Total	23(74.2)	2(6.5)	5(16.1)	1(3.2)	31(100)

Numbers in brackets denote percentages

Other reported conflicts were between beekeepers and their neighbours (16.1%), individuals and beekeeping groups (6.5%) and individuals within the groups. The results suggest that there are more conflicts when beekeepers operate as individuals. The type and level of resource use conflicts in the study area were identified with reference to categories of stakeholders (Mbeyale, 2009). Therefore, the type of resource use conflicts fall in the category of inter micro-micro conflicts which involves people from within the same community. Resource use conflicts emerge because stakeholders have different interests for natural and cultural resources (Matthias, 2005; Sanginga *et al.*, 2007).

Conclusions and recommendations

From the study the following pertinent conclusions are made.

- The stakeholders involved in apiculture in the study area have diverse interests including natural resource conservation and livelihood mainly driven by socio- economic interests
- The study indicated that mobilizing small-scale farmers into groups would help to manage and mitigate stakeholders diverging interests in apiculture in to natural resource management
- For small-scale farmers to engage in natural resource management, economic interest is vital
- Stakeholders' diverging interests in apiculture were significantly influenced by educational level; household size; marital status and major socio-economic activities.
- Increasing the awareness of the stakeholders including women in decision making will likely help to manage the divergent interests
- The most prevalent resource use conflicts are attributed to stakeholders different interests for natural and cultural resources largely influenced by decisions on land utilization and conservation of natural resources
- It is recommended that efforts should be directed towards promotion of apiculture as an economic incentive for sustainable natural resource management and improved crop production
- A stepped-up and focused approach for mobilization of small-scale farmers and establishment of a coordinated framework for natural resource management is strongly recommended
- The many resource use conflicts calls for a pluralistic approach that recognizes the multiple perspectives of stakeholders and the diverse interests in management of natural resource

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Farmers' perception of conservation agriculture in Laikipia East District in Kenya

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Abstract

Agriculture sector contributes about 24% of Kenya's, GDP. Small scale farmers provide 75% of the labour force and 75% of the market output produce. Both land degradation and adverse climatic conditions threatens sustainable food production by small scale farmers. However, land degradation has decreased land resilience thereby exacerbating the effects of droughts. Conservation agriculture (CA) has the potential to contribute in addressing the challenge of adapting agriculture to land degradation and adverse climate. Adoption of a technology depends on several paradigms among them the perception paradigm Perceptions are influenced by factors such as culture, education, gender, age, resource endowments and institutional factors. Laikipia East district is arid semi arid area with the average yearly rainfall is 750 mm, but the distribution is very unequal, and rain-fed agriculture is the predominant activity. Soil degradation is common due to unsustainable agricultural practices such as intensive tillage. The data was collected using 130 questionnaires in seven locations. The data was analyzed using SPSS version 16. Most of the farmer derive their livelihood on farm 75%, The level of education and gender influence farmers perception to CA with female and higher education lever with higher perception towards CA. Land ownership influence farmers perception to CA with higher positive perception in farmers with own land compared to the ones leasing land. There is competition for crop residue between surface cover and livestock feed which negative affect farmers' perception to CA. Farmers associate CA with herbicides that portrays CA as expensive. Socio-economic factors have influence on farmers' perception to CA.

Key words: conservation agriculture, perception, tillage, herbicides, surface cover, livestock.

Introduction

In Kenya, agriculture sector contributes about 24% of the country's GDP (KPMG Kenya, 2012). Small scale farmers provide 75% of the labour force and 75% of the market output produce (Alila and Atieno, 2006). With reliable and consistent climatic conditions of smallholder farmers contribution can lead to economic stability of agriculture dependent countries (Kalungu *et al.,* 2013). However, land degradation has decreased land resilience thereby exacerbating the effects of droughts. The incidence and prevalence of food insecurity is greatest in the arid and semi-arid lands (ASALs) due to poor resource endowment and scanty and unpredicTable rainfall patterns (Alila and Atieno, 2006). Both land degradation and adverse climatic conditions threatens sustainable food production by small scale farmers. Increasing land degradation and deterioration of ASALs has led to significant attention directed to these areas with an effort to meet the Millennium Development Goals notably, eradicating extreme poverty and hunger and ensuring environmental sustainability (Mowo *et al.,* 2010). Adverse effects of climate change continue to be a major threat to rural livelihoods (Pouliotte *et al.,* 2009). Crop failures because of inadequate rains are frequent and subsistence production is not guaranteed (Wiesmann, 1998). Despite the uncertainties of crop production due to unfavourable conditions, smallholder farming plays a huge role in addressing poverty and eradication (FAO, 2012). The adoption of good farming practice influences the agricultural production (Branca *et al.,* 2010). Conservation agriculture has the potential to contribute in addressing the challenge of adapting agricultural practices to climate change (FAO, 2011a; Govaerts *et al.,* 2009). Conservation

agriculture (CA) is defined as an agricultural system involving minimum soil disturbance, permanent residue soil cover and diversified crop rotation (FAO, 2008). CA optimises crop yields and profit while at the same time providing environmental benefits hence sustainable agriculture (FAO, 2011b; Giller *et al.*, 2009).

Friedrich and Kassam (2009) question why CA is it not spreading fast despite benefits usually claimed in its favour. They attribute the slow adoption rate to constraints which include intellectual and knowledge, social, financial, technical, infrastructural and policy constraints. CA has been introduced as a new concept, but knowledge and other elements of an enabling environment for the adoption of CA in most countries does not exist (Friedrich and Kassam, 2009). Therefore, there is need to provide knowledge about CA and create a positive perception for CA adoption to improve. Adoption of a technology depends on several paradigms among them the perception paradigm. According to perceptions paradigm adoption process starts with the adopters' perception of the problem and technology proposed (Adesina and Zinnah, 1993). The paradigm argues that perceptions of adopters are important in influencing adoption decisions (Prager and Posthumus, 2010). Perceptions are influenced by factors such as culture, education, gender, age, resource endowments and institutional factors (Posthumus *et al.*, 2010). Most of the players (Non Governmental Organisations (NGOs), farmers' organisations and national government) involved in promoting conservation agriculture often do not take into account perceptions of smallholder farmers of conservation agriculture (FAO, 2009). Despite this, very little is known about the smallholder farmers perceptions on CA. CA technologies were introduced in the study area more than 20 years ago but the adoption is still low (Schaffer, 2008). Therefore, there is need to understand farmers perception of conservation CA in Laikipia East district. There is no documented information on farmer's perceptions CA in Laikipia district. Understanding how farmers perceive CA could shed light in how productivity among small scale farmers could be enhanced through CA. The perceptions could indicate how farmers will adopt CA in their farming systems. This will be helpful to researchers and government by enabling them to tap on farmers perceptions to CA to enhance sustainable food production. Moreover, the variations in smallholder farmers' perceptions on CA amongst different agro ecological zones and across different timelines is yet to be properly documented in Kenya. Knowing farmers' perception to CA among smallholder farmers will allow researchers, extension educators and farmers to develop research agendas and adopt practical practices that meet present and future farming needs in specific agro ecological zones. This study sought to fill this gap by assessing the smallholder farmers' perceptions to CA. This study documents small scale farmers' perceptions of CA in Laikipia East District.

Methodology

Research area

In March 2013 a survey was conducted in Laikipia East District (0°17'S and 0°45'N and 36°15'E and 37°20'E) at 1600-2300 m. This is a semi-arid area with a high frequency of droughts and floods. There are two seasons of rain: the long rains from April to July and a short rain from October to December. The average yearly rainfall is 750 mm. Distribution is very unequal. However the weather is very unreliable because of influence of Mount Kenya (Kaumbutho and Kienzle, 2007).

Agriculture is practiced in 26.5% of the district (Ojwang' *et al.*, 2010) mianly by small-scale farmers on subsistence basis. Farmers practice mixed farming with rainfed crops (maize, beans, potatoes, wheat and barley) cultivation and livestock keeping (Kaumbutho and Kienzle, 2007). Rainfed agriculture is very vulnerable to droughts which result to food insecurity and loss of livelihoods. Soil degradation is common due to unsustainable agricultural practices such as intensive tillage (Ojwang' *et al.*, 2010).

Data collection and processing

Before the field work was done literature review was done together with interviews with key informants with knowledge on CA to give useful information of the are in regard to CA in the area with help of semi-structured questionnaires. After this the a pre-survey was held with ten farmers with knowledge of CA and included both practicing and non practicing farmers to test the questionnaire get an idea of the possible answers given to evaluate the perception and adoption of CA among small scale farmers in the study area.

For the interviews a structured questionnaire was used. The data was collected using 130 questionnaires in 7 administrative locations in Laikipia East district (Table 1). The questionnaire was applied with a mixture of open ended questions and questions with coded answers. The questionnaire was structured in that the first part had administration location on the interviewees, general information about the farmers, the their fields such as age, family size and how large fields they owned. The second part dealt with social economic aspects such as source of livelihood, family income and expenditure crops and animal kept. The other sections contain information land ownership, management and utilization, conservation agriculture which was major part benefits and challenges, soil fertility management and livestock information. The collected data was processed and analysed with Statistical Package for Social Scientists (SPSS) version 16. Analyses involved descriptive statistics including frequencies, graphs, cross tabulations chi-squared tests and Pearson correlation analysis.

Table 5: The number of farmers interviewed per administrative location

Location	Frequency
Nyariginu	15
Daiga	20
Umande	21
Nanyuki	16
Ngenia	15
Ethi	23
Likii	20

Results and discussion

The head of the households interviewed 83% are male and 17% are female and the average age of the respondent is 55 years. The level of education of the household heads was found to be 2%, 47%, 44% and 8% illiterate, primary school, secondary school and tertiary level in that order. Being a predominantly agriculture based area 75% of the households derives their livelihood on farm, 1% off farm and 24% from both on farm and off farm (Figure 1). This is in agreement with Alila and Atieno (2006) who found that over 80% of the Kenyan population live in the rural areas and derive their livelihood from agriculture. Comparing the ratio of the sampled population of each gender and the number practicing CA of each gender the rate of practicing CA is higher by the female compared to male. This indicate that the female may have a positive perception of CA. This may be because women do the most of the work at home and at the farm and since labour reduction was indicated as one of the major benefit of CA. Women get involved in agricultural activities more than men (Odame *et al.* 2002). Kenyan women provide 84% more family labour than Kenyan men (Saito *et al.,* 1994).

In farming, women participate in numerous agricultural tasks including mainly cleaning the field during land preparation, transporting inputs to the field, weeding, harvesting, transporting, threshing and storage of the production. In addition, women are also involved in managing home garden crops, poultry raising, feeding, watering and cleaning of livestock and milking is also important (Teklewold 2013). Women would thus welcome it as it mean less work at the field releasing them to do other household work.

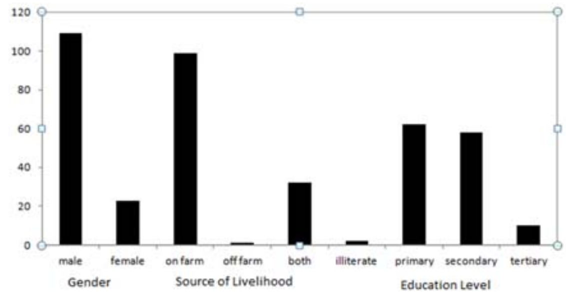

Figure 1: Respondent gender, source of livelihood and education level

Gender affects the distribution of work (Welch *et al.,* 2000). There was a positive and significant relationship between practice of CA among farmers and land ownership (Figure 2). The level of education had influence of CA perception by farmers and the results shows that the higher the level of education the higher the practicing of CA by the farmers. Pearson correlation analysis show that there is a positive and significant relationship between practice of CA among farmers and education level. The reason for this could be the education could have exposed the farmers to understanding the benefits of CA such as sustainability, lower cost environmental conservation leading to positive perception hence the higher adoption rate. Land ownership has influence on the CA adoption with more adoption by the farmers who own their land compared to the people renting (Table 2).

Figure 2: The Pearson correlation analysis of the various factors

		do you practice CA	Gender HH	Age HH	Education HH	Farm size	Land ownership
Do you practice CA	Pearson Correlation	1					
	Sig. (2-tailed)						
Gender HH	Pearson Correlation	-.011	1				
	Sig. (2-tailed)	.902					
Age HH	Pearson Correlation	.078	-.198*	1			
	Sig. (2-tailed)	.375	.023				
Education HH	Pearson Correlation	.174*	.146	-.279**	1		
	Sig. (2-tailed)	.046	.096	.001			
Farm size	Pearson Correlation	.054	-.187*	.187*	-.165	1	
	Sig. (2-tailed)	.542	.032	.032	.059		
Land ownership	Pearson Correlation	.142	-.100	-.064	-.081	.313**	1
	Sig. (2-tailed)	.014	.253	.468	.356	.000	

*. Correlation is significant (0.05) (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed)

Table 6: The number of farmers sampled compared to the CA practicing farmers

Category	Number of the farmer sampled	Number of farmers practicing CA	Farmers practicing CA expressed as% of number of farmers sampled
Gender of household head			
Male	109	84	77
Female	23	18	78
Level of education of household head			
Illiterate	2	1	50
Primary	62	44	71
Secondary	58	48	83
Tertiary	10	9	90
Land ownership			
Own	126	99	79
Rent	6	3	50

CA benefits are not obvious and at the beginning of practicing CA it contradicts so much of the knowledge a farmer has learned and been told. However, the performance improves its performance over time (Friedrich and Kassam, 2009). Farmers hiring land don't want to risk implementing CA and the land owners ask for their land back before they have enjoyed the benefits of CA after overcoming the initial challenges of CA, but the farmers who have a clear land ownership practice CA as they are assured of benefiting from long term effects of CA. The crop grown by the farmers influences farmers' perception to CA. The farmers have perception that CA is suiTable for some crops and not others. They have the perception that CA cannot be applied by the farmers growing crops such as sweet and Irish potatoes. The argument is that this crops requires tilling of the land to make soil loose for good development of tubers and during harvesting soil disturbance occurs that contradicts the principles of CA. From economic point of view there are mixed perception about CA. Some farmers perceive it expensive as they associate CA with herbicides and other equipment such as Jab planters for direct seeding. Since most of the farmers do not afford the herbicides and the equipment they perceive CA as expensive. But there are some farmers who perceive CA as cheap and profiTable due to reduction in routine farm practices in conventional tillage such as tillage and long terms reduction in fertilizers amount due to improved soil fertility as a result of crop rotation and crop residue left that adds humus and ensure nutrients cycling. Despite the knowledge about the CA and its principles, some of the farmers (64%) till the land citing labour availability, lack of equipment for direct seeding, tidy field and negative comments from the neighbour about the untilled land as the reasons. While 36% do not till their land giving reduction in cost, time saving and environment conservation as the reasons This can be classified as social perception as the farmers fear the negative perception by the society. This should be improved through adequate extension and education in the communities so that they understand CA and have a positive perception. Most of the farmers perceive CA as competitor to the livestock due the requirement of surface cover. Hence the study found that there was decrease of animal feed when one practice CA due to use of the crop residue as mulch instead of feeding it to the livestock. This may be the reason why most farmers have a negative perception about CA as most value livestock more as it form major source income of the family. Therefore, there is need to provide alternative source of livestock feed of have varieties with more residues so that there can be enough for the animals and surface cover. Generally most of the farmers practicing indicate that there are benefit of CA including improved yield, timely planting, erosion control, labour reduction, soil water conservation, better profits, improved soil fertility (Table 3). This benefits makes the farmers have a positive perception to CA which will influence the farmers adoption of CA. However, the farmers indicated that there was decrease in the soil fauna due and as reported before decrease in livestock feed to CA practicing. There is perception that CA in

knowledge intensive farming system. Due to the principles such as crop rotation and diversification, minimal soil disturbance and maximum surface cover. Crop rotation as one of the principle of CA is only 14% practice it while 84% practice mixed cropping. The reason for not practicing is that the farmers indicated that they have little or no knowledge about rotation and also the small size of their farm limit crop rotation. The farmers emphasize on practicing mixed cropping as opposed to pure stand cropping and rotation due to maximum utilization of the small farm sizes and risk diversification in case one crop fails. . Some farmers in the area practice one of two of the three principles of CA and concludes they are practicing CA. Thus there is need to clarify what is CA among the farmers so that there can be standardized CA practice as suggested by Derpsch *et al*. (2011). Their perspective is that the consequence of using local jargon and definitions by different researchers results to conflicting no-tillage research results. This causes misunderstandings of the implications of no-tillage on crop production and environmental outcomes.

Table 7: Number of farmers indication increase, decrease or no change in the parameters

Parameter	Increased	Decreased	No change
Yield	72	3	25
Labour requirement	16	61	23
Land preparation time	33	43	24
Soil erosion control	58	17	25
Soil water conservation	75	2	23
Profit	75	3	22
Soil fertility	77	5	18
Soil fauna	30	43	27
Livestock feed	12	70	18

Conclusion

From the study it can be concluded that there exist a different meaning for CA among the farmers compared the real definition of CA. Although CA has the three principles that need to be followed most of the farmers practice one or two principles instead of all the three principles. Therefore, strictly speaking most of the farmers do not practice CA and this may be in line with Derpsch *et al*. (2012) whose observe that there are no standardized CA resulting in different contradicting results from CA farming and research. There are different perception among the farmers about CA which most of the players advocating CA do not consider, therefore there is need to consider the perception paradigm in CA implementation to ensure that the adoption rate will be high and the farmers understand what is CA, it benefits and challenges. There exist a relation between perceptions and factors such as culture, education, gender, age, resource endowments and institutional factors as Posthumus *et al*. (2010) found out. Due to the perception that CA reduce the amount of livestock feed available as the crop residues is the left on the field to cover the surface, there is need to provide alternative source of livestock feed. This can be through agroforestry where some shrubs that can be fed to the livestock are incorporated in CA, or planting crop covers with no negative competition with crop which can be fed to the livestock. The main source of CA information was extension services provided by MoA, this can be useful by training the extension adequately to enhance their extension services and thus improving the farmers perception towards CA.

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THEME 8: ORGANIC RESOURCES

Interactive effects of soil ammendendments on soil exchangeable aluminium and pH of an acid mollic andosol

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Abstract

The current study investigated the interactive effects of Lime (L), minjingu phosphate rock (RP) and manure (FYM) on soil exchangeable Al and pH of an acid soil (pH< 5.0). The field experiment, conducted in 2009 and 2010 at the Kenya Agricultural Research Institute (KARI), Molo, Kenya, was laid out in a randomized complete block design with 2^3 factorial arrangement. The factors each at two levels were L (0 and 3 t ha^{-1}), RP (0 and 60 kg P ha^{-1}) and manure (0 and 5 t ha^{-1}) giving a total of eight treatments; control, L, RP, FYM, L*RP, L*FYM, RP*FYM and L*RP*FYM. The L*RP interaction had significantly higher soil pH at end of the experiment followed by L*MRP*FYM interaction. All treatments, except control, had lower levels of exchangeable Al at termination of the experiment. Since the application of RP and L may have strong carry over effect on soil pH, the L*RP*FYM may be preferable due to the acidifying effect of FYM.

Key words: Soil amendments, soil acidity, FYM, lime, minjingu phosphate rock.

Introduction

Aluminium is the most abundant metal in soils and becomes readily soluble when the pH drops below 5.5 (Marschner, 1996). The most common problem in acid soils the toxicity of aluminium (Al^{3+}) to plants, (Foth and Ellis, 1997; Black, 1992). Studies by Johnson and Wood (1987), Matsumoto (1991), Wood (1995) and Giller (2000) have indicated that Al ions act by binding to DNA, interfering with cell division.

About one third of the tropical soils (1.5 billion hectares) have sufficiently strong acidity for aluminium to be toxic to most crop species (Sanchez *et al.*, 2003). In Kenya, acidic soils cover about 13% (7.5 million hectares) of the total arable land (Kanyanjua *et al.*, 2000).The soils in most parts of the central Rift Valley province of Kenya are inherently acidic with pH below 5.0 (Mochoge, 1993). The application of the amendments lime, rock phosphates and farm yard manure singly or in combination have been recommended for the improvement of soil physical and chemical properties. Field experiments have demonstrated that lime application changes the soil pH over time and helps to remove negative effects of soil acidity (Malhi *et al.*, 1983; Krenzer and Westerman, 1993; Coventry *et al.*, 1997; Hao *et al.*, 2002; Liu *et al.*, 2004). Liming decreases the concentration of exchangeable aluminium in soil (Aitken *et al.*, 1998) and is a widely adopted approach to increase soil pH (Scott *et al.*, 1999). Organic inputs upon decomposition produce organic acids that bind exchangeable and hydroxyl aluminium the key fixers of P in acid soils (Arden-Clarke and Hodges 1988; Vanlauwe *et al*, 2002). Rock phosphate is unprocessed P fertilizer of relatively low solubility. The effect of phosphate rock to raising soil pH is indirect. Minjingu rock phosphate (RP) has a high content of carbonates and has an indirect liming effect (Weil, 2000; Le Mare, 1991).

There is limited information on the interactive effects of application of amendments on soil exchangeable Al and pH in the area. Previous studies have only focused on effect of the amendments on soil pH only (Lelei *et al.*, 2008). The current study investigated the interactive effects of L, RP and FYM on soil pH and exchangeable Al. The results will be helpful in the development of management plans for acidic soils.

Materials and methods

Site description

The study was carried out at the Kenya Agricultural Research Institute (0^o1'S, 35^o41'E, 2500m asl) Molo. The site falls under the UH2 agro - ecological zone. The mean annual rainfall received in the area is 1200 mm. The distribution is a bimodal; the long rain season (LRS) occurs from March to August and the short rains from September/October with peaks in April and November respectively. The mean air temperature is 13.75^{0}C. The soils are acidic, with pH of less than 5.2, well drained, deep, dark reddish brown with a mollic A horizon and are classified as Mollic Andosols.

Application of Treatments and Experimental Design:. The experiment was laid out in a randomized complete block design with a 2^3 factorial arrangement. The factors each at two levels were L (0 and 3 t ha^{-1}), RP (0 and 60 kg P ha^{-1}) and FYM (0 and 5 t ha^{-1}) giving a total of eight treatments; control, L, RP, FYM, L*RP, L*FYM, RP*FYM and L*RP*FYM.

Land was prepared manually using hand hoes and crop residues present were removed manually before application of treatments. The field had maize stubble from a previous maize crop. L and RP were broadcasted and incorporated to a soil depth of 0.15 m two weeks prior to planting. FYM was applied into the planting hole and mixed well with the soil a week prior to planting. Maize H614 and H513 were sown during the LRS of 2009 and 2010 in respective treatments at spacing of 60 x 75 cm; two seeds per hole. Hand weeding was performed twice.

Soil and plant sampling and analysis: Soil samples were collected at three maize growth stages; seedling, tasseling and maturity. Soil was sampled using an auger from the top soil (0-20 cm depth) from at least four locations in each plot between the plants within a row at random and bulked to get one composite sample. The samples were analyzed for exchangeable Al and pH according to methods described by Okalebo *et al*. (2002). The soil data obtained for each measured parameter were subjected to analysis of variance (ANOVA) using SPSS statististical software (SPSS, 1999).

Results

Initial characterisation of the experimental site showed a very acidic soil (pH 4.98). The application of amendments increased soil pH and reduced the exchangeable Al.

Effects of amendments on Soil pH and exchangeable Al^{3+} in the 2009 long rain season

soil pH was significantly higher in L*RP (5.6; 5.5) interaction and L (5.5; 5.4) treatment at seedling maize growth stage in H614 and H513, varieties respectively The control had significantly lower pH values of below 5 both in maize varieties at this growth stage. The exchangeable Al levels were significantly higher in the control treatment in both maize varieties. The levels were significantly lower in all interaction treatments in H614 In the H513 the levels were equally lower in the interactive treatments but was least in the L*RP*FYM treatment.

The soil pH at maize tasseling was significantly higher in L*RP (5.8) interaction than L(5.6), RP(5.5) and L*RP*FYM) (5.5) in H614 maize variety. The same trend was observed in H513, where L*RP had significantly higher values (5.6) than L (5.5), RP(5.4) and L*RP*FYM (5.4). The control treatment had significantly lower pH values than all treatments in both maize varieties. At tasseling growth stage significantly lower levels of exchangeable Al were found in L*RP, RP*FYM and L*RP*FYM in variety H614. The levels H513 were lower in all the interaction treatments.

At maize maturity, for hybrid 614, there were significantly higher pH values of 5.9, 5.8 and 5.9 were in the L, RP and L*RP treatments. The lowest values were found in control (4.9) and FYM (5.1) treatments. For hybrid 513, the highest values were found in L*RP (5.8). Lowest values were recorded in the control 4.7) and FYM treatment (5.2). At maturity, the levels of exchangeable Al were significantly lower in interaction treatments in both maize varieties.

Effects of amendments on soil pH and exchangeable Al^{3+} in the 2010 long rain season

The soil pH values recorded at maize seedling in 2010 showed that the control had pH value of 4.9 in H614 and 4.6 in H513 varieties. The values were significantly lower than other treatments. Significantly higher pH values were recorded in L*RP (6.2) and L (6.0) for H614 at this growth stage . There were however no significant differences between the pH values of L, RP (5.9) and L*RP*FYM (5.8) treatments for H614. Significantly higher pH were observed in L*RP (6.1) than L*RP*FYM (5.8), RP(5.8) and L(5.7) in H513 maize variety. Higher levels of exchangeable Al were found in the control treatment at seedling stage in both maize varieties. Significantly lower amounts were found in the L*RP, L*FYM, RP*FYM and L*RP*FYM interactions in H614 and H513 at seedling

At tasseling growth stage, the L*RP, L and RP treatment had significantly higher pH values (6.2;6.1;6.1) in H614. For H513, L*RP and L*RP*FYM had significantly higher values (6.2; 6.0). At the tasseling growth stage, higher amounts were observed in the control treatment in both maize varieties. The lowest contents were in the L*FYM, L*RP, RP*FYM and L*RP*FYM treatments in H614. In the hybrid 513.

The L*RP treatment had significantly higher values (6.5) for H614 by the end of the 2010 growing season and termination of the experiment. This was followed by L(6.3), L*RP*FYM (6.2), and RP (6.2) For H513 the L*RP treatment has significantly higher values (6.4). This was followed by L*RP*FYM (6.1), RP (6.1) and L (6.0)The greatest increase in pH from the initial values was observed in L*RP treatment. Lowest pH values were observed in the control and FYM treatments.

The control had significantly higher levels of exchangeable Al^{3+} than all other treatments at maturity of both maize varieties.

Table 1: Means of Soil pH changes (0-15 cm depth) during during crop growth

	H614						H513					
	2009 LRS			2010 LRS			2009 LRS			2010 LRS		
	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat
control	4.7d	5.1d	4.9d	4.9e	4.7e	4.4e	4.8	5.0 c	4.7d	4.6d	4.8d	4.6e
L	5.5ab	5.6b	5.9a	6.0ab	6.1ab	6.3ab	5.4ab	5.5ab	5.6b	5.7bc	5.9b	6.0b
RP	5.3b	5.5b	5.8ab	5.9b	6.1ab	6.2b	5.2bc	5.4b	5.5a	5.8b	5.9b	6.1b
FYM	5.0c	5.2c	5.1d	5.2d	5.3d	5.4d	5.0c	5.0c	5.2d	5.4c	5.4c	5.5d
L*RP	5.6a	5.8a	5.9a	6.2a	6.2a	6.5a	5.5a	5.6a	5.8a	6.1a	6.2a	6.4a
L*FYM	5.2c	5.3c	5.4c	5.5c	5.5d	5.7c	5.1c	5.2b	5.3c	5.4c	5.4c	5.6cd
RP*FYM	5.1c	5.3c	5.4c	5.4cd	5.7c	5.9c	5.2bc	5.2b	5.4c	5.5c	5.7b	5.8c
L*RP*FYM	5.4b	5.5b	5.7b	5.8b	5.9b	6.2b	5.3b	5.4b	5.6b	5.8b	6.0ab	6.1b
LSD	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2

L= L; RP= Minjingu rock phosphate; FYM = farm yard manure; LRS= long rain season; Seed= seedling; Tass= tasseling; Mat= maturity; Means in a column followed by the same letter are not significantly different (*P*<0.05)

Table 2: Means of Soil Exchangeable Al (Meq 100g $^{-1}$) during plant growth

	H614						H513					
	2009 LRS			2010 LRS			2009 LRS			2010 LRS		
	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat
control	19a	15a	16a	17a	16a	14a	17a	14a	15a	13a	14a	16a
L	14b	08b	04c	04bcd	03bcd	02b	13b	07c	04d	03bc	03b	02b
RP	12bc	09b	06b	05bc	04bc	02b	11bc	06c	05cd	04b	03b	02b
FYM	11c	09b	07b	06b	05b	03b	09cd	10b	08b	05b	03b	02b
L*RP	09cd	05c	03c	03cd	02cd	01b	10cd	04d	03de	02c	02b	01b
L*FYM	06d	08b	04c	03cd	03bcd	01b	08d	05cd	02e	02c	02b	01b
RP*FYM	07d	05c	04c	02d	01d	01b	09cd	05cd	04de	03bc	02b	01b
L*RP*FYM	05d	03c	02c	02d	02cd	01b	04e	03d	02e	02c	01b	01b
	02	02	02	02	02	02	02	02	02	02	02	02b

Key: Seed= seedling; Tass= tasseling; Mat= maturity

Means in a column followed by the same letter are not significantly different (P<0.05)

Discussion

The low soil pH (<5.0) in control treatment reflects the inherent acidity of the soils in the central Rift Valley province in Kenya. The control had correspondingly higher levels of exchangeable Aluminium. A close correlation exists between the proportion of exchangeable Aluminium in soils and pH (Marschner, 1996). Marschner (1996) reports that acidic soils have excessive levels of free and exchangeable Al which limits plant growth. In acid soils below pH 5.5 an increasing proportion of the cation exchange sites are occupied by aluminium.

The soil at the end of the second cropping season where the amendments were applied showed improved conditions. The application of the amendments raised the soil pH gradually and decreasing the levels of exchangeable aluminium. The total exchangeable Al which was very high (19 cmol/kg) initially, as indicated by Table 2 was reduced probably making the soil more conducive for crop growth.. Meppe *et al*. (2007) reported that L application increased soil pH and neutralized exchangeable Aluminium completely after 2 tons ha-1. Liming materials increased soil pH (p< 0.05) to over 5.5 compared to the control (Nekesa *et al*., 2005).

Response of soil pH to liming could be due to the removal of nutrient imbalance in the soil by reducing aluminium and manganese toxicity as well as providing Ca^{2+} to counteract its deficiency (Biswas and Mukherjee, 1994).

The interactive effects of the amendments on pH were higher than the single effects of the amendments. The higher pH value L*RP interaction, at the termination of the experiment was due to the liming effects of both amendments. RP application has a liming effect (Weil 2003; Lemare, 1993), and therefore equally decreased exchangeable Al and increased pH. Minjingu Phosphate Rock (MPR), contains sizeable quantities of lime, equivalent to 38.3%CaO. P from MPR can reduce cost of farm inputs because it provides P and lime simultaneously (Nekesa *et al*., 2005).

Research by the International Fertilizer Development Center (IFDC) has shown that the application of medium to highly reactive PRs with low free-carbonate contents can result in significant liming effects on acid soils. Although the increase in pH is generally less than 0.5 units, the decrease in exchangeable Al can be significant where the soil pH is less than 5.5 (Chien and Friesen, 2000) as the exchangeable Al level would be almost zero at this soil pH in Oxisols and Ultisols (Pearson, 1975). For example, exchangeable Al

was reduced from 2.0 to 0.4 meq/100 g when a Colombian Oxisol was treated with Sechura PR in a soil incubation study (Figure 29). The soil pH increased correspondingly from 4.6 to 5.0, and the exchangeable Ca rose from 0.2 to 1.5 meq/100 g. Consequently, the Al saturation level also declined from about 80 to 20 percent.

In a five-year field trial conducted in an Oxisol fertilized with various PR sources, Chien *et al*. (1987b) reported that the pH increased from 4.1 with the control to 4.7-5.0 with the PR treatments. The corresponding increase in exchangeable Ca was from 0.17 cmol/kg with the control to 0.31-0.56 cmol/kg with the PR treatments. However, no significant effect on exchangeable Al was observed. In their study with the red soil of China, Hu *et al*. (1997) reported that the soil pH increased from 4.8 with the control to 4.9-5.3 with the PR treatments. A reduction in exchangeable Al of up to 70 percent with respect to the control was also observed with the PR treatments.

Sikora (2002) conducted a theoretical and experimental study to calculate and quantify the liming potential of PRs by laboratory titration and soil incubation. Of the three anions (PO4-3, CO3-2 and F-) present in the carbonate apatite structure of PR, CO3-2 and PO4-3 can consume H+ and cause an increase in pH. Because of the greater molar quantity of PO4-3 compared with CO3-2, PO4-3 exerts a greater effect on the liming potential of PR. The results for the titration of two PRs (highly reactive North Carolina and low-reactive Idaho) showed the ranges of calcium carbonate equivalence (CCE) were from 39.9 to 53.7 percent, which were less than the theoretical values (59.5 to 62.0 percent). The experimental model obtained from the soil incubation study showed qualitative agreement with theory as it showed increased liming ability with increased dissolved P from the PRs. However, the model showed lower percentage CCEs than theoretical calculations when the P dissolved ranged from 20 to 60 percent. Further research is needed to compare actual percentage CCE models across a variety of soil types in order to assess the potential liming effect associated with PR use.

The increased pH the second season in treatments with amendments could be explained by the fact that lime and MRP materials take much longer time in the soil ecosystem a situation commonly referred to as residual effect. They also raise the level of exchangeable base status of soil improves soil structure, and promotes root distribution (Biswas and Mukherjee, 1994).

The lower pH values in L*FYM interaction among interaction treatments at the end of the experiment was due to the acidifying effect of FYM. The pH in this treatment was slightly higher than FYM treatment at the termination of the experiment in both maize hybrids. The pH in FYM treatment was lower than L and RP but higher than control in both hybrids at the end of the experiment.

Conclusion

Rock phosphate and L application in combination (L*RP treatment) decreases the exchangeable Al and raises soil pH significantly. The effects were significant in the first season of application but continued to increase gradually in the second year. The L*RP*FYM has a similar effect but second to the former treatment. RP has a liming effect and increases pH gradually. In the application of both amendments in combination, the danger of overliming and its associated nutrient deficiencies must be carefully considered.

The dissolution of apatite in PR consumes H+ ions and, thus, it can increase soil pH, depending on PR reactivity. If a PR contains a significant amount of free carbonates, it can further increase soil pH. However, although an increase in soil pH may reduce the Al saturation level, it can also reduce apatite dissolution at the same time. The optimum condition would call for a soil pH that is high enough to reduce the Al saturation level but still low enough for apatite dissolution to release P.

Long term studies are recommended to find out how far the pH increase can go due to the application of rock phosphate and consequent effects on nutrient availability.Since the application of RP and L may have strong carry over effect on soil pH, follow up applications should be closely monitored It may be more preferable to apply FYM together with these amendments, due to the acidifying effect of FYM.

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Farm stratification for targeting soil fertility management options in smallholder farms in central Kenya

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Abstract

Quantification of nutrient balances under integrated soil fertility management practices is important in ensuring sustainable crop yields in sub-Sahara Africa. A study, involving Participatory Learning and Action Research and nutrient monitoring, was carried out in central Kenya. A multidisciplinary team of scientists, extension agents and farmers conducted the exercise. The study was carried out to complement the Kenya National Agricultural Livestock and Extension Program focal area approach, involving about 300 farmers in each district. Farms were stratified on the basis of soil fertility management and resource endowment into three farm typologies. The typologies were classified as good, medium and poor. Stratification was also done within individual farms at three levels of good, medium and poor soil fertility management patches. Soils were sampled in the patches of the various classified farms after which wet chemistry was run. The farm typologies differed significantly (P = 0.05) in soil fertility levels. In Kiambu, significant differences were observed in soil nutrient content across the farm typologies and also in soil fertility patches within the same soil fertility management class. Nutrient monitoring carried out across the farm typologies for two cropping seasons showed negative nutrient balances.

Key words: soil fertility classes, nutrient balances, nutrient mining.

Introduction

Declining soil fertility resulting from continuous cropping without adequate nutrient replenishment is a major concern in mixed farming systems of the central highlands of Kenya. Continuous cultivation in these areas without requisite management has resulted in accelerated soil erosion, depletion of the soil nutrient reserves and a decline in the soil physical and chemical characteristics (Kilewe and Thomas, 1992; Gachene, 1989; Mahaney, 1979; Mwonga and Mochoge, 1989). The depletion of some soil nutrients, especially nitrogen (N), is particularly high in the densely populated Kenya highlands (Smaling, 1993; Smaling *et al.*, 1993; Stoorvogel *et al.*, 1993). The declining productive capacity of the soil is demonstrated by the yield decline in experimental and farmers' fields over time. An analysis of a long-term experiment in the highlands of central Kenya showed a decline in maize yield from three to one tonne per hectare for 20 years of continuous cropping (Swift *et al.*, 1994). Variable organic inputs at the farm level have been used to mitigate this decline in soil fertility (Vanlauwe and Sanginga, 2004). The factors influencing the level of soil nutrient depletion are many and complex, including nutrient management, regeneration and plant protection, livestock integration, soil and water conservation, biodiversity management, agricultural policies and marketing structures. Nutrient depletion is the result of a net imbalance, between incoming and outgoing nutrients in farm inputs and outputs. Causes are high crop yields in most cases accompanied by inadequate, untimely or inefficient application of manure or fertiliser, farm management practices, leading to high levels of losses such as leaching and erosion, and inefficient recycling of existing nutrients on the farm and decreasing fallow rates (de Jager *et al.*, 1998). Farmers are primarily concerned about the short-term crop and animal production, for present and possibly the forthcoming season. Long-term processes that adversely affect sustainability, such as decrease of soil nutrient stocks, are less conceptualised and may therefore, receive a lower priority at farm level. Importantly, however, soil fertility management takes place at farm level and at the level of farm activities such as crop and livestock activities,

since decisions are taken by individual farm households or by groups of households at community level. Decision concerning soil fertility management, are determined by the household objectives on the one hand and the available resources and the socioeconomic environment on the other hand (Van den Bosch *et al.*, 1998). The sustainability of a farming system can then be estimated through calculating nutrient balances and relating the costs of replacement to the net farm income. This study sought to understand soil fertility status and capture nutrient flows in farming systems in central Kenya. While studies on nutrient balances are common in Kenya, there is very limited consideration of variability within an ecosystem. This study therefore went a step further to capture variability across farms (catchment level) and within individual patches of the same farm. Documentation of such variability will lead to better understanding of management options that need to be effected, in order to stem the decline in soil fertility. This in turn would lead to increased agricultural productivity and better livelihoods for smallholders.

The objectives of this study were to

- To stratify farm typologies based on farmers' perception of soil fertility management, and soil chemical analysis
- To monitor nutrient flows within the farm typologies using nutrient monitoring package
- To determine nutrient balances under different crops within an individual farm.

Methodology

Study sites

The study was carried out in Kirinyaga District, central Kenya. Kirinyaga District occupies 1437 km^2. Mukanduini village (S' 0°34.68' E' 37°16.22') where the study was carried out is in Kerugoya Division at an altitude of 1303 m. The soils are Humic Nitisols. Eighty percent of the district is arable. It has about 97,970 farm families occupying about 96,938 farm holdings with an average farm size of 1.25 ha. per family. Main agroecological zones include UH0, LH1, UM and LM3 while main enterprises include maize-bean, tomatoes, French beans and bananas production. Mukanduini village is in UM2 AEZ, (Jaetzold *et al.*, 2006) which is a marginal zone characterised by coffee, maize-bean, tomatoes and bananas production.

Participatory learning and action research

A multidisciplinary team of scientists from the Kenya Agricultural Research Institute (KARI) and extension agents from the Ministry of Agriculture (MoA) conducted a participatory learning and action research (PLAR) in two districts of central Kenya: Kirinyaga within National Agricultural Livestock and Extension Program (NALEP) focal areas. One NALEP focal area covers a minimum of 300 farmers. The facilitators held discussions with 20-30 farmers in each focal area, who were representatives of about 300 farmers in each focal area. The discussions in each focal area took three to four days. The first day was for a team building. During this exercise, tools such as introductory village meetings, village (focal area) maps, transects, organisation diagrams, wealth ranking, soil fertility management diversity and farm classification, resource flow models and closing village meetings were reviewed according to methods described by Defoer *et al*. (2000). The team facilitators were divided into five sub-groups, mainly socioeconomics, crops, livestock, land use, soils and agroforestry. One of the days was devoted to learning about resource flow maps. The facilitators held group discussions followed by plenary sessions to share the findings. Farmers determined the criteria to be used in ranking the households in soil fertility management. Three categories or classes were determined comprising of good (class I), average (class II) and poor (class III) soil fertility management. The farmers classified all the households within the focal area according to the above categories. Among the classified farms, ten were selected to represent the group for soil fertility management. The classified farms were further stratified according to crop performance and fertility perceptions of particular portions in the farms. Based on crop performance, patches were classified as good soil fertility patch (SFP), medium SFP and poor SFP. Topsoil samples (0-20 cm) were taken from each farm and analysed in laboratory according to methods described by Okalebo *et al*. (2002).

Nutrient monitoring

After PLAR was carried out, nutrient monitoring (NUTMON) studies were introduced to the farmers through individual farm visits. In each class, two farmers were selected for NUTMON questionnaire administration. The farmers were visited in their farms during cropping season for two cropping seasons. During the visits which involved systematic discussions, farm plans were drawn and soil fertility gradient and cropping pattern in the farms observed. Within the farm, sections with different characteristics based on slope, crop performance, soil colour or presence of stones or sandy areas was marked as farm section units (FSU). Portions in the farm occupied by different crops such as coffee (*Coffea canephora*) sole crop or intercropped with maize (*Zea mays*) or beans (*Phaseolus vulgaris*), maize-bean intercrop or maize sole crop were marked as primary production units (PPU). The types and number of livestock, owned, whether confined or grazed was captured as secondary production unit (SPU). The demographic household structure was also captured, as the number of people living together and sharing food, the age and academic level. Nutrient flows were quantified in different ways. Flows directly related to farm management were quantified by asking the farmers on inputs to and outputs from the different compartments in their farm on monthly or a cropping season basis. Flows quantified this way were the use of mineral fertilisers (IN1), organic inputs (IN2), farm products (OUT1) and removal of crop residues (OUT2). Soil nutrient level, soil physical characteristics and percent nutrient level in farm products was analysed in the laboratory, climatic characteristics obtained from the nearest Ministry of Water weather stations and crop classification like C-factor obtained from the literature. The NUTMON questionnaire findings were entered into the NUTMON data entry model and analysed using the NUTMON data processing model.

Results

Findings of the Participatory learning and action research

During the PLAR exercise, the farmers identified some factors which were perceived as indicators of declining soil fertility. These included low and declining crop yields over time (from 25 bags of maize to three bags per hectare). Poor performance of certain crops such as citrus, pigeon pea (*Cajanus cajan*), bananas (*Musa* (genus)., arrowroots and pumpkins (*Cucurbita pepo*) over time, and dominance of some weed species in spots of the farm. Other indicators included low crop yields and change in soil colour (from dark colour when soils are fertile to reddish as they become infertile) were also cited by farmers. Other observations associated with low soil fertility included change in leaf colour of crops for example maize from green to yellowish and purplish during the crop growth period, an increased disease and pest incidences, as well as declining soil water holding capacity. The causes of soil fertility decline were listed as soil erosion, continuous cultivation, inadequate organic matter, improper crop rotation practices, poor tillage practices, use of inappropriate fertilisers, and poor organic matter management. These results were ranked by farmers and are shown in Table 1.

Table 1: Pair-wise ranking of causes of overall decline in soil fertility

Causes of fertility decline	SE	CC	IOM	ICRP	PTP	UIF	POM	Score	Rank
Soil Erosion (SE)		SE	SE	SE	SE	SE	SE	6	1
Continuous Cultivation (CC)			CC	CC	PTP	UIF	CC	3	4
In-adequate Organic Matter (IOM)				ICRP	PTP	UIF	POM	0	7
Improper crop rotation practices (ICRP)					ICRP	UIF	POM	2	5
Poor Tillage Practices (PTP)						UIF	POM	2	6
Use of In-appropriate Fertiliser (UIF)							POM	4	3
Poor Organic Matter Management (POM)								4	2

According to the classification by the PLAR exercise, class I farmers used manure and mineral fertilisers, construct soil conservation structures and performed deep tillage. Class II farmers used fertilisers and

mineral fertilisers but at a lower rate than the class I farmers and had less elaborate soil conservation structures thanthose in class I. Class III farmers applied manure at very low rates with little-to-very little mineral fertiliser and had poorly maintained soil conservation structures. The differences in soil nutrient levels among the Classes were associated with the farmers' resource endowment levels. Class I were seen as more resource endowed than those in Class I according to the classification. This is in agreement with similar studies done in western Kenya (Tittonell *et al.,* 2005).

The participatory studies identified the soil fertility management problems and ranked them (Table 1). This made it easy to target soil fertility problems facing the farmers in the villages. The soil analysis showed a close relationship between the farmers' observations and interpretations (according to how they classified the farms into different classes) that is the farmers' perception on soil fertility and the chemical laboratory analysis results. At Mukanduini village, Kirinyaga district, N (%) levels in soils were low in all the Classes (0.05-0.12% N), the coefficient of variation of N (%) levels in the soils was about 36%, showing a moderate variation of N (%) content in soils among classes (Table 1). Potassium levels in the soils were generally high (> 300 ppm K) in all the classes and showed a higher variation among the classes. Carbon (%) content in soils in Classes I and II was moderate (1.5-3.0% C) but low in Class I farms (0.5-1.5% C), though the variation from class to class was low (16.2%). There were no significant (P = 0.05) differences in pH level, K, CEC contents in the soils between the classes. NNitrogen (%), ppm P and content (%) in the soils differed significantly (P = 0.05) between Classes I and III and between Classes II and III but the nutrients had no significant differences between Classes I and II.

It is a common phenomenon in smallholder Kenyan agroecosystems to find variability within the same farm. In this study there were portions/patches within the same farm which were lower in fertility /crop yields than others as reported by Giller *et al.* (2005) and Tittonel *et al.* (2005) on work done in western Kenya. The soil analyses results for these patches in Mukanduini (Table 3) show that there were no significant (P=0.05) differences in soil in nutrient content within patches of the same farm within the soil fertility management classes. The variation in N (%), ppm P and ppm K between good, medium and poor patches were high (48-62%) in Class I farms, but within the other classes a close variation was observed. Rather surprisingly, enormously high amounts of P were observed in Kirinyaga. This could be attributed to commercial farming mainly for tomatoes and French bean, which have higher returns on fertiliser inputs.

Table 2: Soil nutrient levels in soils in Classes within farm typologies in Mukanduini village, Kirinyaga District, central Kenya

	Farm nutrient levels					
SF Class	pH	N (%)	ppm P	Ppm K	C (%)	CEC cmol/100g
Class I	5.60	0.10	441.23	410.45	1.59	7.21
Class II	5.75	0.07	632.67	384.62	1.52	7.95
Class III	5.78	0.09	649.83	428.52	1.39	6.82
Mean	5.72	0.09	582.10	409.93	1.49	7.28
Cv %	7.17	35.68	24.84	45.49	16.21	19.61
r^2	0.04	0.12	0.31	0.01	0.12	0.11
Rating						
High		>0.25	>40	175-300	>3.0	
Moderate		0.12-0.25	20-40	50-175	1.5-3.0	
Low		0.05-0.12	10-20	50-100	0.5-1.5	
Very low		<0.05	<10	<50	<0.5	

Variability within and among farms

There was a narrow variation (6-19.99) in soil nutrient levels of pH, N (%), P, C and CEC but the level of K in the soil varied widely in Class II farms in good, medium and poor patches of the same farm. A similar

variation in soil nutrient content was observed in Class III but N (%) and ppm K showed a wide variation in nutrient content in good, medium and poor soil fertility patches in the same Class (Table 3).

Table 3: Soil fertility patches within soil fertility classes in Mukanduini village

SF Class	Farm patches nutrient levels						
	SF Patches	pH	N (%)	ppm P	ppm K	C (%)	CEC cmol/100g
Class I	Good	5.62	0.09	447.31	428.90	1.52	7.20
	Medium	5.71	0.11	400.87	384.63	1.48	6.41
	Poor	5.48	0.10	475.52	417.83	1.75	8.03
	Cv%	9.20	37.27	62.32	48.77	9.24	14.81
	SE	0.21	0.02	158.77	115.57	0.08	0.62
Class II	Good	5.91	0.09	681.52	528.52	1.67	8.81
	Medium	5.58	0.07	657.80	351.42	1.55	8.32
	Poor	5.77	0.06	558.67	273.93	1.36	6.73
	Cv%	6.11	19.99	10.09	40.08	9.43	19.12
	SE	0.20	0.01	36.85	89.01	0.08	0.88
Class III	Good	5.60	0.10	674.21	456.57	1.21	6.87
	Medium	6.04	0.09	596.75	480.35	1.58	7.36
	Poor	5.72	0.09	678.53	348.65	1.38	6.25
	Cv%	7.16	43.91	9.66	49.88	20.85	22.26
	SE	0.21	0.02	31.37	106.88	0.15	0.76

Findings by NUTMON

The nutrient balance is a mixture of primary data, estimates and assumptions. To make clear distinction between primary data and estimates and assumptions, two different balances were defined. The partial balance at farm level (IN1 + IN2-OUT1-OUT2) is made up solely of primary data and mainly reflects the 'way of farming' though there are background calculations, which cannot be directly quantified. OUT1 only reflects the farm products that leave the farm to external destinations for example what is sold to the market or to neighbours. Home consumed farm products are reflected by OUT6. The full balance defined as (IN1-IN4)-(OUT1-OUT6) is a combination of partial balance and the emissions (atmospheric deposition and N fixation) and emissions (leaching, gaseous losses erosion losses and human excreta) from and to the environment respectively (Table 6).

Nutrient balances

In Kirinyaga District, maize-bean mixtures, maize monocultures, coffee and tomato farming characterised most of the farms. A few farmers in Class I planted French beans both under irrigation and rainfed. They had extreme nutrient input and mining and could not represent the other farmers well.

In class I farm (Table 7), high levels of mineral fertiliser input (IN1) were observed, 80 kg N, 21 Kg P and 14 kg K. Harvest of crop products (OUT1) was the leading channel through which most of the nutrients were lost. About 75 kg, 7 kg and 18 kg of N, P, and K, respectively, was lost through crop harvest. This was more prevalent in coffee and tomato fields. Food consumption within the farm was the second channel through which nutrients were lost from the farm. Working nutrient balances (partial balances) were positive but full balances in kg ha^{-1} turned out to be negative, -2.1 for N and -4.1 for K.

Table 6: Nutrient flows and descriptions for NUTMON

Nutrient flows	Description
IN1	Mineral fertiliser
IN2	Manure
IN3	Atmospheric deposition
IN4	Biological nitrogen fixation
OUT1	Harvested products
OUT2	Removal of crop residues
OUT3	Leaching
OUT4	gaseous losses
OUT5	Erosion
OUT6	Human excrement

Table 7: Nutrient flows and balances in three farm typologies in Mukanduini, Kirinyaga District

Nutrient flows	Class I			Class II			Class III		
	N	P	K	N	P	K	N	P	K
IN1	79.9	21.1	14.7	30.3	5.8	6.9	20.4	7.5	5.1
IN2	7.0	2.3	5.8	5.6	1.3	4.8	3.2	1.2	3.6
OUT1	74.7	6.9	18.3	27.6	2.3	15.1	50.9	7.1	25.1
OUT2	0.6	0.1	0.8	0.2	0.0	0.2	2.6	0.5	0.7
OUT3	3.3	0.0	4.3	4.6	0.0	5.7	0.0	0.0	0.0
OUT4	3.3	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0
OUT6	7.1	1.9	1.2	5.8	1.6	1.0	4.0	1.1	0.7
Full balance (kg ha^{-1})	-2.1	14.5	-4.1	-6.9	3.9	-10.3	-8.2	0.3	-17.8
Partial balance (kg)	11.6	16.4	1.4	8.1	4.7	-3.6	-29.9	1.1	-17.1

In Class II (Table 7), lower level of mineral fertiliser inputs were observed 30, 6 and 7 kg N, P and K respectively. Removal of nutrient through crop harvest reflected high nutrient mining compared to input (about 10 kg K was removed than was input). Other channels through which N was lost was leaching and gaseous losses covering up to 30% of N lost in both gaseous losses and leaching. Partial balances was positive for N and P but K was negative (-3.6), while full balances were negative for N and K. In Class III, very low mineral nutrient inputs were reflected (20, 7.5 and 5.1 kg ha^{-1} $year^{-1}$, N, P and K respectively). Nutrient mining through crop harvest exceeded nutrient inputs by more than 100% for N and K. Both partial and full nutrient balances were negative in Class III farm, giving negative nutrient balances. A similar scenario was observed in western Kenya (Vitousek *et al.,* 2009).

Cropping pattern and nutrient balances in Mukanduini

Mukanduini village farms are characterised by well-designed primary production units in the farm, whereby a particular portion of the farm's main crop is coffee or maize-beans intercrops, or Napier grass. The largest primary production unit in Class I farms was occupied by maize-bean intercrop followed by coffee while the largest in class III was maize-bean intercrop. In Class I farm, maize monoculture, maize-bean intercrop occupied 0.07% and 36% of the cultivated land, while Coffee, tomato and Napier grass occupied 29, 14 and 0.07%, respectively (Table 8). Coffee fields received high amounts of mineral fertiliser at 69, 108 and 302 kg ha^{-1}, N, P and K, respectively; and organic fertilisers at 12.3, 4.3, and 12 kg ha^{-1}, N, P and K, respectively. Removal of nutrients through crop harvest (OUT1) was high, but nutrient inputs (IN1 and IN2) exceeded output, thus giving positive nutrient balance, both partial and full balances in coffee

fields. Negative nutrient balances were recorded under Napier grass, maize, maize-beans fields. These fields received low mineral and organic nutrient inputs (4.2, 0.7 and 1.4 kg ha^{-1}, N, P and K, respectively, mineral fertilisers and 1.2, 0.2 and 0.8 kg ha^{-1}, N, P and K, respectively, organic nutrient inputs). The partial balances in the food crops were negative, indicating that the farming system was unsustainable. A similar study carried out in western Kenya recorded negative nutrient balances in food crops (Roy *et al.*, 2003); confirming that most of the farming systems were unsustainable due to more soil nutrients being removed than added.

Table 8: Nutrient mining level in major crops grown in a Class I farm in Mukanduini

Crops grown	Cultivated area (m^2)	Total yield (kg)	Nutrient balances: Full balance (kg ha^{-1} yr^{-1}) N	P	K	Partial balance (kg) N	P	K
Maize, bean	5058	765	-37.2	-5.7	-21.6	-8.1	-1.0	-4.2
Sweetpotato	1012	70	-0.9	-0.2	-1.4	-0.1	0.0	-0.1
Tomato	2023	2650	-27.2	23.7	-53.4	-2.8	2.4	-5.4
Maize	1012	360	-52.0	-12.7	-14.5	-5.3	-1.3	-1.5
Coffee	4047	5870	8.6	6.1	2.8	3.5	1.5	2.7
Napier grass	1012	1200	-47.2	-5.0	-63.4	-4.8	-0.5	-6.4

In Class II farm, 12% of cultivated land was allocated to maize while and 63% was allocated to maize-bean intercrops (Table 9). Napier grass had 0.01% while coffee-maize fields had 12%. Very high negative nutrient balances (-393 N kg ha^{-1} yr^{-1}) and (–157.4 N kg ha^{-1} yr^{-1}) were observed under Napier grass and maize-bean intercrop, respectively. Napier grass fields rarely receive mineral nutrient inputs except occasional organic inputs while harvesting goes on throughout the year. Maize-bean fields received no mineral fertiliser inputs but received organic inputs, farmyard manure (0.9, 0.3 and 1.0 kg ha^{-1}, N, P and K, respectively) and in fields with maize-tomato received 0.4 kg N mineral fertilisers.

Table 9: Nutrient mining levels in major crops grown in a Class II farm, in Mukanduini

Crops grown	Cultivated area (m^2)	Total yield (kg)	Nutrient balances: Full balance (kg ha^{-1} yr^{-1}) N	P	K	Partial balance (kg) N	P	K
Maize, beans	10118	538	-157.4	-13.0	-83.0	-17.8	-1.8	-9.5
Maize, tomato	1012	530	-23.9	-3.0	-17.0	-2.4	-0.3	-1.7
Irish potato	809	100	91.2	4.9	-24.8	7.4	0.4	-2.0
Coffee, maize	2023	1185	-8.6	12.7	23.3	-1.7	2.6	4.7
Napier grass	202	2000	-393.4	-41.8	-528.6	-8.0	-0.8	-10.7
Maize	2023	180	-13.0	-3.2	-3.6	-2.6	-0.6	-0.7

In Class III, 72% of the cultivated area was allocated to maize-bean intercrop and 25% to coffee (Table 10). Napier grass was not grown. In the primary production units, negative nutrient balances prevailed in both partial and full balances.

Table 10: Nutrient mining level in major crops grown in a Class III farm, in Mukanduini

Crops grown	Cultivated area (m^2)	Total yield (kg)	Nutrient balances: Full balance (kg $ha^{-1}yr^{-1}$) N	P	K	Partial balance (kg) N	P	K
Coffee, tomato	9105	3500	-8.9	2.7	-13.7	-8.1	2.5	-12.4
Maize, bean	26305	5190	-14.7	0.3	-7.4	-38.7	0.7	-19.4
Sweetpotato1012700 -8.0 -1.9 -12.2 -0.8 -0.2 -1.2								

Discussion

Soil fertility sustainability is a major concern in the fragile agricultural ecosystems in central Kenya. In Kirinyaga District at Mukanduini village, there were low levels of soil N (%) content, pH and high extracTable K values. Class I farms had high soil organic carbon while Classes II and III had moderate soil organic carbon. According to farmers' observations, the fertility varied within farms. However, there were no significant differences in soil nutrient contents among the three patches within a farm, though there was a wide variation (45.5%). This indicates that a blanket recommendation made for all the farms would not be desirable. Just as observed in other parts of Kenya (Roy *et al*., 2003; de Jager, 2005; Tittonell *et al*., 2005; Vitousek *et al*., 2009), negative nutrient balances dominated the farming systems. A more targeted recommendation regime would result in better efficient resource allocation. In Kirinyaga, There was decreasing preference to napier grass growing from Class I to Class III farmers. This was associated with the fact that Class I owned two to three heads of cattle and Class III owned one or none, according to participatory learning and action research carried out in the area. In the longer term, soil fertility in these agroecosystems may not be unsustainable due to higher negative nutrient balances.

Conclusions

The PLAR exercise showed that farmers in central Kenya can use indigenous technical knowledge to identify indicators of soil fertility potential. In addition farmers were able to stratify the environment they live in with regard to soil fertility management. This in turn shows that using farmer knowledge, it is possible to target soil fertility efforts to address "hot spots" within a farming system. This has two implications that it is possible to target intervention measures to for instance through subsidies, to vulnerable areas, which would lead to improved livelihoods. The general soil fertility decline as shown through NUTMON studies confirm that soil fertility decline continues to be an insidious process, and is likely to remain so in the foreseeable future. This study however presents an opportunity to better target the decline, by considering the variability concept, and possibly the choice of crop.

The nutrient concentrations show that P levels in the study area are not limiting. This is possibly due to increased use of mineral fertiliser levels usually in combination with organic fertiliser. This has been driven by the responsiveness of farmers in this area to the use of fertiliser, propelled by the market demand for horticultural crops. This suggests that a market driven agricultural production is possibly the way forward in addressing the problem of nutrient mining, and presents a window of opportunity towards general increase in productivity and general livelihoods in smallholder farms of central Kenya.

Recommendations

- Indigenous knowledge on soil fertility and soil fertility declined need to be supported scientifically and not overlooked
- Farmers understand their soils well and support is needed to enable them be more productive

- With proper soil fertility amendments, high crop yields can be achieved; and hence application of both organic and inorganic fertilisers should be encouraged

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Decomposition rates and nutrient release patterns of *Tephrosia vogelii* and *Tephrosia candida* residues in Malawi

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Abstract

A study was carried out to determine the rates of decomposition and nitrogen (N) and phosphorus (P) release pattern from *T. vogelii* and *T. candida* plant residues using litterbag experiments in Malawi. The plant residue treatments included *Tephrosia* biomass alone or in combination with maize stover. For each treatment, sixteen replicates of litter bags were buried in the soil at the depth of 20 cm and Samples were drawn from each litter bag at 1, 2, 3, 4, 5, 6, 7 and 8 week intervals and were analyzed to determine remaining dry matter weight (DMW), N and P. The fastest decomposition rates (k) recorded when *T. vogelii* or *T. candida* leaves + twigs + stover were combined, while the slowest was when twigs alone or maize stover alone were used. The *Tephrosia* residues were high in N (>3.5%) and P (critical value of >2.0%). The N release rates were fastest from twigs of *T. vogelii* or *T. candida* followed by maize stover alone, while the slowest release was when *T. vogelii* leaves were combined with twigs. P release pattern from residues was the same as N release. No N and P immobilization was observed throughout the study period. The results have clearly demonstrated that that the *Tephrosia* fallow biomass alone decompose considerably faster attaining their half-life within 2–3 weeks and over 95% within 8–25 weeks but when mixed with maize stover (a low quality farm residues) decomposition was slowed down. Therefore, *Tephrosia* fallow biomass can be used for short-term correction of soil fertility.

Key words: Tephrosia, decomposition, release pattern, litterbag, soil fertility.

Introduction

Land degradation, soil fertility depletion, the inability of most farmers to practice crop rotation due to land shortage and reduced inorganic fertilizer use due to high prices of inorganic fertilizer are some of the major causes of decline in crop productivity (Smale and Jayne, 2003; Akinnifesi, 2009). Given the limitations of inorganic fertilizers and the challenges to make them available at affordable costs in Africa, there is an urgent need for increased use of alternative and complementary inputs in smallholder farming systems in many parts of the developing world. Planting of N-fixing leguminous plant species either as improved fallows or green manures cover crops is receiving considerable attention in the cropping systems of sub-Saharan Africa. The legumes have been reported to increase N fertilizer use efficiency in Malawi (Kamanga *et al*., 2001).

In Agroforestry systems, the main input of nutrients is achieved through biomass decomposition, by which elements that are essential for plant development and are associated to plant tissues not readily available to crops of commercial interest are released. How fast these residues return to the soil is basically a function of the quality of the organic source, the weather conditions and the presence of decomposing organisms in the system (Myers *et al*. 1994). In order to develop more efficient systems to improve soil nutrient dynamics, a well-synchronized balance must be established between specific crop demands and supply of nutrients from decomposition of plant residues.

Tephrosia vogelii and *T. candida* are some of the shrubs that are being used as fertilizer trees in Malawi (Akinnifesi, 2009). The trees are suiTable for rehabilitating degraded land, fixing atmospheric N and raise soil P and K levels in proportion to increased levels of organic matter (Huancheng and Jueiming, 1993). No

much work has been done to evaluate the potential of *T. vogelii* and *T. candida* biomass for soil fertility improvement as well as understanding their decomposition rates and pattern of nutrients release in Malawi. Therefore, the objective of this study was to characterize the decomposition rate and nutrient release pattern of *T. vogelii* and *T. vogelii* residues and optimize their use as sources of organic manure for maize production in Malawi.

Materials and methods

Study area

The decomposition study was carried out at Chitedze Agricultural Research Station (located at 13˚ 85′ S and 33˚38′ E) in Malawi. It lies at an altitude of 1146 m above the sea level. The site has one long growing season in a year (October to April). The station receives a mean annual rainfall of 892 mm, 85% falls between November and March with a mean temperature of 28^{o}C. Climatic data collected during the research period (between January and March 2012) is shown in Figure 1.

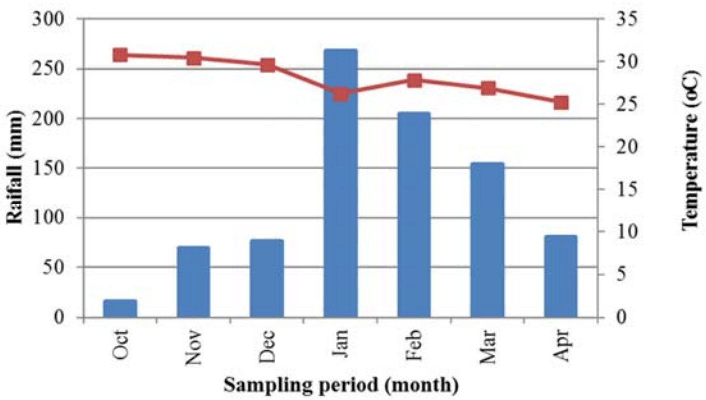

Figure 1: Mean monthly rainfall and temperature data during the experimental period

Experimental design and treatments

The litterbag experiment was carried out for 8 weeks period between January 2012 and March 2012. The leaves and twigs were collected from the two fallow biomass sites under *T. vogelii* and *T. candida* and maize stovers were mixed with *Tephrosia* biomass. The experiment had 6 treatments with each sample weighing 15g as shown in **Table** 1.

Table 1: Treatments for the decomposition experiment on *T. candida* and *T. vogelii* residues and maize stover

No.	Treatment
1	15g *Tephrosia* leaves
2	15g *Tephrosia* twigs
3	10g *Tephrosia* leaves + 5g twigs
4	15g Maize stovers
5	10g *Tephrosia* leaves+ 5g stovers
6	7.5g *Tephrosia* leaves + 3 g twigs + 4.5g stovers

Tephrosia leaves, twigs and maize stover were chopped to about 2cm and placed in 20 x 20 cm nylon bag with a 2 mm mesh size to prevent losses of litter to breakage. For each treatment 16 replicate litterbags were buried at the depth of 20cm. At each sampling period, two litterbags from each treatment were systematically sampled and soil particles and roots growing in the litterbags were manually removed. The litterbags were sampled weekly for 8 weeks.

Laboratory analysis

The samples were analyzed for initial N, P, K, Ca, Mg, and C. On the other hand, the remaining organic materials were washed with distilled water and oven dried at 75°C for 48 hours to a constant weight for dry weight determination, N and P analysis. The N content of the plant tissues were determined by Kjedahl procedure whereas P content were determined calorimetrically according to Murphy and Rilley (1962) and the K content of the plant tissue were determined by the Flame photometer while Ca and Mg were determined by Atomic Absorption Spectrophotometer (AAS). Organic C was determined using Dichromate-Oxidation Method (Jackson, 1958).

Statistical analysis

In all cases, the mass remaining was expressed as percentage of the initial oven dry weight (DMW) of the residues. Remaining dry matter and nutrients of the residues were fitted to the exponential model of Olson (1963) and the decomposition rate and nutrient loss constants (k) were determined as follows:

$$W_t = W_0 e^{-kt}$$

Where: W_o and W_t are the initial and remaining (at time t) weights of oven-dry organic materials or nutrients pool, respectively

k = decomposition rate constant which was estimated as a slope of the model

t = time (week)

The half-life (time required for 50%, $t_{0.50}$ to be released) and 95% ($t_{0.95}$) loss in DMW or element were equal to 0.693/k and 3/k, respectively (Harmon *et al.*, 1999). Non-linear regression procedure of SAS was used to estimate decomposition and N and P release rates. Biases in the estimated values of k (and its 95% confidence limits) were tested using. Hougaard's measure of skewness. The values of k were considered reasonably close to linearity if the absolute value of Hougaard's measure is <0.25 but biased if >0.25. Values of k were declared significantly different if their 95% confidence intervals overlap.

Results and discussion

Chemical composition of organic materials used in the study

The chemical composition of the plant materials used in the decomposition study is presented in Table 2. The N content of the residues ranged from 1.56 to 5.18% with *T. candida* leaves and maize stovers alone recording the highest and lowest N content respectively. The quality of plant residues with respect to decomposition can be defined as its relative ease of mineralization by decomposer organisms (Paustian *et al.*, 1997). Quality is largely determined by the organic constituents and nutrient contents. The N concentrations of all residues apart from maize stover had values >2.0 to 2.5% below which net N immobilization from the soil would be expected when these residues are applied as soil amendment as indicated by Palm and Sanchez (1991).

Table 2 : Chemical characteristics of plant residues used in decomposition study

Species	Treatment	N (%)	P (%)	K (%)	Mg (ppm)	Ca (ppm)	OC (%)	C/N	C:P
T. candida	Leaves	5.18	0.35	0.39	3.88	2.64	36.4	7.0	104.9
	Twigs	2.95	0.31	0.35	3.01	2.58	35.6	12.1	116.7
	Leaves+twigs	3.38	0.27	0.39	2.87	2.52	28.9	8.6	107.0
	Leaves+stover	2.60	0.13	0.26	2.88	2.43	41.6	16.0	114.1
	Leaves+twigs+stover	2.62	0.14	0.43	3.03	2.56	41.2	15.7	302.9
T. vogelii	Leaves	5.02	0.21	0.43	3.96	2.78	32.1	6.4	150.0
	Twigs	2.75	0.21	0.60	2.92	2.54	31.7	11.5	152.4
	Leaves+twigs	3.35	0.18	0.52	3.44	2.58	37.6	11.2	212.4
	Leaves+stover	2.32	0.13	0.26	2.85	2.63	40.0	17.2	317.5
	Leaves+twigs+stover	2.11	0.13	0.39	3.27	2.22	37.2	17.6	297.6
	Maize stover alone	1.56	0.07	0.43	2.93	2.45	41.6	26.7	602.9

Decomposition pattern for different plant materials of **T. vogelii and T. candida**

The decomposition rate constants (k) and the days taken for 50% (t_{50}) and 95% (t_{95}) decomposition for the different residues are presented in Table 3. The k for all the plant residues were unbiased and ranged from 0.15wk^{-1} for maize stover alone to 0.34wk^{-1} with mixture of *T. candida* leaves+twigs+stover. (Table 3). The rate for maize stover alone was significantly slower than most treatments except twigs alone (Figure 2; Table 3). The mass loss in all the plant residues for both species was faster between the first and fourth week. Between the second and fourth week of decomposition, the residues had lost almost 50% of their initial mass (Figure 2). The model used explained 90-99% of the variation (r^2 = 0.90-0.99)

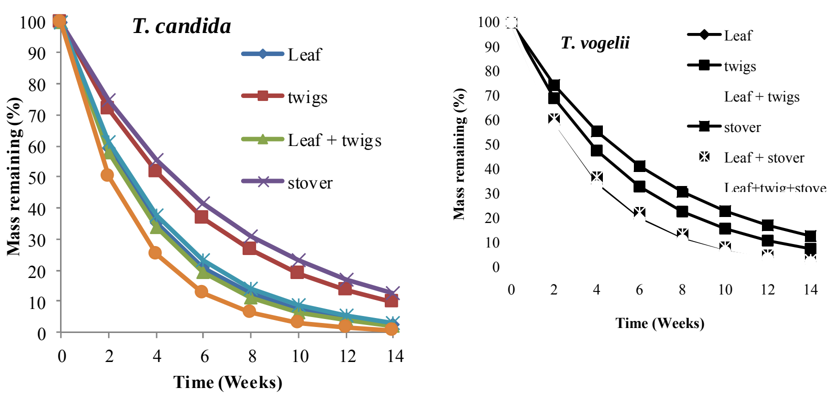

Figure 2: Modeled biomass loss from *T. vogelii* and *T. candida* and their mixtures with maize stover

Table 3: Decomposition rate constant (k), coefficient of determination (r^2), correlation coefficient (r) and half-life (t_{50}) and $t_{0.95}$ of the residues of Tephrosia

Species	Treatment	k (wk^{-1})	95% CL*	t_{50}	t_{95}
T. vogelii	Leaves	0.27	0.20-0.34	2.57	11.11
	Twigs	0.19	0.15-0.22	3.75	16.22
	Leaves+twigs	0.26	0.19-0.32	2.69	11.63
	Leaves+stover	0.25	0.15-0.35	2.77	12.00
	Leaves+twigs+stover	0.28	0.17-0.38	2.51	10.87
T. candida	Leaves	0.26	0.20-0.32	2.67	11.54
	Twigs	0.17	0.13-0.20	4.17	18.07
	Leaves+twigs	0.27	0.15-0.39	2.55	11.03
	Leaves+stover	0.25	0.18-0.31	2.83	12.24
	Leaves+twigs+stover	0.34	0.26-0.43	2.01	8.72
	Leaves	0.15	0.12-0.17	4.71	20.41

The significance of fit for all the treatments was P<0.0001
K values of any two treatments were declared if the 95% confidence bands do not overlap

In both species the pattern was biphasic with an initial rapid phase followed by a slower phase. A similar pattern was observed by Tetteh (2004) and Nhamo *et al*., (2007). The rapid mass loss during the early stages of the organic materials was due to release of water soluble components such as sugars, amino acids and soluble phenolics (Wang *et al*., 2004; Bross *et al*., 1995). The slow loss of biomass recorded during the late stages of decomposition reflected the decline in quality of the biomass and could be due to the presence or decomposition of recalcitrant materials such as lignin, hemicelluloses and soil microbial products (Saviozzi *et al*., 1997). Nyamai (1994) also observed that the decomposition of the foliage of five agroforestry tree species started rapidly and continued for some weeks and then gradually became slow. The rapid decomposition of the plant residues in this study could be due to high levels of nutrients, notably N, which are reported to accelerate the decomposition process (Alhamd *et al*., 2004).

***N release pattern for* Tephrosia**

The percent N release for plant residues for both species was highest in twigs and k_N ranged from 0.12 to $0.39wk^{-1}$ (Figure 3). In all cases, there was an initial rapid release of N and slower release from the sixth week onwards from all the plant residues but *T. candida* residues had the highest N release rates than *T. vogelii* (Table 4).

There was rapid decrease in N content for all the treatments especially in the first week which indicates removal of water-soluble organic substances (Wang *et al*., 2004; Bross *et al*., 1995). High quality residues decompose very fast releasing N initially in excess of plant demand (Handayanto *et al*., 1994). Similar pattern of N dynamics have been reported by Schomberg *et al*. (1994).

The twigs of both species released N rapidly than maize stover especially during the first two weeks. This could be attributed to their high N content and low C: N ratios compared to low N content and high C: N ratio in maize stover. Mixing maize stover with *Tephrosia* biomass or mixture of soft twigs and leaves slowed the rate of decomposition. Residues with high C to N ratios tend to mineralize much slowly than materials with lower ratios under the same conditions. These findings are in agreement with Bunyasi (1997) and Handayanto *et al*., (1997) who reported that mixing high quality with low quality organic materials

contributed to better N use through slowing the fast release of nutrients by former and reducing immobilization by the latter materials.

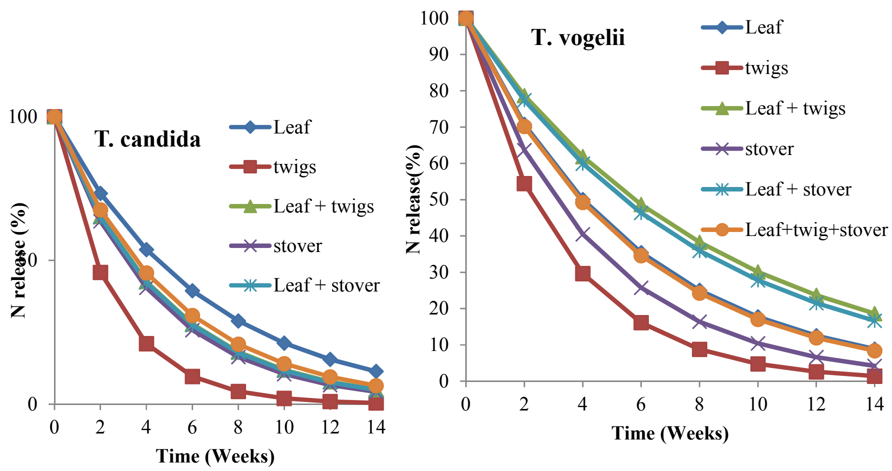

Figure 3: Modeled N release pattern from *T. vogelii* and *T. candida* and their mixtures with maize stover

Table 4: N release pattern for *T. vogelii* and *T. candida* plant residues

Species	Treatment	k wk^{-1}	95% CL	t_{50}	t_{95}
T. vogelii	Leaves	0.17	0.12-0.23	4.01	17.34
	Twigs	0.30	0.25-0.36	2.28	9.87
	Leaves+twigs	0.12	0.08-0.16	5.78	25.00
	Leaves+stover	0.13	0.10-0.15	5.41	23.44
	Leaves+twigs+stover	0.18	0.13-0.23	3.92	16.95
T. candida	Leaves	0.16	0.09-0.22	4.47	19.35
	Twigs	0.39	0.22-0.56	1.78	7.69
	Leaves+twigs	0.21	0.14-0.28	3.25	14.08
	Leaves+stover	0.22	0.13-0.30	3.22	13.95
	Leaves+twigs+stover	0.20	0.12-0.28	3.54	15.31
	Maize stover alone	0.23	0.18-0.27	3.07	13.27

***P release pattern for* Tephrosia**

Release of P from the *T. vogelii* and *T. candida* residues was very rapid and regular for all the residues during the first week (Figure 4). All the plant residues released almost 50% of their initial P content by fourth week. As observed for N, P release rates (k_p week^{-1}) were highest in *T. candida* twigs (k_P = 0.44 wk^{-1}) and lowest in maize stover and TV Leaves + twigs + stove (k_P = 0.16 wk^{-1}) throughout the incubation period (Table 5).

The rapid loss of P observed in this study after the first week was probably due to removal of soluble P after burying the litterbags. Many studies indicated that P can be leached in the early stages of decomposition (Musvoto *et al.*, 2000). However, the increase of P leaching reported here at the last stages

of decomposition period which synchronized with the onset of the rainy season had also been observed in other studies (Blair, 1988; Tripathi and Singh, 1992).

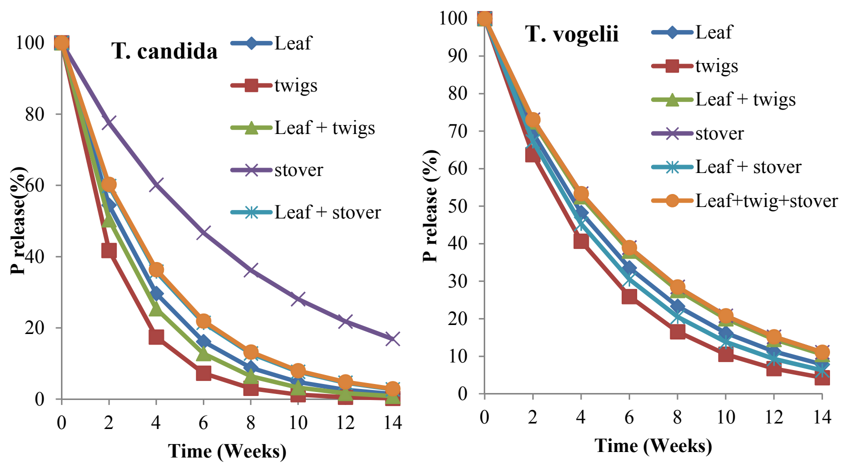

Figure 4: Modeled P release pattern from *T. vogelii* and *T. candida* and their mixtures with maize stover

Table 5 : Parameters of the P release pattern for *T. vogelii* and *T. candida* plant residues

Species	Treatment	k (wk^{-1})	95% CL	t_{50}	t_{95}
T. vogelii	Leaves	0.18	0.14-0.22	3.81	16.48
	Twigs	0.23	0.16-0.29	3.08	13.33
	Leaves+twigs	0.16	0.11-0.21	4.30	18.63
	Leaves+stover	0.20	0.17-0.23	3.50	15.15
	Leaves+twigs+stover	0.16	0.12-0.20	4.41	19.11
T. candida	Leaves	0.34	0.21-0.40	2.04	8.82
	Twigs	0.44	0.23-0.65	1.59	6.86
	Leaves+twigs	0.34	0.28-0.40	2.02	8.75
	Leaves+stover	0.26	0.22-0.30	2.70	11.67
	Leaves+twigs+stover	0.25	0.22-0.29	2.74	11.86
	Maize stover alone	0.16	0.11-0.20	4.41	19.11

The significance of fit for all the treatments was $p<0.0001$

Conclusion and recommendations

From the current study, it can be concluded that the *Tephrosia* fallow biomass alone decomposes considerably faster attaining their half-life within 2 – 3 weeks and over 95% within 8 – 25 weeks. Mixing Tephrosia residues with maize stover significantly slowed down the decomposition rate. Based on these results the fresh leaves or twigs or mixture of leaves and twigs of *T. candida* and *T. vogelii* can be considered of high quality litter and may be applied as green manure to short duration crops such as maize.

Meanwhile, the accelerated decomposition and nutrient release of *Tephrosia* fallow biomass may limit its potential for long term build-up of soil fertility. Results from this study have added to knowledge on the quality, decomposition and nutrient release patterns of *Tephrosia* residues and how to tailor the application of *Tephrosia* biomass in cropping systems and Agroforestry for improved nutrient synchronization in Malawi.

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Soil properties and crop yields under residues management of planted fallows on ultisols in Cameroon

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Abstract

In order to evaluate the effect of residues management of *Sesbania sesban* and *Mucuna utilis* planted fallows on soil properties and maize grain yields, an experiment was conducted over three consecutive years at two locations (Minkoameyos in the semi-deciduous forest zone and Ntui in the forest-savannah - transition zone) in central Cameroon. The experimental layout was a randomized block design made of eight treatments namely T1 : natural fallow with residue burn (NFB), T2 : natural fallow with residue incorporated in the soil (NFI), T3 : natural fallow with residue retained (mulching) (NFM), T4 : *Mucuna utilis* fallow with residue incorporated (MFI), T5 : *Mucuna utilis* fallow with residue retained (mulching) (MFM), T6 : *Sesbania sesban* fallow with residue incorporated (SFI), T7 : *Sesbania sesban* fallow with residue retained (mulching) (SFM) and T8 : Maize/groundnut rotation with residue incorporated (MGR). Each treatment was replicated four times. The results show that no treatment could produce relatively more than the first year of the experiment where maize yields were based on 3-4 year-old natural fallow in both sites. However in Minkoameyos, there was a maize grain yields significant difference ($p<0.048$) between treatments in the third year. In Ntui, all the soil properties tested were affected significantly ($p<0.05$) by the treatments at the end of study; while in Minkoameyos significant differences ($p<0.05$) occurred only for pH, calcium, potassium and total acidity. At both sites, *Mucuna utilis* fallow gave the highest productivity index (1.46 in Minkoameyos and 2.65 in Ntui). These results show that *Mucuna utilis* has a potential for improving plant nutrient availability in these soils for the cultivation of maize.

Key words: residues management, *Sesbania sesban*, *Mucuna utilis*, soil fertility, productivity index, Cameroon.

Introduction

In forest, the quantity of biomass after a fallow period can be so much that planting of food crops becomes difficult and sometimes impossible. Consequently the common practice is to slash and burn biomass before planting. For farmers, burning cleans the farms and makes land preparation easy. Ashes from burning increases soil pH, cations and nutriments availability for a short period. Burning also reduces weeds infestation, pests and diseases. However these advantages are realized for a very short period of time since the exposition of soil surface after burning accelerates the process of soil degradation and loss of nutrients by volatization (nitrogen) and leaching (Kanmegne, 2004; Yemefack *et al.,* 2006). Major inconveniences of burning include emission of carboxyde gases which affect climate changes.

Other practices such as application of residues on soil surface (mulching) or their incorporation into the soil have been suggested as alternative to slash and burn (Kuyate *et al.,* 2000; Kumar and Goh, 2000; Tonyé *et al.,* 1997). Incorporated into the soil of plant residues, particularly those from legumes can provide nitrogen required by the subsequent crop and also improve soil fertility in the long term (Kaho *et al.,* 2011; Kaho *et al.,* 2009; Kuyate *et al.,* 2000; Kumar and Goh, 2000). Mulching protects soil surface again runoff and compaction and also helps to control weed infestation (Hauser *et al.,* 2002). However information on the effect of different methods of legume residues management on soil dynamic and crop yields in the humid forest zone are scanty. Furthermore the data on the durability of these systems are not available in this environment where majority of farmers practice slash and burn agriculture. A farming system or practice

that reduces labor and maintains crop yields at similar level as the system of high intensity of labor is likely to be adopted by many small farmers of the tropics.

This study was therefore carried out in two sites of forest zone of Cameroon in order to determine the effect of three methods of residues management of *Sesbania sesban* and *Mucuna utilis* (burn, incorporate, mulching) on crop yields and soil properties. *Sesbania sesban* and *Mucuna utilis* are nitrogen fixing legumes with the following attributes: high growth rate and adaptability to various climatic and soil conditions, rapid multiplication, easily decomposable biomass and compatibility with food crops (no allelopathy effect on cereals) (Hauser *et al*., 2002; Kwesiga *et al*., 1999).

Materials and methods

Study sites

The study was conducted at two sites in central Cameroon at Minkoameyos (a semi-deciduous forest zone, located 3°51' N and 11°26'E, at 700 m at sea level) and at Ntui (a forest-savannah-transition zone, located 4°26'N and 11°40'E, at 560 m at sea level). The climate in both sites is characterized by two rainy seasons (March-June and September-November). The mean annual rainfall varies between 1500 to 1800 mm in Minkoameyos and 1200 to 1500 mm in Ntui. The average annual temperature is 24°C in Minkoameyos and 26°C in Ntui. Soils in both sites are highly weathered and are classified as ultisols according to the soil taxonomy (Soil-Survey-Staff 1992).

The agricultural land use system is a shifting cultivation based on subsistence food crop production. This fallow-based agricultural system (shifting cultivation) is characterized by two years of mixed food cropping, followed by a fallow period of variable duration ranging from 3 years to 10 years. The short fallow vegetation is usually dominated by *Chromoleana odorata* in the semi-deciduous -forest zone and by grass vegetation in the forest-savannah-transition zone.

Experimental design and treatments

The experimental design was a randomized complete block with eight treatments replicated four times per site. The study was conducted for three consecutive years and the treatments applied in each site werer T1 : natural fallow with residue burn (NFB), T2 : natural fallow with residue incorporated in the soil (NFI), T3 : natural fallow with residue retained (mulching) (NFM), T4 : *Mucuna utilis* fallow with residue incorporated (MFI), T5 : *Mucuna utilis* fallow with residue retained (mulching) (MFM), :T6 : *Sesbania sesban* fallow with residue incorporated (SFI), T7 : *Sesbania sesban* fallow with residue retained (mulching) (SFM) and T8 : Maize/groundnut rotation with residue incorporated (MGR) (Table 1).

Table 1: Sequence of treatments applied in the two experimental sites

Treatments	Season I year 1	Season II Year 1	Season I Year 2	Season II Year 2	Season I Year 3
T1 (NFB)	Maize	Natural fallow	Burn + maize	Natural fallow	Burn + maize
T2(NFI)	Maize	Natural fallow	Incorporate + maize	Natural fallow	Incorporate+maize
T3 (NFM)	Maize	Natural fallow	Mulch + maize	Natural fallow	Mulch + maize
T4 (MFI)	Maize + *Mucuna* (4 WAP)	*Mucuna*	Incorporate+ maize	*Mucuna*	Incorporate+maize
T5 (MFM)	Maize + *Mucuna* (4 WAP)	*Mucuna*	Mulch + maize	*Mucuna*	Mulch+maize
T6 (SFI)	Maize+ *Sesbania* (4 WAP)	*Sesbania*	Incorporate + maize	*Sesbania*	Incorporate+maize
T7 (SFM)	Maize + *Sesbania*(4 WAP)	*Sesbania*	Mulch + maize	*Sesbania*	Mulch + maize
T8 (MGR)	Maize	Groundnut	Maize	Groundnut	Maize

4WAP : 4 weeks after maize planting ; NFB : Natural fallow burn ; NFI : Natural fallow incorporate; NFM : Natural fallow mulch; MFI : *Mucuna* fallow incorporate ; MFM: *Mucuna* fallow mulch ; SFI : *Sesbania* fallow incorporate ; SFM : *Sesbania* fallow mulch; MGR : Maize/groundnut rotation

At the beginning of the study (year 1), a natural bush fallow (3-5 year-old) plots were cleared at both sites and residues incorporated into the soil. After land preparation maize (CMS 8501), 2 seeds per hill were planted in all the plots at plant spacing of 0.75 m x 0.5 m.

Mucuna and *Sesbania* seeds were planted on T4, T5, T6 and T7 plots four weeks after maize planting. After maize harvesting in June of year 1, natural fallow, *Mucuna* fallow and *Sesbania fallow* were allowed to grow freely on T1, T2, T3, T4, T5, T6, T7 plots until the next growing season (March, year 2); while groundnut (*Arachis hypogea,* local variety) was sown on T8 plots in the second season (September, year 1).

In March of year 2, natural fallow, *Sesbania* fallow and *Mucuna* fallow (9 months old) were cleaned with cutlass. In T1 plots (NFB), biomass was burnt and ashes incorporated into the soil with hoe. In T2 (NFI), T4 (MFI), T6 (SFI) and T8 (MGR), residues were also incorporated into the soil with hoe. The same activities were repeated at both sites in the third year.

Soil sampling and laboratory analyses

One composite soil sample (from five spots on the diagonals in a plot) was taken at 0-15 cm depth in each site to determine the baseline fertility status of the trial sites at the beginning of the experiment. At the end of the third year, composite soil samples (0-15 cm depth) were similarly collected in each of 64 experimental plots. All the soil samples were analyzed at the IRAD Soil and Plants Laboratory at Nkolbisson (Yaoundé) for pH water, organic Carbon, total Nitrogen, exchangeable cations (Ca, Mg and K), available phosphorus and total acidity (Al+H). Soil reaction (pH) in water was determined in a soil water ratio of 1:1. Organic carbon was determined using the Walkey and Black method and total nitrogen by Kjeldahl digestion method. Exchangeable bases (Ca, Mg, K) were extracted using the percolation method and read using Atomic Absorption Spectroscopy (AAS). Available Phosphorus was determined using the Bray-II method. These methods are described in Pauwels *et al*. (1992) and Anderson and Ingram (1993).

Statistical analysis

Analysis of variance (ANOVA) was used to determine the effects of treatments on maize yields and soil properties. The Student-Newman-Keuls test was used to detect differences between means. These analyses were performed using the SAS statistical package (SAS Institute Inc, 1997).

Productivity index

An index was used to calculate and compare the productivity of new treatments with reference treatment. The productivity index was computed by dividing the average maize yield produced each year by the average maize yield produced in the first year. PI=Average maize yield of each treatment/Average maize yield of the first year

Results and discussion

Evolution of maize grain yields with time

Maize grain yields for each treatment and during the three years of experiment are presented in Figures 1 and 2. At the beginning of the study, maize grain yields were evaluated for each experimental plot on which treatments were applied. There was no significant difference between experimental units in both sites at the beginning of the study. This led to conclude that there was no significant gradient in soil fertility within experimental sites, and all the treatments could be evaluated on the same basis for maize yield as well as for soil properties changes.

The results on Figures 1 and 2 show that no treatment could produce relatively more than the first year of experiment where maize yields were based on 3-4 year-old natural fallow in both sites. This may suggest that the effect of treatments was only effective as from the third year.

In the two sites, there was a decrease in maize grain yields for all the treatments from the first to the third year of study. This decrease in maize grain yields from the first to the third year could therefore be interpreted as a consequence of the short fallow (8-9 months) which has not been able to restore the fertility of soil at the same level as year 1 where maize was sown after a 3-4 years fallow. Similar results were found

in the same region by other authors with *Desmodium distortum*, *Pueraria phaseoloides, Mucuna pruriens* and *Cajanus cajan* (Hauser *et al.,* 2002; Kaho *et al.,* 2004; Tonyé *et al.,* 1997).

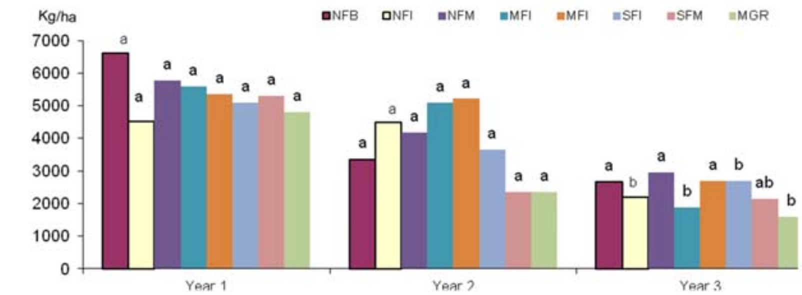

Figure 1: Effect of different treatments on maize grain yields (kg.ha^{-1}) in Minkoameyos

NFB : Natural fallow burn ; NFI : Natural fallow incorporate; NFM : Natural fallow mulch; MFI : *Mucuna* fallow incorporate ; MFM:

Mucuna fallow mulch ; SFI : *Sesbania* fallow incorporate ; SFM : *Sesbania* fallow mulch; MGR : Maize/groundnut rotation

Bars with the same letters are not significantly different at p<0.05.

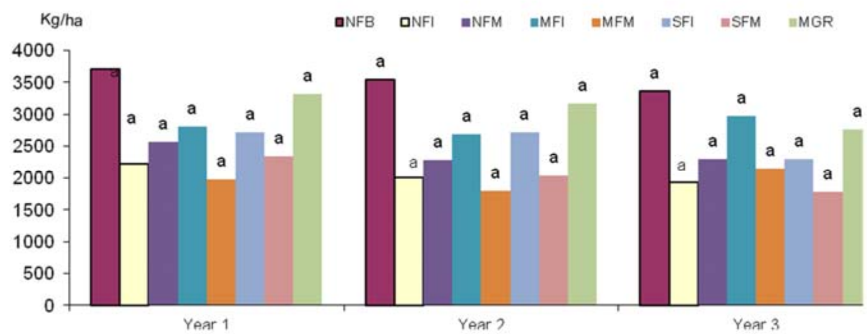

Figure 2: Effect of different treatments on maize grain yields (kg.ha^{-1}) in Ntui

NFB : Natural fallow burn ; NFI : Natural fallow incorporate; NFM : Natural fallow mulch;

MFI : *Mucuna* fallow incorporate ; MFM:*Mucuna* fallow mulch ; SFI : *Sesbania* fallow incorporate ; SFM : *Sesbania* fallow mulch; MGR : Maize/groundnut rotation

Bars with the same letters are not significantly different at p<0.05.

Effect of treatments on maize grain yields

The effect of treatments on maize grain yields were evaluated from the second year to the third year of the study. Figures 1 and 2 present the effect of treatments on grain yields. In Minkoameyos, a significant difference (p<0.048) was observed between treatments in third year (Figure 1). Under natural fallow, T1 (natural fallow burn) and T3 (natural fallow mulch) produced more than T2 (natural fallow incorporated). There was no significant difference between T1 and T3. Similarly, no significant difference occurred

between T6 (*Sesbania* fallow incorporated) and T7 (*Sesbania* fallow mulch). Under *Mucuna*, T5 (Mucuna fallow mulch) produced 43% (2705 vs 1891 kg. ha^{-1}) more maize grain yields than T4 (*Mucuna* fallow incorporated).

The lowest yields obtained on T8 plots (maize/groundnut rotation) at both sites may be attributed to the difference in the quantity of vegetal biomass incorporated in soil during cropping. In fact, natural fallow, *Sesbania* fallow and *Mucuna* fallow plots could produce more biomass than T8 plots. This shortage of incorporated biomass may result to a rapid deterioration of soil properties in T8 due to continuous cultivation and resulting exposure of soil surface to heavy showers at the beginning of each cropping period.

The significant increases in maize grain yields in T5 (*Mucuna* mulch) in the third year indicates that the effect of *Mucuna* leaf mulch had residual effects and hence, was cumulative over the seasons. This suggests that the synchronization process of nutrients release from *Mucuna* prunings with plant uptake could play an important role for greater efficiency of this technology. Indeed, the absence of significant treatment effect on N (Table 2) and the resulting increase in crop yield implies that N mineralized from the plant biomass was immediately used for crop growth. Hence, the increases in maize grain yields on these soils with very low N content. It has been well established that the quality, quantity, timing and mode of application of organic materials would play important roles in better nutrient management strategies (Cobo *et al*. 2002; Palm 1995). This is in line with finding of Tonye *et al*. (1997) in the forest zone of Cameroon who found that *Cajanus cajan* was efficient in the third year in improving maize grain yields in Minkoameyos site. Elsewhere in the Adamaoua Region of Cameroon and in Zambia, Satterle *et al*.(2009) and Kwesiga *et al*.(1999) found that *Entada abyssinica* and *Sesbania sesban* prunings have significantly improved maize grain yields in the first year of their incorporation into the soil.

In Ntui, no significant difference was observed among treatments during the three years of study (Figure 2). However, in *Mucuna* plots (T5 and T6) a tendency in increase in maize grain yields was observed from the second year to third year; 11% (2971 vs 2683 kg ha^{-1}) and 19% (2149 vs 1806 kg ha^{-1}) for T5 (*Mucuna* fallow mulch) and T6 (*Mucuna* fallow incorporated) respectively.

During the three years of study, Minkoameyos site was more productive (5387 kg.ha^{-1}) than Ntui site (2711 kg ha^{-1}) in the first year; and 3855 kg ha^{-1} and 2895 kg ha^{-1} respectively for the general overall mean of the three years. This difference is hard to explain because there was no significant difference between chemical soil properties of the two sites at the beginning of the study. However, a small difference exists between the two sites as far as climatic conditions concern (see section study sites). Some physical soil properties could have played a role on the productivity of the two sites since the soil of Minkoameyos is more clayed than Ntui soil (Kotto-Samé 1983; Mimbe 1985). However, no analysis was done for physical properties in this study to confirm this assertion.

Effect of treatments on soil chemical properties

Soil chemical properties were analyzed at the beginning and at the end of study in order to evaluate the effect of treatments on soil properties of the two sites. One representative sample from each study site was analyzed at the beginning of the study; while at the end, soil samples were analyzed from treatment plots. Tables 2 and 3 present the results of these analyses.

In Minkoameyos, significant differences occurred between treatments for soil pH ($p<0.0001$), Ca ($p<0.0061$), K ($p<0.0004$) and total acidity ($p<0.027$) (Table 2). In Ntui, apart for soil pH, all the soil properties tested were significantly influenced by treatments with $p<0.001$; $p<0.031$; $p<0.0023$; $p<0.0001$; $p<0.001$; $p<0.0099$ and $p<0.016$ for C, N, P, Ca, Mg, K and Al+H respectively (Table 3)

Table 2: Soil chemical properties (0-15 cm) before and at the end of study in Minkoameyos

Treatment	pHwater	C%	N%	P(ppm)	Ca (cmol/kg)	Mg(cmol/kg)	K(cmol/kg)	Al+H(cmol/kg)
Before	5.4	1.82	0.16	3	2.81	1.25	0.27	/
At the end								
NFB	6.35a	2.14a	0.19a	5.95a	4.51a	1.6a	0.5a	0.21b
NFI	5.77b	2.22a	0.2a	5.05a	3.19b	1.24a	0.26b	0.22b
NFM	5.44b	2.15a	0.2a	5.46a	2.72b	1.24a	0.18b	0.22b
MFI	5.62b	2.16a	0.19a	4.49a	2.86b	1.28a	0.26b	0.24b
MFM	5.43b	2.18a	0.19a	5.07a	2.48b	1.0a	0.2b	0.24b
SFI	5.57b	2.01a	0.19a	3.39a	3.12b	1.0a	0.14b	0.23b
SFM	5.52b	2.2a	0.18a	6.69a	2.59b	1.35a	0.2b	0.25b
MGR	5.32b	1.88a	0.18a	3.99a	1.89b	0.81a	0.13b	0.41a

NFB : Natural fallow burn ; NFI : Natural fallow incorporate; NFM : Natural fallow mulch; MFI : *Mucuna* fallow incorporate ; MFM: *Mucuna* fallow mulch ; SFI : *Sesbania* fallow incorporate ; SFM : *Sesbania* fallow mulch; MGR : Maize/groundnut rotation
Means with the same letters in the same column are not significantly different at p<0.05

Table 3: Soil chemical properties (0-15 cm) before and at the end of study in Ntui

Treatments	pHwater	C%	N%	P(ppm)	Ca (cmol/kg)	Mg(cmol/kg)	K(cmol/kg)	Al+H(cmol/kg)
Before	5.5	1.66	0.10	4.00	2.30	1.17	0.51	/
At the end								
NFB	6.29a	1.34a	0.097b	4.27ab	2.68a	1.07a	0.57a	0.13b
NFI	6.24a	1.43ab	0.101b	3.21ab	2.13bc	0.44b	0.43ab	0.26a
NFM	6.03a	1.36ab	0.096b	3.20ab	2.012bc	0.43b	0.4ab	0.20ab
MFI	5.97a	1.44a	0.106a	5.02a	2.37ab	0.5b	0.43ab	0.20ab
MFM	6.05a	1.35ab	0.097b	2.99b	1.91bc	0.5b	0.48ab	0.23ab
SFI	6.04a	1.43a	0.105a	4.04ab	2.24b	0.59b	0.47ab	0.22ab
SFM	6.09a	1.38ab	0.096b	2.51b	2.0bc	0.4b	0.35ab	0.23ab
MGR	5.99a	1.27b	0.087c	2.88b	1.75c	0.34b	0.32b	0.29a

MFI : *Mucuna* fallow incorporate ; MFM: *Mucuna* fallow mulch ; SFI : *Sesbania* fallow incorporate ; SFM : *Sesbania* fallow mulch; MGR : Maize/groundnut rotation
NFB : Natural fallow burn, NFI : Natural fallow incorporate, NFM : Natural fallow mulch; Means with the same letters in the same column are not significantly different at p<0.05

In both sites, the highest values of pH and Ca were recorded on T1 (natural fallow burn). This increase in pH and Ca was followed by a significant decrease in total acidity in the same plots and its increase in T8 (maize groundnut/rotation). This suggests that ashes from burning and incorporated into the soil have therefore improved nutrients availability as shown by previous studies (Yemefack *et al*., 2006; Tonyé *et al*., 1997). The increase in total acidity on T8 plots (maize/groundnut rotation) may probably be due to continuous cropping. Similar results were obtained in Nigeria under maize/cassava rotation and in Cameroon under maize/soybean rotation (Juo *et al*., 1996; Kaho *et al*., 2004).

For N, significant differences were observed in Ntui; with the highest values obtained on plots where residues were incorporated into the soil (NFI, MFI and SFI). Elswhere, Ladd *et al*. (1994) and Powlson *et al*. (1987) also observed the highest values of N and C in plots where residues were incorporated or applied on soil surface compared to plots where residues were burnt. In the same site (Ntui), under *Mucuna* and *Sesbania* treatments, plots where residues were incorporated had higher N concentration than plots where residues were mulched. Under residues incorporated, T3 (*Mucuna* incorpore) and T6 (*Sesbania* incorpore) had higher N concentrations than T2 (Natural fallow incorporate). Paradoxically, the significant increase in N concentrations (Table 3) in Ntui was not followed by a significant increase in maize grain yields as observed in Minkoameyos. This suggests that in Ntui conditions, N mineralized from plant biomass was not immediately used by maize crop for its growth and development.

Productivity index of each system

A productivity index of each system was calculated in order to identify the most productive system compared to slash and burn system. The productivity index of each system is presented on Table 4. In the normal shifting cultivation system, maize is cropped once and the piece of land is left to fallow after all the associated crops are harvested in one or two years. The results of Table 4 show that *Mucuna* fallow produced the highest productivity index in both sites; 1.46 in Minkoameyos and 2.65 in Ntui. These results show that *Mucuna* fallow system could be a suiTable alternative to shifting cultivation.

Table 4: Productivity index of soil management systems (Average maize yield of each treatment/Average maize yield of the first year)

Soil managemen t system	Minkoameyos Year1	Year 2	Yera 3	Total	Ntui Year1	Year 2	Year 3	Total
NFB	1	Fallow	Fallow	1	1	Fallow	Fallow	1
NFI	-	0.62	0.49	1.11	-	1.3	2.23	2.53
NFM	-	0.83	0.41	1.24	-	0.74	0.71	1.45
MFI	-	0.77	0.55	1.32	-	0.84	0.84	1.68
MFM	-	0.94	0.35	1.29	-	1.23	1.42	2.65
SFI	-	0.96	0.50	1.46	-	0. 66	0.79	1.45
SFM	-	0.67	0.50	1.17	-	1.01	0.84	1.85
MGR	-	0.43	0.40	0.83	-	0.75	0.65	1.4
	-	0.43	0.29	0.72	-	1.16	1.01	2.17

Conclusion

The results of this study indicate that, in semi-deciduous - forest zone (Minkoameyos), the different modes of residue management of planted fallows had a significant effect on maize grain yield as from the third year; while in forest-savanna-transition zone (Ntui), no significant difference was observed between treatments. In both sites, *Mucuna* fallow had the highest productivity index compared to natural fallow and *Sesbania* fallow. This therefore suggests that *Mucuna* has a potential for improving plant nutrients

availability in these soils. This leguminous shrub could constitute an important source of nitrogen for maize production for small farmers of the study zones. However, one of the constraints of the adoption of "residue incorporate" system could be extra labor to incorporate residue into the soil.

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Soil fertlity improvement using crop residues and azolla for sustianable production of rice and fish in irrigated rice-fish farming system in the Lake Victoria basin of Kenya

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Abstract

A balance, equiTable and sustainable food supply to the rural farmer, local market and export can only achieved, if potential resource productivity is addressed. An experiment was set up in Lake Victoria basin, West Kano Irrigation Scheme (WKIS) targeting to increase both water and land productivity through poly-culture of rice and fish. It also explores un-utilized, cheap and readily available resources into increasing the culture yields from the present. The experiment with six treatment combinations and control was laid in Completely Randomized Design (CRD) replicated four times. The treatments consisted of two levels of commercial Urea, at 48 &72 kg N/ha in combination with two organic inputs; Nitrogen bio-fixer azolla at 2 ton/ha and rice straw at 3 ton/ha and fish culture. Results showed that application of azolla at 2 ton/ha+ urea, 72 kg N/ha+ Fish and that of Urea 72 kg N/ha+ Fish gave significant increase in plant height of 25.9% and 15.8% respectively compared to control. The former treatment gave the highest rice yield 4.16 ton/ha. It was also evident that yields from two azolla containing treatment did not differ significantly ($P \leq 0.05$) from each other despite having different levels of commercial urea. Fish potential in rice nutrient inputting was explained by experiment i.e. there is significant ($P = 0.05$) increase in rice yield in treatment with fish as the only nutrient input. Influence of other treatment to fish growth in the culture was also investigated. Isolation of fish from other rice nutrient sources gave the highest fresh body weight yield 134.7 kg/ha. The fish yields of the latter treatment was no significantly ($P \leq 0.05$) difference to that of 2 ton azolla +48 kg N/ha Urea which yielded 131.0 kg/ha.

Introduction

Agriculture is the backbone of Kenya's economy. Its dominance is indicated by several factors including contributing 24.0% of GDP (year 2007); generating over 60% of foreign exchange earnings; providing employment to over 70% of the population; providing raw materials to about 70% of all industries and providing over 45% of the annual government budget. The main goals of the sector are to provide food security, raw materials for industry, employment and to generate foreign exchange earnings (GoK, 2007). Fresh water fisheries account for almost all of annual national production and almost all fisheries production derives from Lake Victoria. The Lake has the highest concentration of fishermen (mainly small-scale). In the year 2000, the total catch landed by approximately 33,037 fishermen using 10,014 vessels was 192,738 t valued at KES 7,468,968,000.The lake accounts for about 92% of the total fish production in the country. Recent disputes in the fish-rich areas of Lake Victoria for instant Mighingo area deprives Kenya of its potential fisheries production and lesson should borrowed from Japan experience during the Second World War. In Japan, problems of food supplies during the Second World War stimulated extensive fish culture in paddy- fields (Kuronuma 1954).The latter case, coupled with natural and artificial decay of fish population, influenced by animals and human activities calls for stimulation off-lake culture of fish. According to Tamura (1961) fish culture in paddy- fields was introduced into south-east Asia from India about 1500 years ago. However fish production from aquaculture in Africa is still insignificant at the global scale and according to the FAO (2004) and statistics from FISHSTAT (FAO, 2006a; FAO, 2006b), the continent contributed only 1% to the total world aquaculture production. Currently the dominant aquaculture production systems in Africa, particularly in Sub- Sahara Africa (SSA) are earthen ponds. It is only of late that the government of Kenya (GoK) through economical stimulus package (ESP) rolled out

Kshs. 1.12 billion programme funded by treasury targeting construction of 28,000 earthen ponds in140 constituencies (GoK, 2010).This should be complemented by exploring other potential production systems such as paddy-fields. Paddy-fields are potential fishponds since in its aquatic phase the rice field can produce a crop of fish. The use of rice fields to grow rice and raise fish concurrently or rotationally is one way of increasing productivity of paddy-fields. It is generally accepted that integrated rice- fish farming often increase rice yield and produce fish while using the same resource based of land, water, fertilizer, and labour. The accessibility of rice farming to the rural poor, and the fact that little extra capital investments are required to modify rice field for rice-fish culture, therefore farmers needs awareness on compensatory income gained despite losing part of their rice-field to pond construction. Rice-fish farming is therefore relevant to agricultural development plan of increasing productivity, framer's income and improving nutrition of the rural population. Globally Inorganic fertilizer required to increase rice productivity of small scale resource- poor farmer remain an expensive commodity. In response an experiment was set up in West Kano Irrigation Scheme (WKIS) in which low cost rice nutrient sources were utilized, they included; rice straw, azolla, and fish in contrast to high cost commercial urea-46%N fertilizer. The experiment capitalizes on two symbiotic relationships, rice-fish symbiosis where rice benefit from; urea-rich fish droppings, pest control and soil physical properties improvement and on the other hand fish benefit on physical protection and attraction of food-insect. Azolla is a genus of small water ferns of the *salviniaceace* family commonly growing in paddy-fields. The plant is of particular interest to agriculture because blue-green algae *Anabaena*- Azolla present in cavities in the leaves and are capable of assimilating atmospheric nitrogen. Symbiosis based on this nitrogen fixation, the fern utilizing nitrogen from the algae and algae benefiting by mineral and physical protection from the fern. The potential of using azolla in rice cultures as a source of nitrogen is well documented and based on studies done mainly in china and other Asian countries (Lejeune *et al.,* 1999).Rice straw though cheap nutrient source may be expensive depending on its quality and time of incorporation. Nitrogen is immobilized by microbes and often inhibits the growth and N uptake of paddy rice if C: N ratio is high beyond threshold values.

Materials and methods

The on -farm experiment was carried out at West Kano Irrigation Scheme (WKIS) Nyando district, Nyanza province, Kenya. The farms are owned by small scale farmers who usually grow a crop of maize and legumes, besides having rice-fields within the irrigation scheme. The site lies between 00 6'S and 00 12'S latitude and 34 48' E and 34 57'E longitude and at altitude of 1137 m. It receives average annual rainfall of about 1100mm which is distributed as long rains from March to early June and short rains from September to December. The six treatments experiment was laid out in a Completely Randomized Block Design (CRD) replicated four times. The treatments comprised of; Urea at 72 kg N/ha +Fish (T1), Urea at 72 kg N/ha +2ton/ha azolla incorporation +Fish (T2), Urea at 48 kg N/ha +2 ton azolla incorporation +Fish (T3), Urea at 72 kg N/ha +3ton/ha straw incorporation +Fish (T4), Urea at 48 kg/ha +3ton/ha rice straw incorporation + Urea 48 kg N/ha+ Fish (T5), Fish as the only input (T6), and a control (T7). Six treatment plots and a control, each measuring 5m by 5m were constructed. Each plot had elevated dikes with base of 0.6m, top width 0.4m and height of 0.4m having separate screened water inlets and outlets. The plots were physically modified to provide refuge for the fish by constructing peripheral trenches each with an area of 5m^2 and a depth of 0.5m.The plots were ploughed, flooded and puddling followed prior transplanting of rice. Rice straws and azolla green manure were incorporated to the soil 2 weeks to rice transplanting. IR 2793 -80-1 seeds were germinated and seedling managed for 30 days. Rice seedlings were transplanted from the nursery to experimental plots at 35 days after seeding (DAS) and at spacing of 25 cm between the rows and 10cm within the rows, with 2 seedlings per hill. The seedlings were allowed to establish at a shallow water level of less than 5cm to allow anchoring and then raised to 25 cm on the day of fish stocking (DFS) 14 days after transplanting (DAT) at a rate of 6000 fingerlings per hectare. The average weight of the fingerlings at stocking was 15.4 ± 0.6g. During the experiment the fish in the rice-fish culture received supplementary feeding of rice bran at 3% of body weight. The feeding was started 1day after stocking and was provided manually into two equal daily portions at 9.00hrs and 15.00hrs until 98 days after fish stocking. Nitrogen fertilizer Urea was applied manually, placed at 5cm below soil surface in three parts to

give the total prescription in each urea-containing treatments. This was according to Rao *et al*. (1971), who concluded that a transplanted rice crop needs half of the total quantities of N fertilizer at transplanting time then 25% about 3weeks later and the balance at pinnacle initiation. During fertilization flooded field were drained and fish made refuge in trenches. Water physical and chemical properties were monitored during the culture period to ensure fish growth was not inhibited, the condition are given in Table

Table 1: SuiTable physical and chemical properties in the two rice cultures

Parameter physical/chemical	Rice-monoculture	Rice-fish culture
Depth of water	- Minimum; above soil field capacity. Ideal; continous flooding starting at 3cm depth gradually increasing to maximum of 15cm 60 days after transplanting and complete draining 2 weeks to harvest	-15 cm at transplanting and 25 cm after stocking with fish
Water temperature	- Water and soil temperature of up to 40 ^{O}C with diurnal range less than 10 Oc.	- 25-35 ^{O}C with diurnal range of less than 10 ^{o}C; 6.5-9.0 (Boyd 1979)
Water pH	- Neutral to Alkaline	- Neutral to Alkaline
Oxygen/dissolved oxygen (DO)	Important during seedling stage for development of radicles	-Preferably near saturation or saturation level (5.0-7.5ppm) depending on temperature.

Rice performance was monitored in terms of plant height, productive tillers/m2, straw yield, grain yield, N in grain sink and N in straw all at harvest. Pre-cultivation and post harvest soil nutrient status was monitored by soil analysis for pH, total Carbon, total Nitrogen, and available OlsenP. Characterization of soils and rice tissues was performed using the following laboratory analyses; soil carbon was determined by Walkley and Black sulphuric acid-dichromate digestion followed by back titration with ferrous ammonium sulphate (Nelson and Sommer, 1982). Total N determined using Se, $LiSO_4$, H_2O_2 and conc. H_2SO_4 digestion (Anderson and Ingram, 1993) followed by colorimetric calibration. Soil pH was determined using a glass electrode pH meter at 1: 2.5 soil: water ratio (Okalebo *et al*., 2002).The available P was extracted by the Olsen method as described by Okalebo *et al* (2002) .Rice grain, rice straw and Fish fresh weights was determined using digital balance and extrapolated to yield/ha is conversion;

Yield/ha = Plot yield* Hectare size/plot size

Results

Azolla at 2 ton/ha+ urea 72 kg N/ha + fish (T2) and that of Urea 72 kg N/ha+ Fish (T1) gave significant increase in plant height of 25.9% and 15.8% respectively compared to control (Table 2). On the contrary application of 3 ton/ha straw+ urea 48 kg N/ha+ Fish (T5) significantly gave 21% decrease on plant height compared to control. The remaining three treatments had no significant difference on plant height as compared to control. T1, T2, and T3 gave significantly higher productive tillers/m^2 compared to control while other three were of the contrary. Significantly highest yield was recorded in treatment with 2 ton/ha azolla +Urea 72 kg N/ha+ Fish (T2) yielding 4.160 ton/ha but this yield do not differ significantly to that of 2 ton/ha azolla + Urea 48 kg N/ha+ Fish (T3). Urea 72 kg N/ha+ Fish (T1), Urea 72 kg N/ha+ 3 ton/ha straw+ Fish and that Fish alone were significantly lower in yield compare to the latter two treatments, also significant difference in yield existed within the three treatments and also when each treatment is compared to control. Nitrogen assimilated rice grain sink differed significantly within all treatments and also when each treatment is compared to control. Nitrogen content in straws had the same trend as that in rice grain as influenced by the six treatments, only that the value in straw was approximately half that of the grain. Plant height indicated positive correlation with both grain-N and straw-N. Post-harvest soil status data are presented in Table 3.0.The data shows that only two treatments; urea 72 kg N/ha +Fish and

urea 48Kg N/ha +3 ton/ha straw +Fish had significant increase in pH compare to control but the former had the highest value 6.68.The four other treatment neither differed significantly within the treatments nor when compared to control. Organic input of either azolla or straw yielded significant increase in soil organic carbon as compared to control or those without carbon rich organic input. Control (T7) had the least decline in available phosphorus when compared to all treatments. All the two treatments with azolla in the combination had the highest residual nitrogen and existed no significant difference between the two treatments. Low post-harvest soil Nitrogen status was registered in T1 despite having high input of commercial urea fertilizer. Fish alone (T6) had significantly higher post-harvest soil Nitrogen compared to control. All the soil treatments expect that of Urea at 48 kg N/ha +2 ton/ha Azolla had significant (P=0.05) lower fish yield when compared to fish alone treatment. Treatment Urea at 72 kg N/ha with fish (T1) had the lowest fish yield. Comparing the two Urea levels at 72 kg N/ha and 48 kg N/ha, the higher dose of Urea had negative effect on yields of fish but to less extend on combination with Azolla.

Table 2: Mean effects of treatment combination on rice growth components and yield

Treatment	Ht (cm)	Productive tillers/m^2	Grain yield ton/ha	Grain-N kg/ha	Straw-N kg/ha
T1	104b	302c	3.670b	51.00b	20.900a
T2	133.2a	308.5b	4.160a	53.30a	21.175a
T3	84.5c	235.7a	4.140a	44.18c	17.750c
T4	85c	219.5f	3.505d	32.80d	18.900b
T5	71d	194.5g	2.120f	23.25g	12.750d
T6	89.2c	230e	3.980c	26.75f	12.925d
T7	89.75c	233.6d	3.070e	27.83e	13.050d
LSD (0.05)	5.533	2.13	0.0859	0.946	0.5575
SED	2.634	1.001	0.0409	0.450	0.2654

Values in the column followed by a common letter are significantly difference at (p≤0.05)

Table 3: Post-harvest soil nutrient status after treatment application

Treatment	Soil pH	Soil Carbon (%)	OlsenP (mg/kg)	Soil Nitrogen (%)
T1	6.683a	2.397d	55.82a	0.158d
T2	6.115c	3.000b	45.54e	0.345a
T3	6.145c	3.745c	47.86d	0.323a
T4	5.963d	3.990b	51.36c	0.251b
T5	6.328b	4.075a	51.00c	0.167c
T6	6.003d	2.412d	57.84b	0.179c
T7	5.988d	2.397d	59.63a	0.104e
LSD (0.05)	0.1351	0.0504	0.851	0.0302
SED	0.0881	0.02399	0.405	0,0143
LSD (0.05)	0.1351	0.0504	0.851	0.0302

Values in the column followed by a common letter are significantly (p≤0.05) difference

Table 4: Yield of fish as affected by other paddy-field nutrient input

Treatments	Fish yield (kg/ha)
1	104.0c
2	114.7d
3	131.0a
4	108.3cd
5	121.0b
6	134.7a
LSD (0.05)	7.80

Values in the column followed by a common letter are significantly difference at ($p \leq 0.05$)

Discussion

Plant height may be determined by the genetic constitution of the cultivar. Additionally plant height may be influenced by external factors, including status of soil fertility. The later is testified by the experiment results in which higher application of Nitrogen resulted to taller rice crop than in low or no Nitrogen application. A combination of azolla, urea and fish posted higher grain yields even at low N-rates of commercial urea this was evident when the results showed no significant difference ($P \leq 0.05$) between two urea rates N at 48 kg/ha and at 72 kg/ha in two treatment combination T2 and T3.The findings subsets (Watanable, 1981; Ladha *et al.*, 1992), in which incorporation of two crops of azolla led to rice yield increase by about 20-42% accompanied by improvement of soil structure. The yield increase is due to decomposition of the incorporated azolla releasing nitrogen for the rice crop (Liu, 1979). Bohlool *et al.*, (1992) showed that azolla fixes N which is made available to rice upon death and decay. According to IRRI (1990), a combined rice –Azolla-fish culture protects the environment and increases the farmer's income through fish production and reduces fertilizers and pesticides. Yields of the treatments combination (T4&T5) with straw incorporation were low; this is attributed to immobilization of nitrogen by soil microbe. This had been noted by Bird *et al.*, 2001; immobilization of fertilizer nitrogen and crop residue N is one of the most critical aspects affecting long-term fertility in rice. Bird *et al.*, (2001) showed that increased retention of N in the residue incorporated plots contribute to increased plant N availability in the second crop cycle in a fertilizer ^{15}N study. This can be confirmed by setting up residual experiment in the second season. Although the low N organic compounds will release ammonium ions, they decompose slowly under anaerobic conditions, so only substances with higher N percentages will release appreciable amounts of ammonium over a period of few weeks (Russell,1989).The significant ($P \leq 0.05$) higher rice yield in treatment with fish alone compare to control can explained. This was most likely due to improved nutrient availability resulting from the excrements produced by fish as well as aeration of the growth medium as the fish move around. Fertilizer requirement is reduced with the introduction of fish (Gupta *et al*, 1998) and a rice field has a higher capacity to produce and capture nitrogen than one without fish. Assimilation of nitrogen in grain and straw is dependent on the N-sources applied to the soils. The nutrient replenishing idea can be explained taking reference to control in which during the experimental season 40.88Kg N was siphoned out without addition of nitrogen. Long term fertility trail in tropical and temperate region have shown that about 50Kg N/ha is absorbed by each rice grown without addition of fertilizer (Koyama and App, 1979). Singh showed that 32-52 Kg N/ha was absorbed by the rice crop in the field without N application. This is a range within which the experiment results fits. Considering that on average fish input for each treatment was approximately 90 kg (15 g×6000 fingerling/ha), there was a net gain in fish weights in all treatments at time of harvesting (98 DAS). The gains seem to have been influenced by environment, food supply or both. Little can be clearly explained in this experiment on the two factors and also on their interaction effects. For instant the insignificant ($P \leq 0.05$) decline in treatment T3 could be due to better environment i.e. less Urea, Azolla

shading, and pH stabilization or N-rich food source Azolla. Isolation of the two factors is subject to research experiment. Addition of ammonia to the soil is always accompanied increase in soil pH. Hydrolysis of ammonia liberate OH- ions responsible for increase in soil reaction, this explain the value in treatment T1. Treatments with OMs straw or azolla exhibited a buffering effect and there was no significant difference at ($P \leq 0.05$) when compared to control, mainly due weak organic acid produced under anaerobic decomposition which tends to counter the increase in soil pH. Urea rich fish droppings was confirmed by increase in soil pH in treatment T6 fish alone compare to control, due urea dissociation followed ammonium formation with hydroxyl ion liberation. OMs inputs addition to soil increased soil carbon was confirmed by significant increase in soil total carbon in treatment T2, T3, T4&T5 compare to control. Significant ($P \leq 0.05$) higher post-harvest Olsen P in control explain the importance of synergic effect of soil N on uptake of phosphorus i.e. increase in available N and its higher subsequent uptake increases uptake of phosphorus, and vice versa is true. This means absence of nitrogen input in control resulted low available nitrogen to boost phosphorus uptake. Azolla application posted the highest residual nitrogen testifying its nitrogen bio-fixing.

Conclusion

Rice-Azolla-fish culture exhibits high potential in increasing resource productivity and environmental conservation. Azolla a cheap nitrogen source, on application showed improvement of soil nutrient status and rice yield. Straw application was accompanied by poor yields, due to N immobilization by microbes to decompose the carbon-rich material, and its viability as nutrient source is to be assets in results residual experiment. There is need to culture fish beyond rice harvest time 98 days after transplanting (DAT) probably for two season to achieve appreciable fish sizes by local who are used huge-sized from the Lake.

Recommendations

The experiment testify viability of rice-fish culture and recommends Urea at 48 N kg/ha + 2ton Azolla +fish (T3) and fish alone (T6) for resource poor farmers of kano plains.

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THEME 9: AGRONOMY AND ECOSYSTEM RESTORATION

Tillage and crop rotation effects on structural properties of two sandy clay loam soils in Zanyokwe Irrigation Scheme, South Africa

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Abstract

Intensive tillage and monoculture crop production practices have adversely affected soil structural stability in most of the arable lands in South Africa. Crop production practices that enhance soil organic matter (SOM) contributes to soil structural stability through strengthening the binding of mineral particles by organic bridges and enhancing water repellence of the soil aggregates. Two soils of contrasting mineralogy in Zanyokwe Irrigation Scheme (ZIS) were used to evaluate the impact of tillage and rotational cover cropping on soil aggregate stability and stability index (SI) under irrigated maize (*Zea mays* L) production. A split-plot arrangement of the treatments in a randomized complete block design was used with tillage as the main-plot and crop rotations as subplots. Conventional tillage (CT) was compared to no-till (NT) and crop rotations were maize-fallow-maize (MFM), maize-wheat-maize (MWM) and maize-oat-maize (MOM). The impact of tillage and crop rotations on soil aggregate stability and SI were evaluated after 5 cropping cycles. Across tillage practices, MOM rotation significantly increased soil aggregate mean weight diameter (MWD) as determined by fast wetting (FW) compared to MFM and MWM rotations in Lenye and also resulted in higher SI relative to MFM and MWM rotations at both sites. Scanning electron microscope (SEM) revealed that soils under NT and MOM rotation had dense organo mineral coatings and organic bridges than soils under CT and MFM rotation. No till and rotational cover cropping had positive impact on soil structural properties reflecting them as more sustainable options than the current intensive-monoculture based crop production practices.

Key words: tillage, rotational cover cropping, aggregate stability.

Introduction

Over 25 % of soils in the Eastern Cape Province, South Africa are severely degraded. Water erosion is common in smallholder farms while wind erosion affects commercial farming areas. Crusting and erosion on cultivated soils result from aggregate breakdown and detachment of the soil fragments by rain (Le Bissonnais, 1996). Breakdown of soil aggregates is exacerbated by CT operations accelerating the oxidation of organic matter previously protected by soil aggregates thus weakening them (Barnard and Newby, 1999). Further, majority of soils under crops have low organic matter (Barnard, 2000) and low Ca: Mg ratios, both of which enhance soil structural instability and increase the susceptibility of the soils to degradation (Mills and Fey, 2003).

Agricultural practices that improve soil aggregate stability, coupled with increase in soil surface cover, could significantly reduce soil degradation. Soil surface cover as advocated in conservation agriculture (CA) practices reduces the kinetic energy of the raindrops, disruption and detachment of the soil particles (Findeling *et al.,* 2003). This is consistent with findings of Rhoton (2000) who observed higher aggregate stability under NT than CT in a period of 4 years on a Grenada silt loam. Similarly, continuous addition of residues on cropped soils increased the proportion of water sTable soil aggregates in USA (Whalen *et al.,* 2003).

Aggregate breakdown may result from; (i) breakdown caused by compression of entrapped air during rewetting (slaking), (ii) breakdown by differential swelling, (iii) breakdown by raindrop impact, and (iv) physicochemical dispersion due to osmotic stress (Chenu *et al.,* 2000). Methods proposed for measuring these mechanisms are slow wetting (SW) by capillary and fast wetting (FW) (Le Bissonnais, 1996). The FW

simulates a field environment where aggregates are exposed to high intensity rainfall resulting in entrapment of the air while SW simulates situations where aggregates are exposed to low intensity rainfall. The MWD of soil aggregates is eventually used to determine the aggregate stability of the soil.

However, soil aggregate stability analytical methods do not provide a sound basis for soil stability comparisons for samples from a wide geographic area. Amezketa *et al* (1996) proposed the SI, which is a ratio of aggregate MWD determined by FW to MWD determined by SW, as an index for aggregate resistance to slaking. The use of SI allows soil stability comparisons on a scale of zero to one, with a value of 0 indicating complete breakdown of aggregates and unity for no structural change of aggregates with FW relative to SW treatment.

The impact of some CA practices on crop yield and soil chemical properties is extensively documented in South Africa (Smit, 2004; Kotze and Du Preez, 2007) but there is limited information on interactive effects of tillage and rotational cover cropping on soil physical properties, particularly under the semi-arid subtropical areas in the Eastern Cape Province. The purpose of this study was to evaluate the short-term effects of tillage and crop rotations on selected soil structural properties of two sandy soils under irrigated maize production..

Materials and methods

Soils, location and experimental design

The study was carried in Burnshill and Lenye blocks of Zanyokwe Irrigation Scheme (ZIS) (32º 45′ S, 27º 04′ E) in the Eastern Cape Province of South Africa. The Burnshill site was on Arcadia soil form and Lenye on Shortlands soil form (Chromic Luvisol) (Table 1). The area experiences summer rainfall pattern with a maximum in autumn and minimum in winter with mean annual rainfall of 590 mm. Previously, Burnshill was under irrigated NT maize while Lenye site was under CT cotton for a year.

A split-plot arrangement in a randomized complete block design with tillage practices as main plots (8 × 18 m) and crop rotations as subplots measuring (8 × 6 m) was used. The CT treatments involved ploughing (20 cm depth) followed by single disking (10 cm depth) before planting each year. The crop residues were left on soil surface under NT while above ground crop residues were removed under CT. The rotation treatments were MFM, MWM and MOM with a 2 m path to allow for independent use of farm machinery was between plots.

Six soil cores were taken in using a 1.9-cm diameter core sampler for the 0 to 20 cm depth after removal of crop residues from the soil surface in 2005. The cores were sectioned into 0 to 5 and 5 to 20 cm depth intervals, composited according to depth, air dried and sieved (< 2 mm).

Table 1: Selected soil physical and chemical characteristics of the study sites in 2008

Soil characteristic	Burnshill	Lenye
Classification	Arcadia (SA)	Shortlands
	Pellic vertisol (FAO)	Chromic Luvisol
	Pellusterts (USDA)	Palexeralfs
	Medium sub-angular blocky	Strong medium sub-angular blocky
% sand	46	44
% silt	22	26
% clay	32	30
SOC (g kg^{-1})		
MFM	12.2	7.5
MWM	13.0	6.8
MOM	14.5	7.8
Fe (mg kg^{-1})	13	80

Aggregate stability analysis

Aggregate stability samples were taken using a spade (0 - 10 cm depth) and then placed in rigid containers to avoid further breakage of aggregates. Aggregate stability was determined at the end of the study in duplicate and according to methods proposed by Le Bissonnais (1996). The samples were passed between 3 and 5 mm mesh sieves and dried at 40°C for 48 h. Sub-samples were subjected to FW and SW by capillary according to Attou *et al*. (1998). The FW was done by gently immersing soil aggregates in 50 mL deionized water for 10 min followed by drawing the water leaving behind the slaked aggregates. The SW was done by placing aggregates on a filter paper maintained at a matric potential of -0.3 kPa for 30 min and the residual aggregates collected thereafter.

The residual aggregates were then transferred to a 50 μm sieve immersed in ethanol to prevent further disruption of aggregates. Aggregates retained on the sieve were transferred to evaporation dishes and dried at 40 °C for 24 h. The fragment size distribution (FSD) was determined by dry sieving the aggregates with a set of six sieves of 2, 1, 0.5, 0.2, 0.1 and 0.05, mm diameter. Weight of aggregates on each sieve was determined and expressed as a percentage of the initial sample dry mass. Aggregate stability was described using the resulting FSD in the seven granulometric classes and the MWD in mmcalculated as follows:

$$MWD = \frac{\sum_{1}^{7} \overline{x_i} w_i}{100}$$

where x_i was the mean inter-sieve size and w_i is the percentage of soil fragments left in the sieve.

Micro-morphological characteristics of the samples were examined using SEM (Quanta 200 Phillips).

Data analysis

Statistical analysis was done following analysis of variance techniques as outlined by Gomez and Gomez (1984) using the Genstat Release 4.24DE statistical software (Lawes Agricultural Trust, 2008). Significance was determined for all analysis at the 0.05 probability level. Treatment means comparisons were made in accordance with Duncan's multiple range test (Duncan, 1955) using the Mstat C software.

Results

The MWD (average of all tillage and crop rotation treatments) by FW method was higher in Lenye than Burnshill (Table 2). Tillage, rotation and their interaction effects on soil aggregate MWD as determined by FW were not significant in Burnshill ($p \le 0.05$) while in Lenye only crop rotations affected this parameter ($p \le 0.01$). Averaged across tillage treatments, maize-oat rotation resulted in signficantly higher aggregate MWD by FW method compared to MFM and MWM rotations in Lenye.

Across tillage and crop rotations, the MWD by SW method was higher in Lenye than Burnshill (Table 3). Crop rotation significantly affected this parameter in Burnshill ($p \le 0.01$) but not in Lenye. Averaged across tillage treatments, MFM and MWM rotations resulted in significantly higher aggregate MWD relative to MOM rotation. In Lenye, the two-way interaction of tillage × rotation was significant for aggregate MWD determined by SW method ($p \le 0.01$). The MOM rotation resulted in lower aggregate MWD determined by the SW method relative to MFM and MWM rotations under NT while the converse was the case under CT.

The mean SI across tillage and crop rotation treatments was higher in Lenye than Burnshill (Table 4). Tillage had no effect on the stability index (SI) in Burnshill but had a significant effect in Lenye ($p \le 0.05$). No till resulted in a significantly higher SI relative to CT in Lenye. Crop rotations had a significant effect on SI in both sites. The MOM rotation resulted in constantly higher SI values relative to the MFM and MWM rotations at both sites. Generally, Lenye soil displayed higher aggregate MWD values for all the three soil aggregation measurements (Tables 2-4).

Table 2: Effects of tillage and crop rotations on aggregate stability as determined by fast wetting in Burnshill and Lenye

	Site					
	Burnshill			Lenye		
	Tillage (T)					
	NT	CT	Means	NT	CT	Means
Rotation (R)			MWD (mm)			
MFM	0.27	0.25	0.26	0.63	0.47	0.55a
MWM	0.30	0.26	0.28	0.54	0.50	0.52a
MOM	0.28	0.27	0.27	0.78	0.63	0.69b
Means	0.28	0.26		0.64	0.53	
Grand mean		0.27				0.59
ANOVA Probability of greater F parameters						
T	NS			NS		
R	NS			**		
T×R	NS			NS		
CV (%)	9			17		

MWD=mean weight diameter (mm); ** p ≤ 0.01; a, b - means in row and column followed by different letters are significantly different at p ≤ 0.05; NS=not significant; CV=coefficient of variation

Table 3: Effects of tillage and crop rotations on aggregate stability as determined by slow wetting in Burnshill and Lenye

	Site					
	Burnshill			Lenye		
	Tillage (T)					
	NT	CT	Means	NT	CT	Means
Rotation (R)			MWD (mm)			
MFM	0.65	0.52	0.58b	1.05b	0.93a	0.99
MWM	0.60	0.73	0.66b	1.05b	0.91a	0.98
MOM	0.44	0.51	0.48a	0.98ab	1.15b	1.07
Means	0.56	0.62		1.03	1.00	
Grand mean			0.59			1.02
ANOVA Probability of greater F parameters						
T	NS			NS		
R	*			NS		
T×R	NS			**		
CV (%)	18			7		

MWD=mean weight diameter (mm); NS = not significant, *, ** p ≤ 0.05 and 0.01, respectively, means in the same row and column within a location followed by different letters are significantly different at p ≤ 0.05? CV= coefficient of variation

Table 4: Effects of tillage and crop rotations on aggregate stability index in Burnshill and Lenye

	Site					
	Burnshill			Lenye		
	Tillage (T)					
	NT	CT	Means	NT	CT	Means
Rotation (R)						
MFM	0.42	0.50	0.46a	0.60	0.51	0.55a
MWM	0.50	0.37	0.44a	0.51	0.55	0.53a
MOM	0.63	0.53	0.58b	0.79	0.54	0.66b
Means	0.52	0.47		0.63b	0.53a	
Grand mean			0.50			0.56
ANOVA Probability of greater F parameters						
T	NS			*		
R	*			*		
T×R	NS			NS		
CV (%)	18			18		

* $p \leq 0.05$, NS = not significant, means in the same column or row followed by different letters are significantly different at $p \leq 0.05$? CV= coefficient of variation

Scanning electron microscope revealed microstructural differences between aggregates from NT, CT, MOM and MFM in Burnshill and Lenye. Soil aggregates from NT and MOM rotation treatments were coated and glued together by web-like organic structures for Burnshill and Lenye, respectively. By contrast, aggregates under CT and MFM rotation had little organo-mineral coatings or/and web-like structures on their surfaces.

Discussion

Soil aggregate MWD is qualitatively related to aggregate strength and increases with increasing aggregate stability (Muukhom and Kay, 2002). According to Le Bissonnais (1996), MWD can be categorized into the following classes related to soil aggregate stability: < 0.4 mm is very unsTable, 0.4-0.8 is unsTable, 0.8-1.3 is partly unsTable, 1.3-2 is sTable, and > 2 mm is very sTable. Based on the criteria used by Le Bissonais (1996), all crop rotations under NT and CT systems had low aggregate stability as determined by FW which could be classified as very unsTable in Burnshill (MWDs < 0.28 mm) and unsTable in Lenye (MWDs < 0.64 mm) (Table 2). High SOC increases the cohesion of aggregates and relatively higher SOC content under NT compared to CT contributed to more stabilization of soil aggregates under the former compared to the latter tillage practice (Chenu *et al.,* 2000). Water ponding after irrigation in Burnshill and Lenye could be attributed to collapse of unsTable aggregates resulting in surface sealing and physical crust formation.

The less aggregate disruptive forces associated with SW resulted in unsTable (MWDs < 0.62 mm in Burnshill and partly unsTable aggregates in Lenye (MWDs < 1.03) when considered across tillage and crop rotation practices (Table 3). These results indicate that the soils for the three rotations under both tillage practices in Lenye had higher aggregate stability compared to Burnshill as determined by SW. The higher inherent soil stability in Lenye relative to Burnshill is also inferred in their soil structure where Lenye is rated as strong medium subangular blocky and Burnshill as medium subangular blocky (Table 1).

The more organic debris as reflected in higher SOC content under MOM rotation enhanced water repellence of soil aggregates relative to the MFM and MWM rotations in Burnshill and Lenye (Tables 1-4) hence minimises soil aggregate disruption resulting in a greater proportion of large sized aggregates. The

superiority of MOM rotation in improving soil aggregate stability relative to the MFM rotation (Table 2) was further revealed by dense surface coatings with visible organic bridges compared to those under MFM which showed less binding of mineral particles by organic bridges. Aggregates under NT also displayed more binding by organic matter compared to CT. Reduced soil-residue contact under NT minimised organic matter incorporation into the soil under all rotations despite higher plant biomass inputs under MWM and MOM rotations than MFM rotation resulting in similar aggregate sizes all crop rotations in Burnshill.

The stability index (SI) proposed by Amezketa *et al*. (1996) reflects soil stability and Lenye soil displayed relatively higher SI compared to Burnshill (Table 4). The high SI observed under NT relative to CT in Lenye reflects less tillage related mechanical soil disturbance associated with NT compared to CT (Coelho *et al.*, 2000). The high SI for MOM relative to MFM and MWM rotations in both sites could be linked soil aggregate stabilization by SOM due to higher oat biomass decomposition relative to maize and wheat. Lenye soil had greater soil aggregate MWD determined by the two aggregate stability methods and SI relative to Burnshill despite having lower SOM levels. According to Shepherd *et al*. (2001) this could reflect the influence of factors other than SOM on aggregate stability such as soil mineralogy type and the location of organic C in soil aggregates. Reid and Goss (1981) and Karim *et al*. (2003) have shown that Fe oxides contributed to soil aggregate stabilization by strengthening the links between organic matter and soil mineral matrix. Manyevere (2010) showed that the Fe content in Lenye was six times higher than in Burnshill and it is therefore possible that higher Fe content in Lenye was responsible for the observed greater soil structural stability at this site compared to Burnshill (Tables 1-4).

Conclusions

The selected soil structure stability parameters studied were highly influenced by soil organic C quantities and distribution within the profile rather than tillage practices. No consistent trend was observed between tillage practices in relationship to aggregate stability as determined by slow wetting in Burnshill and Lenye probably reflecting the influence of both soil organic C and minerlology on this parameter. However, the positive effect of minimising aggregate disruption with SOC increase was evidenced by higher aggregate SI under MOM compared to MFM and MWM rotations in Burnshill and Lenye. The higher aggregate stability index under NT compared to CT observed in both sites reflected the positive aspect of both tillage and SOC accumulation on minimizing soil aggregate disruption. Overall, NT and MWM and MOM rotations that promoted rapid SOC accumulation hence enhancing soil structural stability relative to NT and MFM rotation.

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The effect of beekeeping on vegetation restoration and conservation of degraded water sources and riverbanks in West Usambara Mountains, Tanzania

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Abstract

This paper examines the effect of beekeeping on vegetation restoration and conservation of degraded river banks and water sources as an alternative conservation approach. Data was collected in two sites, Umba-river bank in Mwangoi village and the water catchment area in Migambo village both of Lushoto District, Tanzania. Methods used for data collection include vegetation assessment through a fine scale survey focusing on the area where beekeeping is carried. Concentric nested circular plots for the larger plot were used with 10% sampling intensity. Data from the forests was summarised and analysed using the excel computer programme, while socio-economic data was subjected to content analysis. The results indicated that over the past three years beekeeping has shown to improve the management of the area and the regeneration of plant species was significantly enhanced. Though the plant diversity of the two pilot areas was relatively low but was better than before the intervention. Moreover, the densities of regenerants are still higher compared to many forests in the Eastern Arc Mountains. Therefore it is recommended that enrichment planting with suiTable tree species suiTable for apiculture be introduced to sustain the ongoing beekeeping activity that promotes conservation of these fragile areas.

Key words: conservation, beekeeping, water sources, riverbanks, west Usambara.

Introduction

General overview

Degradation of water sources and river banks is rampant as people seek to utilize wet areas or irrigable areas for crop production especially in the face of changing climate and fluctuating rainfall regimes (Speranza *et al,* 2010). The continuing vegetation loss and degradation of river banks and water sources however, is an indication of the imbalance between human needs and the capacity of ecosystems to support life. But on the other side it can be a question of institutional arrangement in the whole setting (Mbeyale, 2010). The great challenge remains with natural resources management (NRM) practitioners, policy makers and environmentalists to device different strategies that address adequately both livelihood issues and sustainable NRM. Over the past three years, 2007-2010 a project supported by ASARECA on NRM has attempted to engage the local communities in Mwangoi and Migambo villages, Lushoto district, Tanzania to use beekeeping as a strategy for improving peoples livelihood while promoting vegetation restoration and biodiversity improvement along the degraded Umba River bank and water sources. The beekeeping technology utilises modern beehives namely SUA-ITATOBE-(Sokoine University of Agriculture, Improved Tanzania Top Bar Hive); a technology developed from the Sokoine University of Agriculture in Tanzania. After a positive uptake of the technology by local communities it was found necessary to assess the effectiveness of the introduced technology in the regeneration and restoration of degraded sites where beehives were hanged. The assessment of vegetation in the two selected pilot areas (in Mwangoi and Migambo villages) provides viable indicator for the potentials of beekeeping in addressing livelihoods and environmental conservation in fragile degraded ecosystems.

Objectives

- To determine the biodiversity value of the rehabilitated water sources and river banks resulting from bee keeping intervention
- To assess the intensity of bee keeping on regeneration potential of the sites over the past 3 years

Methodology

The study area

The two ASARECA project pilot areas were located Mwangoi and Migambo vilages, West Usambara Mountains in Lushoto district, Tanzania. The two pilot areas under study are covering an area of about 10 ha each. Their importance as forest areas is increasing due to the ongoing beekeeping activities. The Mwangoi pilot area is still under the Lutheran Church thus the forest area is interrupted by human settlements and agricultural activities leaving the bank of the Umba River (2 ha) for the beekeeping. The Migambo pilot area which is characteristically a catchment area was managed as a farmland until recently when the village government acquired it for conservation as a water source. With difficulties the village government in Migambo strived to maintain the area but fuel wood cutting and grazing were the main setback to their efforts. However, through beekeeping it was possible to do away these human activities including farming, fuel wood collection and animal grazing.

Data collection

Data were collected through a fine scale survey focusing on the area where beekeeping is carried out by hanging beehives. The data collection activity took place in May and July 2010 for Mwangoi and Migambo pilot areas respectively. The first step was a reconnaissance survey to determine and estimate the area under study and to get sketch maps that facilitated layout of plots. Concentric nested circular plots with the radius of 15 m for the larger plot were adopted (De Vries 1986). Given the small area under study, the adopted sampling intensity was 10% so as to acquire data from almost all patches of forest. Therefore, three plots for Mwangoi and four for Migambo each of 0.07 ha, were laid out whereby an objective sapling technique was used to scatter plots at a distance not less than 50 m apart. Life-stages of all trees were counted, measured and identified to genus or species level in each nested circular plot as follows; 2 m radius of the plot - all seedlings (<30 cm tall, > 30 cm but < 1 cm dbh), 5 m radius - all samplings (≥1 cm dbh but < 5 cm dbh), 10 m radius - all sub-adults (≥ 5 cm but < 20 cm10 dbh), 15 m radius - all adult trees with dbh ≥ 20 cm.

These data were used to calculate density, abundance and dominance of different tree species and diversity indices of the two pilot areas. Also, within a 1m x1m quadrant all herbs and grasses were counted and identified to determine their composition and density. The reproductive condition of each identified plants was recorded by observing presence of flower, flower buds/fruits. Transect walk with key informants in the pilot areas and other areas nearby where bee keeping is practised was done and informants were also interviewed to capture their experience on the bee keeping activity. Observation made by participants contributed to knowledge sharing and exchange of information which were all recorded as important data for this research.

Data analysis

The collected data were analysed to get the species composition, richness, diversity and their regeneration potential using the regeneration ratios. Species diversity was computed using Shannon's and Simpson's diversity indices. The Shannon Diversity Index was computed as

$$H' = -\sum Pi*lnPi$$

Where H' is the index of diversity, Pi is the importance value of a species as a proportion of all species.

Simpson's Diversity Index was computed as

$$C = \sum Pi2$$

Where C is the index number and Pi as defined above .

Basic vegetation assessments based on calculations of species numbers, frequencies, basal areas and mean *dbh* as well as on species "Importance Value Index" (IVI) at that site were carried out. The IVI is calculated as follows:

$$\text{Index of dominance} = \sum\left(\frac{n_i}{N}\right)^2$$

Where n_i = number of individual of a species (of one forest)

N = Total number of individual of all species (of one forest)

$$\text{Relative density} = \frac{\text{Number of individuals of a species X 100}}{\text{Total number of individuals of all species}}$$

$$\text{Relative dominance} = \frac{\text{Total basal area of a species X 100}}{\text{Total basal area of all species}}$$

$$\text{Relative frequesncy} = \frac{\text{Frequency of species X 100}}{\text{Sum of all frequencies}}$$

- Frequency = Number of quadrates in which a species is found
- Cover value Index (CVI) = Relative density + Relative dominance
- Importance value index (IVI) = CVI + Relative frequency

These information and data were summarised using the Excel Spread Sheet. The socio-economic data were subjected to content analysis.

Results and discussion

Biodiversity value of the rehabilitated water sources and river banks

Species diversity. The results in Table 1 which indicates different IVI (the Importance Value Indices for different species in the two forest sites) show that the exotic tree species *Acacia mearnsii* is the one dominating the Mwangoi village forest site (IVI= 0.82) while in Migambo, the dominant species is an indigenous tree *Pyrus communis* (IVI=1.02) (Senzota and Mbago, 2009).

Table 2 shows the diversity indices of the two sites. The Simpson's and Shannon's Diversity Indices for Migambo were 0.19 and 3.7, respectively, which show low diversity of plant species if compared to many of what are called forest in West Usambara. The Simpson's and Shannon's Diversity Indices of Mwangoi were 0.207 and 1.7 which is also low compared to many forests. The Simpson's Diversity Index (SIDI) represents the probability that any species encountered at random would be different species, and its range is $0 \geq \text{SIDI} < 1$. The Shannon's Diversity Index represents the quantity of 'information' per individual thus giving an indication of the extent of species diversity in the system.

The higher the information contained therein, the more diverse is the system hence the higher species diversity of species composition of an ecosystem. Its range is >0, without limit (McGarigal and Marks, 1995) and the higher the value, the greater the diversity. Values > 2 for Shannon's Index have been assigned medium to high diversity (Omeja *et al.*, 2004). Based on the results, though the biodiversity seem to be low but there are signs of improvement over the years, given the vegetation cover increases of 15-20% above ground and 0-5% ground cover in 2008 to 40- 70% above ground tree cover and 40-55% ground cover in both sites.

Table 1: IVI values in Migambo and Mwangoi sites

Location	Tree Species	IVI
Migambo	*Pyrus communis*	1.021
	Solanecio mannii	0.469
	Prunus mritima	0.324
	Albizia schimperana	0.312
	Acacia mearnsii	0.293
	Prunus persica	0.264
	Vernonia galamensis	0.139
	Cussonia holstii	0.089
	Cyprus distans	0.022
Mwangoi	*Acacia meansii*	0.826
	Grevilea robusta	0.804
	Eucalyptus sp.	0.661
	Jacaranda mimosifolia	0.193
	Markamia lutea	0.177
	Comiphora sp.	0.120
	Acrocapus flexinifolius	0.089
	Dombeya sp.	0.056
	Albizia sp.	0.051
	Bridelia sp.	0.018

Table 2: Biodiversity indicators in Mwangoi and Migambo villages

Parameter	Values	
	Mwangoi	Migambo
Species richness	40	35
Trees	12	7
Shrubs	16	12
Herbs	9	11
Climbers	0	2
Fern	0	2
Grasses	3	1
Number of plant families	23	23
Density (stem h^{a-1}) DbH ≥ 5 cm	464	205
Species diversity		
Simpson Index	0.207	0.191
Shannon-Winner Index	1.796	3.755

The intensity of beekeeping and Plant regeneration potential of the two sites

Beekeeping intensity and vegetation cover. Table 3 indicates the intensity of beekeeping in the two sites; management and vegetation cover changes over the three years of the project intervention. In Mwangoi village the site which was under study is a 1 km stretch along the Umba River. The river bank was highly degraded after being used for production of annual crops such as maize, beans and banana. After

introduction of the beehive, there has been improvement in terms of vegetation cover as people are no longer using the area for crop production. The vegetation cover of the sites has increased from 15% tree cover above ground and 0 ground cover in Mwangoi in 2008 to 40% trees above ground cover and 55% ground cover in 2010, while in Migambo the change has been from 20% above ground cover and 5% ground cover in 2008 to 40% above ground cover and 70% ground cover in 2010 (Table 3).

Most of the threats in the two sites including firewood cutting particularly by women, grazing and cultivation have stopped since bees have a policing effect, whereby most people are afraid of the bee stings. This has enhanced vegetative regeneration. It is also noted that of recent there has been some claims by famers seeing an increase in the production of fruit trees resulting from the effect of pollination by bees e.g *Persea americana* , while other farmers have noted some increase in beans and maize production in areas where the bee hives have been located in a farm plot. This perception is motivating more people to adopt the technology because of its multiple benefits.

Table 3: Intensity of beekeeping and management of the two sites

Site	Years	No. of bee hives	Honey yield (kg)	Management	Status of vegetation cover
Mwangoi	2008	10	40	Patrolling the apiary, maintaining and cleaning the beehives, regular visits to oversee the performance of the beehives	15% trees cover above ground and 0% ground cover
	2009	20	120		30% trees cover above ground and 20% ground cover
	2010	33	220		40% trees cover above ground and 55% ground cover
Migambo	2008	10	50	Patrolling the apiary, maintaining and cleaning the beehives, regular visits to oversee the performance of the beehives	20% trees cover above ground and 5% ground cover
	2009	30	165		30% trees cover above ground and 25% ground cover
	2010	37	185		40% trees cover above ground and 70% ground cover

Plant regeneration potential of the two sites

Fourty plant species belonging to 23 plant families and 35 plant species belonging to 23 plant families were identified in Mwangoi and Migambo, respectively (Tables 4 and 5). The density of trees with DbH ≥ 5 cm were 464 stems ha^{-1} in Mwangoi, almost two times than those in Migambo which was only 205 stem ha^{-1} (Table 2). More than 60% of the stems in Mwangoi had DBH less than 20 cm while Migambo had more than 80%. Most of the native trees in both areas are of DBH less than 10 cm. Though the two areas were highly disturbed but differ in their conservation history; Mwangoi is a secondary forest which regenerate with mainly exotic species *A. mearnsii*, *Eucalyptus* spp., *Grevilea robusta* and *J. mimosifolia.* Large trees are the remnants of the previously managed plantations which were for fuel wood, building poles and timber. Migambo is purely a young secondary forest which recovers from a highly disturbed catchment forest and is currently dominated by shrubs and young trees of DBH less than 5cm. The density of tree regenerants at Migambo site is 16,463 per ha and regenerants of other three life forms combined is 212,370 individuals per ha. In Mwangoi, forest has tree regenerants density of 25,464 ha^{-1} and regenerants of other three life forms combined a opulation of individuals 342,774 ha^{-1}. The relatively low density of regenerants of tree species in Migambo could be attributed to few numbers of mature trees which are the source of germplasm and also suppression from shrubs which currently dominate the area. The densities of regenerants in Mwangoi and Migambo are still higher compared to many forests in the Eastern Arc Mountains.

Table 4: List of plant species identified in Mwangoi site

Botanical name	Vernacular name	Family	Life form
Abutilon spp.	Unknown	Malvaceae	Shrub
Acacia meansii	Wati	Mimosoideae	Tree
Acalypha fruticosa	Unknown	Euphorbiaceae	Shrub
Bidens pilosa	Kimbara/mbwembwe	Compositae	Herb
Clausena anisata	Mjavikai	Rutaceae	Tree
Clerodendron robundifolium	Unknown	Verbenaceae	Shrub
Comiphora sp.	Unknown	Burceraceae	Tree
Dodonea sp.	Unknown	Sapindaceae	Shrub
Dombeya sp.	Unknown	Sterculiaceae	Tree
Drymaria cordata	Ugwiashighi	Caryophyliaceae	Herb
Eucalyptus sp.	Mkaratusi	Myrtaceae	Tree
Pteridium sp.	Silu	Dennstaedtiacea	Shrub
Setaria chevalieri	Unknown	Graminaeae	Herb
Solanum sp.	Mtura	Solanaceae	Shrub
Sonchus sp.	Unknown	Compositae	Herb
Targetis minuta	Unknown	Compositae	Shrub
Turiaea robusta	Dwayu	Meliaceae	Tree
Vernonia myriantha	Unknown	Compositae	Shrub

Table 5: List of plant species identified in Migambo site

Botanical name	Venecular name	Family	Life Form
Acacia mearnsii	Miwati,Wati	Mimosaceae	Tree
Acalypha hirtella	Mzindu	Euphorbiaceae	Shrub
Ageratum conyzoides	Beenge	Asteraceae	Herb
Albizia schimperana	Mshai	Mimosaceae	Tree
Basella alba	Ndeema	Basellaceae	Climber
Brucea antidysenterica	Unknown	Simaroubaceae	Shrub
Centalla asiatica	Unknown	Umbelliferae	Herb
Chysanthemoidesmonilifera	Kibugha	Asteraceae/compositae	Herb
Clausena anisata	Mjavikai	Rutaceae	Shrub
Commelina Africana	N'kongo	Commelinaceae	Herb
Pteridium aquilinum	Shiu	Dennstaedtiaceae	Fern
Pyrus communis	Peas	Rosaceae	Tree
Rubus niveus	Mshaa	Rosaceae	Shrub
Ruellia patula	Unknown	Acanthaceae	Shrub
Rumex usambararensis	Nywanywa	Polygonaceae	Herb
Senecio deltoideus	Uwenge	Asteraceae	Shrub
Verbena rigida	Unknown	Verbenaceae	Herb
Vernonia galamensis	Mhasha	Asteraceae	Shrub

High densities of regenerants were expected in young or disturbed forests like these and with time the two areas are capable of naturally restoring to dense forest. Normally recovering of highly disturbed forest starts with annual plants and shrubs which enrich soils that support trees (Ndangalasi *et al.,* 2003). This is a positive sign for the restoration of the degraded sites.

Conclusions

The study revealed that there is a significant increase in densities of trees and ground cover in both forests due to the effect of beekeeping and hence quick signs of vegetation restoration. Both areas are still low in plant species richness and diversity. Mwangoi as other disturbed forests which are close to human settlements is vulnerable to invasion by alien plant species such as *Lantana camara* which escapes from settlements to nearby disturbed forests. To promote regeneration of desired tree species particularly for beekeeping purposes enrichment planting on both forests is ineviTable. Based on the fact that beekeeping is exclusively tree and flower dependent the enrichment planting is important to sustain and improve the beekeeping activity. Assessment and monitoring of populations of alien plant species is recommended to detect the adverse effects on the restoration which may be a result of invasive species domination.

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Assessment of genetic variability among Kenyan soybean (Glycine max (L.) Merill) accessions and other introductions

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Abstract

Knowledge on genetic variability forms the basis of a successful crop improvement. Unfortunately, Kenyan soybean accessions have not been characterized and little efforts have been made to assess their genetic variability and use it in the breeding programme. This study was conducted to evaluate genetic variability, heritability and genetic advance among Kenyan soybean accessions and other introductions. One hundrend and ten (110) soybean genotypes were evaluated in three locations (Embu, Mwea and Igoji) for 2 seasons using alpha lattice design arranged in 10 rows x 11 columns replicated three times. The genetic variability was estimated using variance components. Genotypes were grouped using hierachial cluster analysis. High to moderate genotypic coefficients of variation were observed for pod shattering, lodging scores, number of pods/plant, plant height and grain yield indicating sufficient variability of these characters for genetic improvement through simple selection. High heritability estimates coupled with high genetic advance were recorded for plant height, pod shattering and number of pods/plant indicating additive mode of gene action. Cluster analysis grouped the accessions into two major clusters. The clustering pattern had no clear relationship between the origin of the accessions and the genetic diversity. However, clustering was based on the similarity of traits, impliying that genotypes from a certain cluster with greater similirities of a particular trait may be selected for hybridization. In this regard, genotypes GBK 033245, GBK 033251, GBK 045342, GBK 033229 and BRS MG46 would be selected and incorporated in hybridization programme to develop high yielding soybean varieties. Similarly, genotypes Dowling and PI 2007477A would be selected for developing short, early maturing, lodging resistant and large seeded genotypes. This study confirmed the presence of variability and an opportunity for breeders to exploit additive gene effects and hybridize diverse parents with complimentary traits to obtain desirable segregating generations that will eventually improve soybean yields and other attributes.

Key words: soybean genetic variability, heritability, genetic advance and cluster analysis.

Introduction

Soybean (Glycine max (L.) Merill) occupies an important position among grain legumes for its economic benefits. In Kenya, interest in soybean is increasing, largely due to the recognition of its nutritive value for both humans and livestock. However, its production is just a fraction of what is demanded by the food and feed processors. While this demand is projected to increase to about 150,000 tons per year for the next 10 years, the production in the farmer's field is estimated to be less than 10,000 tons (Wasike *et al*., 2009). The deficit (140,000 tons) has to be acquired through importation from the neighbouring countries. Therefore, there is need to increase local soybean production, primarily by breeding better soybean varieties.

The development of high yielding varieties will depend on the presence and magnitude of the genetic variability available in a population (Karnwal and Singh, 2009). Hence, the assessment of genetic diversity is useful to plant breeders for the selection of divergent parents that are suitable for hybridization (Tyagi and Sethi, 2011). According to Tyagi and Khan (2010) crosses involving diverse parents with complimentary traits are anticipated to produce promising heterotic effects and a wide range of genetic variability, which will provide an opportunity of attaining desirable recombinants or segregating generations. Unfortunately, no studies have been conducted to assess the genetic variation on soybeans available in Kenya. This study could play an important role in formulating a breeding programme that will aid in selecting superior genotypes for the development of new varieties. Therefore the objective of this study was to (i) determine genetic variability, heritability, genetic advance and the pattern of genetic diversity among Kenyan soybean accessions and other introductions and (ii) identify the most divergent parents for future breeding program.

Materials and methods

Germplasm sources and study location

Soybean germplasm used in this study consisted of 10 genotypes acquired from Makerere University (Uganda), 6 from Pannar seed company (South Africa), 64 from National gene bank of Kenya (Muguga), 26 from Kenya Agricultural Research Institute (KARI-Njoro) and 4 from farmers' field as presented in Appendix 1. All the genotypes were evaluated in three locations i.e. KARI-Embu, KARI-Mwea and KARI-Igoji. KARI-Embu is located at latitude 000 30'S and longitude 37°42'E at 1508 m above sea level, with an average rainfall of 1200-1495 mm per year. The mean temperature ranges between 14.1 and 250C and the soil type is Humic nitosol. KARI-Igoji is located at latitude 00034'S and longitude 37o19'E, at 1189 m above sea level, with mean annual rainfall of 1095 mm and temperatures ranging between 20.9 to 22.9^{o}C. The soil type is Eutric nitosol. KARI-Mwea is situated at latitude 000 37'S and longitude of 37o 20'E, at an altitude of 1159 m above sea level. This site receives a mean annual rainfall of 850 mm and the temperature ranges from 15.6^{o}C to 28.6^{o}C with a mean of 22.8^{o}C. The soil types are nitosols. All the sites have a bimodal rainfall pattern, with long rains received between mid-March and June, and short rains in Mid-October to early January.

Experimental layout and data collection

The experiments were conducted for two seasons during short rains (October-December) and long rain (April to July) between 2010 and 2011. Soybean accessions were sown in plots consisting of three rows of 2 m long spaced at 30 cm between rows and 15 cm within the rows. The experiments were laid out in alpha lattice arrangement (10x11) replicated three times. Five soybean plants were selected at random in every plot to observe quantitative data as described by Cho *et al*. (2008). Data on days to 50% flowering, days to 75% maturity, plant height (cm), number of pods/plant, number of seeds/pod, lodging scores, shattering scores, branching ability, grain yield (kg) and 100 seeds (g) were collected.

Data analysis

All the data was subjected to analysis of variance (ANOVA) using Genstat statistical package (12th edition) for all the traits measured to test the significance of variation among the accessions. Data on lodging scores, branching ability and shattering scores were square root transformed before analysis of variance. The estimation of the variability parameters were calculated as suggested by Johnson *et al*. (1955) and Al-Tabbal and Al-Fraihat (2012). Cluster analysis was performed on the Euclidean distance matrix with the unweighted pair group method based on arithmetic averages (UPGMA). The relationship between genotypes was presented using a dendrogram (Powell *et al*., 1996).

Results and discussion

Genetic variability

The means, phenotypic and genotypic coefficient of variation, broad sense heritability, genetic advance and genetic gains are presented in table 1. The genotypic coefficient of variation (GVC) and phenotypic

coefficient of variation (PVC) showed a wide range of estimates for all the characters. The genotypic variation of coefficient (GVC) recorded moderate to high estimates for shattering ability, lodging scores, number of pods per plant, plant height and grain yield indicating sufficient variability of these characters for genetic improvement through simple selection. High to moderate variability for seed yield and other traits in soybeans have also been reported by Karnwal and Singh (2009). Low GCV and PVC estimates observed for days to 75% maturity, days to 50% flowering, plant stand and pod length is a sign of a narrow range of variation that exists in these traits indicating a slightly low scope of selection. Bangar and Mukbekar (2003) reported similar findings for days to maturity and flowering in soybeans.

Close PVC and GCV values observed for days to 75% maturity, days to 50% flowering, pod length, plant height, 100 seed weight and branching ability implies that the observed variability among soybean genotypes were mainly attributed to genetic factors while the environmental influence on the expression of these characters were minimal. Therefore selection of these characters based on phenotypic appearance is likely to have a substantial improvement at early generations. These findings are in accordance with observations reported by Aditya *et al*. (2011). However, higher PVC estimates than GVC estimates for lodging scores, grain yield, plant stand and shattering ability suggest that these characters were greatly influenced by the environment and the genetic factor had a low expression for these characters. Therefore selection of such characters needs to be done carefully because environmental fluctuations are unpredictable and the results can be misleading (Karnwal and Singh, 2009).

Although the coefficient of variation provides information on the extent of total variability existing in characters, it does not partition this variability into heritable and non-heritable variations (Govindaraj *et al*., 2011). In this case heritability becomes an important parameter as it precisely indicates the heritable expected gains, thus providing information on the suitability and the method of selecting a particular character (Selvaraj *et al*., 2011). In this study, broad sense heritability estimates for all the characters recorded more than 50% except for plant stand (11.9%). Heritability exhibited high values for plant height (94.49%). This was closely followed by number of days to 75% maturity (94.09%), days to 50% flowering (92.81%), pod length (91.99%), shattering ability (91.73%), 100-seed weight (89.68%), pods per plant (83.28), branching ability (81.11%) and seeds per pod (71.81%). This indicates that a large portion of phenotypic variance is due to genotypic variance which is responsible of transmitting genes to the offsprings. Therefore reliable selection of these characters is possible based on their phenotypic performance as they are less influenced by environmental factors. Ramteke *et al*. (2010) and Malik *et al* (2006) also reported high heritability for different traits in soybeans. Other characters such as grain yield (56.79%) and lodging scores (59.56%) exhibited moderate heritability values.

According to Johnson (1955) heritability alone does not provide information on the genetic progress for an effective selection of the best individual. It is therefore important to combine high heritability estimates with genetic gains and GVC values which are powerful indicators of additive gene action. Based on this consideration, this study revealed that plant height, pod shattering and number of pods per plant exhibited high broad sense heritability coupled with high genetic gain, indicating the presence of additive gene action and that improvement of such characters would be effective through selection. Aditya *et al*. (2011) also reported high heritability coupled with genetic gain for number of pods per plant, dry matter weight per plant and plant height.

High heritability coupled with moderate genetic advance were also recorded for 100 seed weight, days to 75% maturity, days to 50% flowering and branching ability suggesting that the expression of these traits are controlled by both additive gene action and non additive gene action. Therefore, these characters could be effectively improved through mass selection or progeny testing. Similar findings were reported in wheat (Tripathi *et al*., 2011). However, other characters such pod length and number of seeds per pod showed high heritability estimates coupled with low genetic gain suggesting that these characters are controlled by non additive gene action. In this case the improvement of these characters through early generation selection is not likely to provide reliable results but they can be successfully improved through heterosis breeding. High heritability with low genetic advances were also reported by Ramteke *et al*. (2010) and

Aditya *et al*. (2011) for protein and oil content, number of primary branches per plant, 100 seed weight and days to 50% flowering.

Table 1: **Means, phenotypic and genetic variability, heritability, genetic advance and genetic gains estimates for soybean traits**

Traits	Range	Grand mean	GV	PV	PCV%	GCV%	H %	GA	Gg %
100 seed wt	7.40-32.78	18.29	12.32	13.73	20.27	19.19	89.68	6.85	37.44
Branching	5.000- 8.66	7.24	1.16	1.43	16.52	14.88	81.11	2	27.6
Flowering	24.00- 84.00	45.5	45.83	49.39	15.44	14.88	92.81	13.44	29.53
Grain yield	104-10778	1794	155700	274167	29.19	21.99	56.79	612.56	34.14
Lodging	1.000-8.72	2.02	2.08	3.49	92.73	71.56	59.56	2.29	113.78
Maturity	69-152.00	96.88	179.19	190.45	14.24	13.82	94.09	26.75	27.61
Plant stand	12.12-100.00	65.22	6.1	51.25	10.98	3.79	11.9	1.76	2.69
Plt Height	5.00-121.50	34.45	283.23	299.75	50.26	48.85	94.49	33.7	97.82
Pod length	2.600-6.35	4.61	0.29	0.32	12.25	11.74	91.99	0.92	23.2
pos/plt	10.5-310.00	63.67	612.52	735.47	42.59	38.87	83.28	46.53	73.07
Seeds/pod	1.000- 3.500	2.63	0.08	0.12	13.05	11.06	71.81	0.51	19.31
Shattering	1.000- 8.72	2.08	7.8	8.5	140.32	134.39	91.73	5.51	265.14

GV is Genotypic variance, PV is Phenotypic variance, PCV is Phenotypic coefficient of variation, GCV is Genotypic coefficient of variation, H is Broad Heritability, GA is Genetic advance and Gg is the Genetic gain.

Cluster analysis

Hierachial cluster analysis was performed using the average linkage grouping for 12 quantitative traits and it was presented using a dendrogram (Figure 1). The dendrogram classified soybean genotypes into two distinct major clusters. The first cluster contained 30 genotypes of which 8 were from National genebank of Kenya, 11 from KARI, 9 from Uganda and 2 from the farmer's field. The second cluster had the largest number of genotypes (80) from different sources, of which 15 were from KARI, 56 from Gene bank and 2 from farmer's field. All the genotypes (6) from South Africa and 1 genotype from Uganda were also classified under this category. Based on these result it was clear that genotypes from the same source were not necessarility grouped in the same cluster and vice versa. This is an indication of genotypes from heterogenious origins, suggesting that the clustering pattern had no clear relationship with the origin of the germplasm. Malik *et al*. (2011; 2009) also reported difficulties in establishing the relationship between the origin of the accessions and the clustering pattern. This trend implies that the origin of accessions is not the only cause of the genetic diversity. Random distribution of accessions from different sources into the same group may also be as a result of undirectional selection pressure applied for yield maximazation in different enviroments. In addition, exchange of germplasm among different regions could lead to genetic diversity due to modification of the breeding germplasm. Another possible reason for this type of clustering is genetic drift (Sirohi and Dar, 2009). For this reason, parents for hybridization shoud be selected based on genetic diversity instead of geographical diversity.

Although origin of the germplasm was not reflected by the genetic diversity, some degree of relationship between source and genetic diversity was evident for some genotypes. For instance, commercial varieties, advanced lines and most of the genebank accessions were grouped together an indication of low levels of variability amongst themselves. This could be attributed to similarities and close relationships of several traits in these genotypes an indication of narrow genetic base that needs to be broadened. It is also possible

that these genotypes have some resemblance genes originating from the same parental lines which are clearly noted by similar codings (e.g. 916/5/19, 917/5/16, 931/5/34, 932/5/36 and 911/6/3) given for the advanced lines. Selection pressure applied by breeders and the farmers towards certain desirable traits may be also a consequence of narrow diversity among advanced lines and commercial varieties. Bhartiya *et al*. (2011) had similar observations in black soybeans. In such a situation close genotypes could be crossed with the most diverse genotypes for the development of biparent crosses that will be useful for breaking undesirable linkages between yield and its attributes.

Regardless of the source of the germplasm, clustering pattern especially at the subcluster level was mainly based on the similarities of traits. Zafar *et al* (2008) also observed that 139 soybean genotypes clustered together on the basis of morphological similarities. This implies that genotypes from a certain cluster with greater similirities of a particular trait may be selected for hybridization. In this study, sub cluster 1 in cluster 1 had tall, highly branching but late maturing with lodging susceptible genotypes grouped together. Of specific interest was the promising moderate to high yielding genotypes that would be selected for hybridization grouped in sub cluster 2. Similarly, selection for short early maturing, lodging resistant and large seeded genotypes Dowling and PI 2007477A would be selected in subcluster 1 in cluster 2. However, this group had low values for several traits that needs improvement for high yields and increased number of pods per plant. Other early maturing genotypes GBK 029622, GBK 033237, GBK 033247, GBK 033241 and GBK 033225 grouped in subcluster 2 would need improvement for seed colour, pod shattering resistance, improved branching with longer pods and increased number seeds per pod with acceptable sizes. Based on these findings, selection of superior genotypes with desirable traits is possible from different clusters.

For hybdridization purposes, parents may be selected based on the traits performance and the cluster pattern. The present study observed that genotypes GBK 033245, GBK 033251, GBK 045342, GBK 033229, GBK 033222, Ex- Kirinyaga and BRS MG46 in Cluster 1, subcluster 2, would be selected for yield segragants because they are tall with many branches, increased number of pods per plant and high yielding potential. The negative aspect with this group of genotypes was their lodging susceptibility and late maturity. However, incorporation of shorter plants, early maturing, lodging resistant and large seeded genotypes is possible with genotypes Dowling and PI 2007477A in cluster 2 acting as donor parents. Therefore a hybridization programme involving high yielding genotypes in cluster 1 and short, early maturing genotypes with better seed size in cluster 2 would result into a broad spectrum genetic variability and an opportunity for isolating transgressive segregants for earliness, medium plant height with lodging resistant and high yielding with large seeded genotypes.

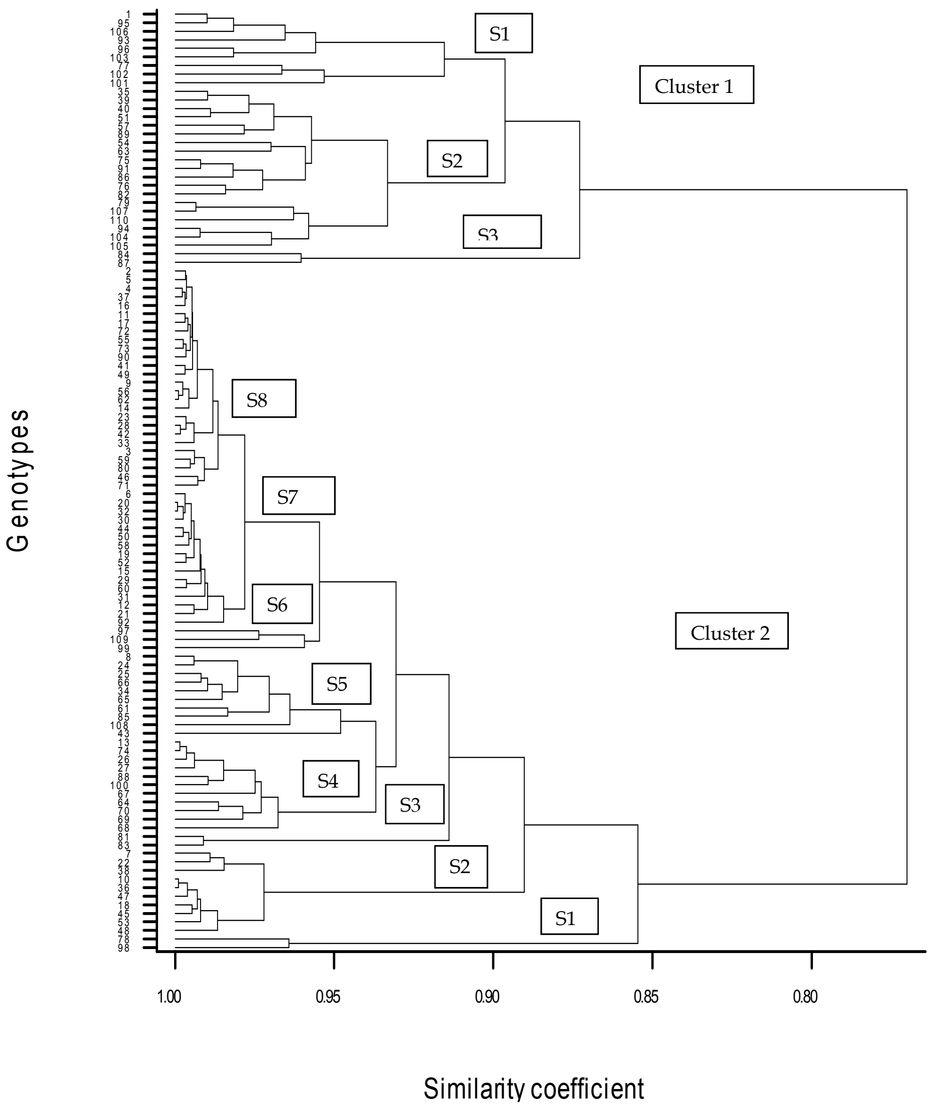

Figure 1**: Dendrogram of 110 soybean genotypes based on the average linkage groupings for 12 quantitative traits. The genotype numbers on the Y axis corresponds with the genotype names/identification numbers**

Conclusion and recommendations

This study showed that there is a considerable genetic variability for quantitative traits in the germplasm used that can be exploited for development of new soybean varieties. In spite of this variabiity, further molecular characterization is needed to supplement agronomic characterization. This study also revealed

that plant height and number of pods per plant exhibited high broad sense heritability coupled with high genetic gain, indicating the presence of additive gene action and improvement of such characters through selection. Further analyis, based on the cluster pattern showed that genetic diversity among the genotypes used in this study was sufficient for improving soybeans through hybridization and selection. Genotypes such as GBK 033245, GBK 033251, GBK 045342, GBK 033229, GBK 033222, Ex- Kirinyaga and BRS MG46 with promising yields and other desirable attributes for different agronomic traits could be used directly or incorporated in the hybridization program. Similarly, selection for short early maturing, lodging resistant and large seeded, genotypes Dowling and PI 2007477A would be selected. Therefore genetic improvement of soybeans is possible by exploiting additive gene effects and crossing of divergent parents to obtain heterotic effects and segregants with high genetic variability for yields and other desirable attributes.

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Status of commercial macadamia nurseries in central Kenya and incidence of seedling chlorosis

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Abstract

Kenya is the fifth largest producer of macadamia (*Macadamia* spp.) after Australia, Hawaii, South Africa and Guatemala. Since the improvement of nut prices in the world market in 2004, there has been a steady rise in demand for seedlings accompanied by mushrooming of private nurseries. Propagation nurseries however have to combat with seedling chlorosis which is attributed to a deficiency of iron or magnesium. The disorder can cause substantial losses in young rootstock and grafted seedlings. In a project designed to resolve this serious nursery problem, one objective was to establish the scale of macadamia seedling chlorosis in major producing areas of Kenya. A situational analysis was carried out in commercial nurseries in central Kenya to capture various nursery management practices and the incidence of macadamia seedling chlorosis followed by descriptive analyses of the data using Statistical Package for Social Sciences (SPSS) 12.0. 63% of the nurseries were certified, 81% were male operated, and 56% of the operators had received formal training on nursery management. Half the nurseries grew other tree seedlings in addition to macadamia which was found in 75% of the nurseries. Kiambu 3 and Murang'a 20 were the preferred macadamia varieties. 56% of the nurseries used own red soil, 19% used virgin forest soil and 44% re-used potting media soil. Most nurseries used fertilizers (81%) and manure (88%) in the potting media, 88% grafted their own seedlings and 95% applied supplemental irrigation. 88% of operators were familiar with macadamia seedling chlorosis which was cited as a persistent problem in 44% of the nurseries. The disorder was mostly attributed to soil reuse and pest infestation. Only a handful of operators (6%) related it to iron deficiency. The study confirmed that macadamia seedling chlorosis was a widespread and persistent problem in commercial nurseries that resulted in substantial loss to seedlings.

Key words: macadamia seedling chlorosis, potting media soil, fertilizers, manure, irrigation.

Introduction

Kenya is the fifth largest producer of macadamia (*Macadamia* spp.) after Australia, Hawaii, South Africa and Guatemala (KARI, 2005). Popular in the confectionery industry, macadamia nuts are used for direct consumption as dessert in raw and roasted forms and as an ingredient in various confectionery products. Both shells and husks are good sources of fuel. The husk is sometimes used for mulching. The oil from macadamia (unsaturated and cholesterol free) is used mainly in the pharmaceutical and cosmetic industries while the macadamia cake, a by-product from oil extraction is used as livestock feed (KARI, 2005). Major producing areas are found in the Coast (Taita/Taveta), Central (Meru, Embu, Kirinyaga and Thika) and Rift Valley (Baringo and Koibatek).

Good export prices for the nut 2004 initiated rapid expansion, resulting in a high demand for planting material, information on macadamia production technology and mushrooming of private nurseries (MOA, 2003; 2006; 2007; KARI, 2005). However macadamia seedling chlorosis has been a persistent problem in propagation nurseries (KARI, 2005; MOA, 2003; MOA, 2004). Losses in young rootstock can be as high as 40-50% and in grafted seedlings, 30% (KARI, 2005).

Macadamia seedling chlorosis is caused by a deficiency of either iron or magnesium (Marrocos *et al*., 2000). Chlorosis comes in various degrees; from slightly chlorotic to severely chlorotic (Marrocos *et al*., 2000; Bittenbender and Hirae, 1990; Wallace, 1959) and can cause death in grafted seedlings. Iron deficiency starts from new leaves owing to immobility of this element while, magnesium deficiency first appears in older

leaves, coinciding with greater mobility (Mengel and Kirkby, 1987; Tisdale *et al.,* 1985). In Kenya, macadamia chlorosis is a common problem of grafted seedlings propagated on red soils (KARI, 2005) and is confined to young leaves, pointing to iron deficiency. Red soils are typically characterized by high Fe concentrations and low soluble P owing to high Fe/P precipitation reactions and low organic matter contents, (Brady and Weil, 1996; Sombroek *et al*, 1982). Macadamia chlorosis can develop in seedlings receiving excessive amounts of phosphorus (Hue *et al*, 1988) if the recommended P rates in nursery potting media are in excess, hence have potential to intensify Fe/P reactions, in the process removing plant soluble Fe from the soil solution, which in turn can aid the development of Fe chlorosis.

Available control options in Kenya include use of resistant rootstock (e.g. KMB-3) and controlled watering of seedlings. Previous studies however showed that chlorotic seedlings had lower Fe/P ratios compared to healthy ones (Kiuru, unpublished data) while foliar applications of iron sulphate (Irambu *et al.,* 2003) and selection of resistant rootstock/scion combinations (Gitonga *et al.,* 2003) met with minimal success. Considering the heavy losses associated with macadamia seedling chlorosis in young rootstock and grafted seedlings (KARI, 2005), the need to find a lasting solution for this problem quickly is imperative, if production for the export market is to be sustained and increased. This KARI project was initiated to: 1) Establish the scale of macadamia seedling chlorosis in major producing areas, 2) Formulate soil type specific potting media recommendations and 3) Share information with stakeholders. This paper highlights the findings of the first objective.

Materials and methods

A situational analysis was carried out in 2012 in the major commercial nurseries found in Kiambu, Murang'a, Embu, Kirinyaga and Nyeri counties to capture nursery management practices and the incidence of macadamia seedling chlorosis. Sixteen (16) fruit seedling nurseries were visited and a semi-structured questionnaire administered to operators to capture nursery management practices. The nursery management information captured included certification, types of tree seedlings grown, macadamia seedling varieties, types and sources of potting media soil, manure and fertilizer types, water sources and incidence of macadamia seedling chlorosis, causes and intervention measures. Descriptive analyses of the data were performed using the Statistical Package for Social Sciences (SPSS) 12.0 version after cleaning the raw data.

Results and discussion

Characterization of macadamia nurseries and nursery operators in central Kenya

Most (81%) of the nurseries were operated by males (Table 1), with most of the operators having attained secondary and tertiary level of education. The average operator age was 51 years. 56% of the nursery operators had received formal training in nursery management on topics such as nursery bed establishment, seeding, transplanting, grafting, pruning and de-suckering.

Of the nurseries visited, 75% had macadamia seedlings and 50% grew other fruit tree seedlings as well (Table 2).

Reasons given for abandoning macadamia seedling nurseries were:

- Seedlings were drying out before maturity.
- Seedlings were taking too long to germinate.
- Grafted seedlings were taking too long to take off.
- There was no market demand for macadamia seedlings due to poor and seasonal price variation of nuts

Table 1: Characteristics of macadamia nursery operators in central Kenya

Name of nursery	Name of operator	Gender	Age	Education level
Avocado Masters	David Murigi	Male	56	Primary
Flamawas	*Not provided*	Female	43	Secondary
Freshco/Farm nut/Equitorial	Nelson Nyandiva	Male	52	Secondary
Gituya	Morgan Peter	Male	58	Secondary
HDP Macadamia	*Not provided*	Female	51	Tertiary
Juakari nursery	Gabrile Nyaga	Male	63	Primary
Jungle nuts (closed)	Wainaina	Male	*Not provided*	Tertiary
Kamiu tree nursery	Silas Kariuki	Male	32	Secondary
KARI Thika	Grace Watani	Female	*Not provided*	Tertiary
Kene tree nursery	Kamugane	Male	63	Secondary
Kenya Nut	Paul	Male	*Not provided*	Tertiary
Kenya Prisons	*Not provided*	Male	*Not provided*	*Not provided*
Macnuts farm products	Mugii Nahashon	Male	45	Tertiary
Practical Training Centre	Mumo	Male	66	Tertiary
Selesio	Selesio Njeru	Male	32	Secondary
Jason	Jason Karira	Male	55	Tertiary

Table 2: Fruit trees found in macadamia nursery operations

Nursery name	County	Any macadamia seedlings?	Other fruit tree seedlings
Avocado Masters	Nyeri	No	None
Flamawas	Nyeri	Yes	Pawpaw, passion, tree tomato
Freshco/Farm nut/Equatorial	Murang'a	Yes	None
Gituya	Murang'a	Yes	Avocado, pawpaw, passion, tree tomato, mango
HDP Macadamia	Murang'a	Yes	None
Jason	Embu	Yes	None
Juakari nursery	Embu	Yes	None
Jungle nuts	Kiambu	No	None
Kamiu tree nursery	Embu	Yes	Mango, apples, passion, strawberry, avocado, tree tomato, guava, loquats, grapes
KARI Thika	Murang'a	Yes	Mango, avocado, pawpaw, passion, strawberry, tree tomato, grapes
Kene tree nursery	Embu	Yes	Avocado, loquats, mango
Kenya Nut	Kiambu	Yes	None
Kenya Prisons	Kirinyaga	No	Tree tomato, avocado, mango, oranges, passion
Mac nuts farm products	Murang'a	No	Pawpaw, passion, mango, strawberry
Practical Training Centre	Kiambu	Yes	Avocado, pawpaw, mango, passion
Selesio	Embu	Yes	None

Macadamia varieties

Seventy-five percent of the nurseries had macadamia seedlings with Kiambu 3 (7 nurseries) and Murang'a 20 (5 nurseries) being the preferred types (Table 3).

Table 3: Macadamia varieties found growing in commercial nurseries

Name of nursery	County	Varieties
Flamawas	Nyeri	Mixed- Kiambu 3, Murang'a 20
Freshco/Farm nut/Equitorial	Murang'a	Both pure and mixed- Kiambu 3, Tetraphila
Gituya	Murang'a	Pure- Kiambu 3, Murang'a 20, Murang'a 4
HDP Macadamia	Murang'a	Mixed- Kiambu 3, Kerugoya 15, Embu 1
Jason	Embu	Pure- Murang'a 20, Kirinyaga 3
Juakari nursery	Embu	Pure- Embu 3
Kamiu tree nursery	Embu	Pure- Murang'a 20, Embu 1, Kirinyaga 3
KARI-Thika	Murang'a	Mixed- Kiambu 3
Kene tree nursery	Embu	Pure- Murang'a 1, Murang'a 20
Kenya Nut	Kiambu	Both- Kiambu 3
Practical Training Centre	Kiambu	Mixed- Kiambu 3
Selesio	Embu	Tetraphila

Potting media soil, watering regime and grafting practice in macadamia nurseries

Nurseries using own red soil in the potting media were 56%, 19% used virgin forest soil and 44% re-used potting media soil citing cost cutting and waste avoidance as their reasons. Those who did not reuse potting media soil cited avoidance of the spread of diseases and abundance of fresh soil as their reasons (Table 4). Most nurseries (88%) grafted their own seedlings and applied irrigation (95%) from various sources including stream water, piped water, dam water and borehole (Table 4).

Table 4: Potting media soil sources and irrigation

Nursery	Type of soil	Source of potting media soil	Source of water	Frequency of watering/week	Re-use soil in potting media?
Flamawas	Red	Own farm	Rain	Daily	Yes
Freshco/Farm nut/Equitorial	Red	Own farm	Borehole	Thrice	No
Gituya	Red	Own farm	Stream	Twice	No
HDP Macadamia	Virgin	Forest	Stream	Thrice	No
Jason	Loam	Own farm	Stream	Thrice	No
Juakari nursery	Loam	Own farm	Piped	Thrice	Yes
Jungle nuts	Virgin	Forest	Piped	Daily	Yes
Kamiu tree nursery	Loam	Own farm	Stream	Twice	Yes
KARI Thika	Red	Forest	Piped	Thrice	No
Kene tree nursery	Red	Own farm	Piped	Thrice	No
Kenya Nut	Red	Own farm	Dam	Twice	Yes
Macnuts farm products	Red	Own farm	Stream	Twice	Yes
Practical Training Centre	Red	Own farm	Stream	Twice	Yes
Selesio	Red	Own farm	Stream	Thrice	No

Fertilizer and manure application

Fourteen out of 16 nurseries (88%) applied manure in the potting media mix. The most frequently used manure type was farmyard manure of which 12 out of the 16 nurseries (75%) were found using. Only two nurseries applied compost instead. Those who did not apply said that avoidance of manure application to prevent the yellowing of leaves. Thirteen of the 16 nurseries (81%) used fertilizers regularly. The fertilizer types used included nitrogen based fertilizers such as calcium ammonium nitrate (26:0:0), and urea (45:0:0); phosphate fertilizers like triple superphosphate (0:46:0); and compound fertilizers such as di-ammonium phosphate (18:46:0), 23:23:0, 17:17:17, 23:23:23 and 20:10:10. Those who did not use fertilizers said that they were either too costly or unnecessary.

Incidence of macadamia seedling chlorosis

Looking at the picture of macadamia seedling chlorosis provided, 14 operators (88%) said that they were familiar with macadamia seeding chlorosis. Only two (13%) operators had not had seen the condition, while seven (44%) reported that the problem was still persisting in their nurseries. Reporting on the year of greatest loss, Macnuts Seed Products said they had lost 500, Jason Nurseries 150 seedlings, Kamiu Nurseries 2000 and Juakari Nurseries 20. Operators had varied reasons for causes of macadamia seedling chlorosis, ranging from lack of water, problems with pests and diseases to poor nutrition (Table 5). Control measures enforced ranged from fertilizer application to change of soil used in the potting media (Table 6). Only one operator (6%) related the condition to iron deficiency.

Table 5: Causes of macadamia seedling chlorosis

Cause	Percent (%)
Insects that suck the fluids	5.9
Lack of iron and diseases	5.9
Lack of iron, type of variety-Embu & Kirinyaga	5.9
Lack of nitrogen	5.9
Lack of water	5.9
Pests (especially thrips) and soil borne diseases	11.8
Soil re-use	11.8
Type of water used	5.9
Source of soil (poor soils)	5.9
Total	64.9

Table 6: Macadamia seedling chlorosis control strategies in commercial nurseries

Control	Percent
Use of foliar feeds and CAN fertilizer	5.9
Use ferrous sulphate for iron deficiency	11.8
Change soil site from one part of the forest to another	5.9
Use forest soil	17.6
Total	41.2

Conclusions and recommendations

The study confirmed that macadamia seedling chlorosis was a widespread and persistent problem in commercial nurseries that resulted in substantial loss to seedlings. Only one operator (6%) related it to iron deficiency. Less than half of the operators (41%) attempted to correct the problem through application of fertilizers (nitrogenous and ferrous) and change of soil in the potting media. The findings should be used as the basis for formulating soil type specific potting media recommendations for red soils in Kenya.

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Agronomic and financial analysis of maize- legumes production in western Kenya

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Abstract

Maize (*Zea mays L.*) and grain legumes are the dominating crop enterprises in western Kenya. Whilst maize provides the backbone to food security, grain legumes are multi-functional sources of household protein, fix atmospheric nitrogen to the soil and provide livestock feed. Maize yield is typically less than 1.0 tons per hectare (t ha^{-1}) against the potential of 5.0 t ha^{-1} whilst legume yields are less 0.2 t ha^{-1} relative to potential 2.5 t ha^{-1}obtainable under research, mainly due to low soil fertility. Against this backdrop, during long rain seasons in the years 2010 and 2011, 24 on-farm demonstrations were set up to disseminate Integrated Soil Fertility Management (ISFM) technologies in four sub-Counties in western Kenya. The demonstrations were designed in a Randomised Complete Block Design involving four treatments: 1. Maize-bean; 2. Maize-soybean, 3. Sole maize (control) and 4. Maize-groundnut intercrops. The objectives of this study were to evaluate effect of different maize-legume intercrops on maize and legume grain yields; and to analyse costs and benefits of the maize-legume intercrops. Data were collected on maize and legume yields, quantities of inputs applied and prices of both inputs and outputs. Results showed that the highest maize grain yields (4.8 t ha^{-1}) were obtained from maize-bean, followed by maize-groundnut (4.7 t ha^{-1}) intercrops. Amongst the legumes, soybean gave the highest grain yield (0.5 t ha^{-1}). The highest benefit-cost ratio of 2.5 was obtained from maize-bean intercrop and the lowest (1.9) was from sole maize (without fertilizer) mainly because beans had the highest demand and market price per unit. As such, there is need to develop policies that promote smallholder farmers' access to efficient input and output markets.

Keywords: Benefits, costs, demonstrations, intercropping, soil fertility.

Introduction

The need for sustainable intensification of agriculture in sub-Saharan Africa (SSA) has gained support, in part because of the growing recognition that farm productivity is a major entry point to break the vicious circle underlying rural poverty. Landmark events to promote agriculture in Africa include the African Heads of State Fertilizer Summit held in Abuja, Nigeria in 2006 (IFDC, 2006) and the launching of the Alliance for a Green Revolution in Africa (AGRA). Kofi Annan, former the Chairman of the Board of AGRA, has repeatedly stressed that the African green revolution should be made uniquely African by recognizing the continent's great diversity of landscapes, soils, climates, cultures and economic status, while also learning lessons from earlier green revolutions in Latin America and Asia (United Nations, 2004)

Maize (Zea mays L.) and grain legumes are the dominating crop enterprises in western Kenya. Whilst maize provides the backbone to food security, grain legumes are multi-functional sources of household protein, fix atmospheric nitrogen to the soil and provide livestock feed. The yield of maize -the staple food crop- in the densely populated Western Kenya is, however, typically less than 1.0 tons per hectare (t ha-1) against the potential of 5.0 t ha-1. Legume yields are equally low, at less than 0.5 t ha-1 relative to potential of 2.5 tha-1 .(KARI, 2013). Maize production has, therefore, not kept up with the population growth leading to serious food insecurity and poverty (Odendo *et al.*2009). The low yields in western Kenya have been blamed on soil degradation and Striga weed menace on maize (KARI, 2013).

Reversing the low and declining crop yields in western Kenya requires increasing investments in technologies that improve soil fertility and control of the Striga weed, whilst improving farmers' access to improved seeds and output markets. Several proven integrated soil fertility management (ISFM)

technologies that could improve crop yields have been developed and disseminated in western Kenya. These include inorganic fertilizers and organic inputs such as farm yard manure and grain legumes.The most promising grain legumes in Western Kenya are soybeans (Glyxine max), groundnuts (Arachis hypognea), common beans (Phaseolus vulgaris) and climbing beans (Vigna umbellata). These grain legumes can be taken to scale in Western Kenya either in rotation or as intercrops with cereals, especially maize.

Improved maize-legume intercropping systems are part of ISFM technologies (Mucheru-Muna *et al*., 2010; Shyamal and Patra, 2013) that are currently receiving global attention because of their prime importance in World Agriculture, though intercropping in itself is an age-old practice. According to Bationo *et al*. (2011), intercropping maize with legumes is one of the most common cropping systems in Africa. However, in Western Kenya there is dearth of knowledge on agronomic performance, costs and benefits of intercropping. Against this backdrop, on farm demonstrations involving intercropping of maize with different legumes were conducted in four sub-Counties in Western Kenya to create awareness on maize-legume intercrops and disseminate ISFM options. As part of the on farm demonstrations, the objectives of this study were to: evaluate effect of different maize-legume intercrops on maize and legume grain yields; and analyse costs and benefits of the maize-legume intercrops.The findings of this study assist farmers, researchers and development agencies in making informed decisions on maize legume intercrops for improved productivity.

Materials and methods

The study area

The study was conducted in Emuhaya, Kakamega South, Mumias and Gem sub-Counties of western Kenya (Figure 1). These sub-Counties were purposively chosen to represent varying farming circumstances. Emuhaya, Mumias and Gem fall in the Lower Midland (LM) Agro ecological zone, whilst Kakamega South is predominantly in the Upper Midland zone with higher agricultural potential compared to LM (Jaetzold *et al*., 2006).

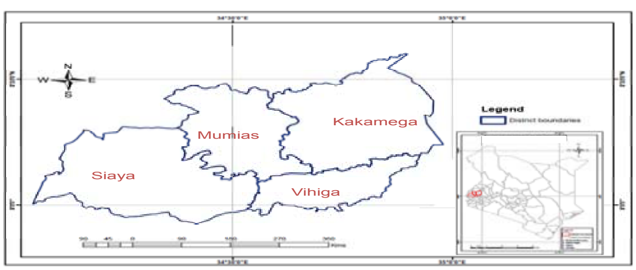

Figure 1: Geographical location of the study sites in Western Kenya

Experimental design

During the long rain croppin-g seasons of 2010 and 2011, on-farm demonstrations were set up in -Kakamega South, Mumias, Emuhaya and Siayasub-Counties. The demonstrations consisted of four treatments: 1. maize-bean; 2.maize -soyabean, 3.maize-monocrop, and 4. maize-groundnut. The treatments were selected by researchers and extension agents in consultation with farmers. The demonstrations were laid out in randomized complete block design (RCBD), each treatment occupying 10 x 10 m plot and replicated on 12 farms per season for two seasons. Recommended fertilizer rate of 60 kg N ha^{-1} and 26 kg P

ha^{-1} was applied. Maize was planted at 75×30 cm and legumes were inter-cropped following recommended spacing of 10 cm intra-row spacing.

Data collection and analysis

Agronomic data that was collected included maize and legume yields, whilst economic data entailed production costs and benefits of each treatment. In estimating the cost of production, only the variable cost items were considered. The variable costs were the expenditure on legume seed and labor. Other costs such as those of fertilizers, maize seed, and weeding were constant across the treatments were recorded but not applied in this analysis. The agronomic data were evaluated by Analysis of Variance (ANOVA) and Benefit cost ratios (BCR) were applied in financial analysis.

Benefit-cost analysis provides a framework for predicting the likelihood of adoption of ISFM options using the principles of (1) economic threshold: act only if the benefits of acting outweigh the costs, and (2) input/output optimization: when choosing among multiple options such as ISFM, choose the one that maximizes net benefits (Walker, 2012). Under this general framework, a farmer is expected not to choose a given ISFM strategy unless the net benefit of doing so is positive. Following Dixon and Hufschmidt (1986) benefit - cost ratio was calculated as: Total Revenue (TR)/Total Variable Costs (TVC). The TR was obtained by adding income from maize and legume grains, while total cost was obtained by adding all the expenditures that varied across treatments in the production process. An option with higher ratio is more profiTable. A benefit-cost ratio lower than one means the option is not profiTable.

Results and discussion

Maize yields

The highest mean grain maize yields were obtained from maize-bean, followed by maize-groundnut treatments. Analysis by sub-Counties shows that the highest grain maize yield (6.8 t ha^{1}) was from maize - groundnut intercrop in Mumias sub-County (Table 1). The lowest yield was from sole maize, planted without fertilizer as a control. There were significant differences between the control and the other treatments in all study sub-Counties except in Emuhaya sub-County. A similar study by Nzabi *et al*. (2000) in Kisii Kenya showed that maize intercropped with soybeans gave yield of 3.2 t ha^{-1} whilst sole stand of maize with no crop residue incorporation, as was in this study, had the lowest mean grain yield of 2.9 t ha^{-1}.

Table 1: Maize grain yields (t ha^{-1}) in maize-legume intercrops in Western Kenya (Long rains 2010 and 2011)

	Yield (t ha^{-1})				
Treatment	**Emuhaya**	**Gem**	**Kakamega South**	**Mumias**	**Pooled mean**
Maize-bean	4.08	4.89	3.76	6.12	4.77
Sole maize	1.16	2.88	0.9	0.31	1.02
Maize-groundnut	1.69	4.13	4.64	6.82	4.72
Maize soyabean	2.77	3.7	3.83	5.94	4.41
Mean	**2.68**	**3.9**	**4.14**	**6.32**	**4.6**
LSD (P<0.05)	3.46	1.69	1.37	1.54	1.36
CV (%)	36.68	21.74	34.16	21.9	35.11

Means with the same letter in the same column are not significantly different at (P<0.05)

Source: Authors' analysis of on-farm demonstrations (2010 and 2011)

With regard to legume yields, again there were no significant yield differences across sites (Table 2). However, the highest yield was obtained from maize-bean intercrop in Emuhaya sub-County. This could be attributed to the growth habit of the beans which enables it to be more compatible with maize. The general low yields of legumes could be attributed to the high incidences of legume diseases (e.g., bean root rot, anthracnose) and pests (e.g., aphids) during the long rains, when moisture and temperatures are conducive for prevalence of diseases and pests

Table 2: Legume yields (t ha^{-1}) in maize-legume intercrops in Western Kenya (Long rains 2010 and 2011)

	Yield (t ha^{-1})		
Sub-County	**Beans**	**Groundnut**	**Soybean**
Emuhaya	0.72a	-	0.25a
Gem	0.61a	0.61a	0.26a
Kakamega South	0.54a	0.22a	0.46a
Mumias	0.30a	0.21a	0.32a
LSD (P<0.05)	0.62	0.41	0.34
CV (%)	31.23	18.62	27.81

Means crop not planted at site

Benefit-cost analysis of maize-legume intercrops in Western Kenya

Benefit-cost analysis (BCA) of the 2010 and 2011 long rains seasons maize and legume crop yields indicate that the maize-bean intercrop yielded both the highest net benefits of KSh.. 57,216 and benefit-cost ratio (BCR) of 2.5 followed by maize-groundnut (2.1). Sole maize crop gave the lowest BCR (Table 3).

Table 3: Benefits and costs of maize-legume intercrops in Western Kenya (Long rains 2010 and 2011)

Cost/Revenue item	**Costs and revenue (Ksh.)**			
	Maize-bean	**Maize-groundnut**	**Maize soyabean**	**Sole maize (no fertilizer)**
Maize revenue	85860	84960	79380	16524
Legumes revenue	10800	5670	2880	0
Total Revenue	96660	90630	82260	16524
Total Variable costs	39444	43179	39754.5	9088.2
Net Benefit	57216	47451	42505.5	7435.8
Benefit /cost ratio (BCR)	2.45	2.10	2.07	1.82

Treatments that had higher net benefits also had a higher benefit-cost ratio (BCR) as exemplified by results in Table 3. It is, however, noteworthy that net benefit alone could be misleading as far as cost effectiveness of the different soil fertility amendment inputs is concerned. Therefore, BCR seems to be the most appropriate and convenient economic tool for determining the most economical soil fertility amendment technologies because it is a comparison between net benefits and costs thus showing the return per shilling invested. The factors associated with differential BCR amongst the treatments include field cost of legume seed, grain legume prices and cost of labour.

The findings support an earlier study conducted in Western Kenya by Odendo and Kalybara (2004) that found that changing from sole maize cropping to maize-bean intercropping resulted in a Marginal rate of return (MRR) of 370%, in which they concluded that growing maize in association with beans was overwhelmingly advantageous compared with planting maize as a sole crop. Similarly, Mucheru-Muna *et al*. (2010) found out that legume intercrop increased crop yields and economic benefits in the in the

highlands of Central Kenya. Moreover, Yilmaz *et al*. (2008) reported 65-34% increase in monetary profit per unit area in intercropping legumes with maize compared to sole legume or sole maize planting.

Overall, this study confirms that maize-legume intercropping systems are a sound means of yield improvement for the fact that it involves integrating crops through efficient use of resources, reductions in costly inputs (Morris and Garrity, 1993) and increase in productivity per unit of land per unit time (Sullivan, 2003). One of the main reasons for higher yield in intercropping is that the component crops are able to use growth resources differently, so that when grown together, they complement each other and make better overall use of growth resources than when grown separately (Willey, 1979; Shyamal and Patra, 2013). Besides, intercropping leads to equiTable and judicious utilization of land resource and inputs including labour, whilst providing insurance against crop failure (Singh and Bajpai, 1991).

Conclusions and recommendations

There were significant differences in maize grain yields, except in Emuhaya sub-County. The highest maize grain yields (4.8 t ha^{-1}) were obtained from maize-bean, followed by the maize-groundnut (4.7 t ha^{-1}) intercrops. Similarly, there were no significant differences in legumes grain yields across the study counties. Amongst the legumes, soybean gave the highest grain yield (0.5 t ha^{-1}).The highest benefit-cost ratio of 2.5 was obtained from maize-bean intercrop and the lowest (1.9) was from sole-maize crop.

From the findings of this study, research should explore more innovative maize-legume intercropping and rotational systems that optimize the yields of both legumes and maize. This should involve intercropping patterns and development of an improved strategies for controlling legume diseases and pests. The findings of this study also point to the need to develop policies that promote smallholder farmers' access to efficient input and output markets.

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Effects of different Maize (Zea mays L.) – Soybean (Glycine max (L.) Merrill) Intercropping Patterns on Soil Mineral-N, N-uptake and Soil Properties

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Abstract

The adoption of ISFM technologies such as maize-soybean intercropping system is being promoted as one of the options to address low soil fertility and crop productivity among the farmers of the central highland of Kenya. The purpose of this study was therefore to determine the effects of maize-soybean intercropping patterns on soil inorganic N, N uptake and soil chemical properties. The experiment was conducted during 2012 LR and 2012 SR and arranged in a randomized complete block design (RCBD) with four replications. The treatments were four: maize (M) – soybean (S) intercropping patterns (conventional=1M:1S; MBILI-MBILI=2M:2S; 2M:4S; 2M:6S) and two sole crops of maize and soybean, respectively. The results showed that at Embu during 2012 LR, at harvest the MBILI and 2M:4S treatments observed significantly (p=0.05) the lowest N03- - N content (8.24 mg kg-1 and 9.15 mg kg-1, respectively); and at Kamujine during the same 2012 LR, at harvest the sole soybean treatment recorded statistically (p = 0.0301) the highest N03- - N content (8.24 mg kg-1). At Embu site the soil mineral N was not significantly affected by the intercropping patterns. Whereas, at Kamujine the sole soybean treatment recorded statistically (p=0.0131) the highest (12.84 mg kg-1) soil mineral N. The N uptake by maize and soybean was significantly affected by the intercropping patterns and it was positively correlated with soil mineral N, at both sites during the sampling period. During 2012 SR at Embu site, the MBILI treatment observed significantly the highest soil total N value of 0.05% (p=0.0530). The soil SOC was not significantly affected by the intercropping patterns at this location. At Kamujine site, the soil total N was not affected by the intercropping patterns. The SOC was significantly affected by the intercropping and the conventional treatment recorded the highest value of 2.46%, p=0.0020.

Key words: maize-soybean; intercropping patterns; soil mineral-N; N-uptake; chemical soil properties; central highlands; Kenya.

Introduction

Soil fertility depletion in smallholder farms is the fundamental biophysical root cause for declining per capita food production in SSA (Mugwe *et al.*, 2007). An average of 660 kg N ha-1, 75 kg P ha-1, and 450 kg K ha-1 has been lost during the last 30 years from about 200 million ha of cultivated land in 37 African countries (Smaling *et al.*, 1997). The major reasons for the nutrient depletion process are (i) the breakdown of traditional practices and (ii) the low priority given to the rural sector (Sanchez *et al.*, 1997). Increasing pressures on agricultural land have resulted in much higher nutrient outflows and the subsequent breakdown of many traditional soil fertility maintenance strategies, such as fallowing land, intercropping cereals with legume crops, mixed crop-livestock farming, and opening new lands (Sanchez *et al.*, 1997). Thus, continued population pressure has reduced farm sizes to the point where farms can only provide adequate living for their families if the land is farmed very intensively and if there is off-farm income (Sanchez *et al.*, 1997). Luck of an effective fertilizer supply and distribution system has resulted in reduced crop productivity and food insecurity as the main consequences of the soil fertility depletion in Africa (Palm *et al.*, 1997). Therefore, it is necessary to adopt improved and sustainable technologies in order to guarantee improvements in food productivity and thereby food security (Landers, 2007; Gruhn *et al.*, 2000). Such technologies include the use of integrated soil fertility management practices (ISFM) such as intercropping cereals with grain legumes as one of its main components (Mucheru-Muna *et al.*, 2010;

Sanginga and Woomer, 2009). Cereal – grain legume intercropping has potential to address the soil nutrient depletion on smallholder farms (Sanginga and Woomer, 2009). The legumes play an important role in nitrogen fixation (Peoples and Craswell, 1992), and are important source of nutrition for both humans and livestock (Nandwa *et al*., 2011). In the central highlands of Kenya, cereal – legume intercropping is already being widely practiced by the smallholder famers. According to Sanginga and Woomer (2009) intercropping cereal and grain legume crops helps maintain and improve soil fertility, because crops such as cowpea, mung bean, soybean and groundnuts accumulate from 80 to 350kg nitrogen (N) ha-1 (Peoples and Craswell, 1992). For instance, soybean can positively contribute to soil health, human nutrition and health, livestock nutrition, household income, poverty reduction and overall improvements in livelihoods and ecosystem services, than many others leguminous grain crops (Rakasi, 2011; Raji, 2007). Improved intercropping systems are part of ISFM technologies (Mucheru-Muna *et al*., 2010; Sanginga and Woomer, 2009) and in central highlands of Kenya the information is scarce regarding to optimum cropping pattern of maize-soybean intercropping system, and regarding to its effect on soil chemical properties.

Materials and methods

Study area

The experiment was carried out in two sub counties of central highlands of Kenya, namely Embu West and Tigania East sub counties. Embu West District is located in Embu County, in the central highlands of Kenya, and occupies an area of 708 Km2. The experimental site lies within N 0° 31´ 4.2´´ E 370 27´ 20´´ and at the altitude of 1468 m above the sea level (ASL), at Embu Agricultural Staff Training College (Jaetzold *et al*., 2006). The average annual rainfall varies from 909 to 1230 mm with long rainy season between March and June and short rainy season between October and December, respectively. Tigania East Sub County is located in Meru County, in the central highlands of Kenya and it occupies 108.6 km2. The experimental site lies within N 0° 6´ 19.5´´ E 037° 64´ 39.6´´ and at the altitude of 935 m above the sea level (ASL), at Kamujine Dispensary in Mikinduri Division. The average annual rainfall varies from 1000 to 2200 mm with long rainy season between March and June and short rainy season between October and December, respectively (Jaetzold *et al*., 2006) Table 1 shows the soil characteristics of the soils in Embu and Kamujine.

Table 1: Soil Characteristics at Embu – ATC and Kamujine sites, Kenya

Soil parameter	Embu – ATC Site	Kamujine Site
pH in water (1:2.5)	5.30	5.50
Total N (%)	0.03	0.01
Total soil organic carbon (%)	2.64	1.88
ExtracTable P (ppm)	13.40	9.54
Exchangeable Ca (C mol kg-1)	0.22	0.21
Exchangeable Mg (C mol kg-1)	0.53	0.53
Exchangeable K (C mol kg-1)	0.12	0.08
Clay (%)	65	45
Sand (%)	17	20
Silt (%)	18	35

Experimental design and management

First, composite soil samples from the experimental sites were collected at 0 – 15 cm depth for analysis for organic carbon, total nitrogen using standard methods (Okalebo *et al*., 2002), extracTable P, Ca, Mg, K, Na using Mehlich-1 (M1) extraction method, where P and Mg2+ were determined colourimetrically in a spectrophotometer and Ca2+, and K + were determined using flame photometer. The experiment was laid out as a randomized complete block design (RCBD) with four replicate blocks and plot size measuring 7 m

x 4.5 m. The cropping system was of sole maize (Zea mays L.), sole soybean (Glycine max (L.) Merrill) and maize (M) – soybean (S) intercropping with cropping patterns (Table 2).

Table 2: Treatments in the two sites (ATC-Embu and Kamujine)

Treatment	Cropping system	Treatment	Cropping system
T1	Sole maize	T4	Maize-Soybean (2:2)
T2	Sole soybean	T5	Maize-Soybean (2:4)
T3	Maize-Soybean (1:1)	T6	Maize-Soybean (2:6)

Soil sampling and determination of soil mineral N

Soil sampling was done during two seasons, in March long rain (LR) and in October short rain (SR) of 2012, at the beginning of the season before planting, at 0 – 15 cm depth (t0). Subsequent samples was taken at 2, 4, 6, 8, 12, 16 and 20 weeks after planting (WAP) at the same depth, in all plots, during the LR season (March-August/2012). The soil samples was taken at 10 different spots per plot then bulked to give one composite sample, this aimed to eliminate the variability of inorganic N. Then, the soil samples was packed in cooler boxes and delivered to the laboratory within 24 hours. To avoid any further mineralization before extraction, the samples were stored in the fridge at 5 °C. The soil extraction was done using 2M KCl, then the analysis of extracTable nitrate (NO3-) though a flow injection system, using cadmium reduction column method, followed by determination of extracTable ammonium using colorimetric method through a flow injection system (Okalebo *et al.,* 2002).

Determination of maize and soybean N uptake

Destructive random sampling of maize and soybean plants was carried out at 4, 6, 8, 12, 16 and 20 WAP (harvest) for determination of N concentration in the plant tissue. This sampling was done outside the net plots. The samples were then oven-dry at 60 °C for 48 hours, milled and sieved through a 1.0 mm sieve and then analyzed separately for nitrogen concentration using Kjeldahl acid digestion method, followed by colorimetry method (Okalebo *et al*., 2002). Nitrogen uptake by maize and soybean crops was determined by multiplying the dry matter yields (kg ha-1) with nitrogen concentration (%).

Determination of the soil chemical properties

The soil samples that were taken for mineral N determination was also measured on 2.5:1 water to soil suspension for pH using pH meter model AD1000. The same samples were used to determine the extracTable phosphorous (P) and the exchangeable cations (Na+, K +, Ca2+ and Mg2+) though Mehlich-1 (M1) extraction method, where P and Mg2+ were determined colourimetrically in a spectrophotometer and Ca2+, K + and Na+ were determined using a flame photometer. Total N was determined though Kjeldahl acid digestion method, using an automatic CN elemental analyzer 2000, while organic carbon was determined by the sulphuric acid and aqueous potassium dichromate mixture, also , using an automatic CN elemental analyzer 2000.

Data analysis

Data of soil mineral N, N uptake by maize and soybean, and soil chemical properties were subjected to analysis of variance using SAS version 8. To test the differences between different cropping pattern and conventional intercropping systems, the means were subjected to t-student test at 95 per cent of significance level ($p<0.05$). The correlations between soil inorganic N and N uptake were done using Pearson Correlation Coefficient (r).

Results and discussion

Soil mineral N

At Embu during 2012 LR, no significant differences were observed in soil nitrate – N content (N03- - N) as affected by the intercropping patterns during all the sampling periods, except at 12 WAP where the 2M:4S

treatment observed significantly (p=0.0285) the highest N03- - N content (9.01 mg kg-1) than all other treatments, excluding sole maize treatment; and at harvest (20 WAP) where the MBILI and 2M:4S treatments observed significantly (p=0.05) the lowest N03- - N content (8.24 mg kg-1 and 9.15 mg kg-1, respectively) than the sole soybean and conventional treatments, with 14.95 mg kg-1 and 14.62 mg kg-1, respectively. This indicated that intercropping reduced the soil nitrate that moved to region where it couldn't be easily absorbed by plant roots. At Kamujine during the same 2012 LR, no significant differences were also observed in soil nitrate – N content (N03- - N) as affected by the intercropping patterns during all the sampling periods, except at 20 WAP where sole soybean treatment recorded statistically (p = 0.0301) the highest N03- - N content (8.24 mg kg-1) than all other treatments, excluding the 2M:4S treatment (Table 3).

The lower soil nitrate content observed at harvest (20 WAP) in maize – soybean intercrop was also reported by Ye *et al*., (2008). Li *et al*. (2005) and, Zhang and Li (2003) reported that intercropping maize with faba beans decreased the soil nitrate – N content at harvest. Intercropping faba beans with wheat reduced the nitrate concentration in soil profile (Stuelpnagel, 1993). This might be due to the complimentary root distribution of cereal/legume intercrop or the increased time of plant uptake of N by maize in intercropping systems (Li *et al*., 2005). For instance, Li *et al*. (2005) found that in the maize – faba beans system, maize roots were distributed in both the profiles of maize and faba beans. Thus, maize could utilize the nitrate in the strip of intercropping faba beans (Li, 1999).

Table 3: Soil nitrate-N at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu and Kamujine sites

Location	Treatment	Weeks After Planting						
		0	4	6	8	12	16	20
		………… Nitrate – N (NO3⁻ - N) mg kg-1 ………....						
Embu	Sole maize	5.19	9.18	6.55	6.65	6.72	4.59	8.24
	Sole soybean	7.42	9.81	8.62	7.83	5.78	5.76	14.95
	Maize-Soybean (1:1)	6.95	11.36	6.06	8.17	4.71	5.01	14.62
	Maize-Soybean (2:2)	10.22	6.08	7.80	8.77	5.66	5.10	12.20
	Maize-Soybean (2:4)	8.77	10.07	6.50	8.07	9.01	5.56	9.15
	Maize-Soybean (2:6)	8.76	8.50	7.49	5.53	4.69	7.16	10.38
p-value		ns	ns	ns	ns	0.0285*	ns	ns
LSD(0.05)		5.36	4.04	5.52	5.23	2.62	3.69	5.01
Kamujine	Sole maize	13.31	5.75	7.38	5.47	5.12	5.17	3.73
	Sole soybean	12.87	9.37	9.00	8.79	8.06	6.67	8.24
	Maize-Soybean (1:1)	10.71	8.51	6.25	4.12	4.38	4.08	3.78
	Maize-Soybean (2:2)	11.94	6.31	4.14	5.57	3.40	4.30	3.14
	Maize-Soybean (2:4)	14.72	6.40	6.38	6.06	5.76	5.32	6.14
	Maize-Soybean (2:6)	9.53	8.04	6.62	6.51	4.01	4.93	1.66
p-value		ns	Ns	ns	ns	ns	ns	0.0301*
LSD(0.05)		6.70	5.71	3.86	2.80	3.13	2.84	3.90

ns – not significant; *significant at p ≤0.05;

At Embu during 2012 LR, no significant differences were observed in soil ammonium – N content (NH4+ - N) as affected by the intercropping patterns during all the sampling periods. Similar results were also observed at Kamujine, where the treatments had no significant effect of soil ammonium – N (Table 4). This signified that the intercropping patterns had little effect on soil ammonium nitrogen. Similar results were also observed by Huang *et al*. (2011) who did not find significant differences on soil ammonium N under maize-legume intercropping systems.

Table 4: Soil ammonium-N at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu and Kamujine sites

Location	Treatment	Weeks After Planting						
		0	4	6	8	12	16	20
		………. Ammonium – N (NH_4^+ - N) mg kg-1 ………..						
	Sole maize	5.24	5.07	5.82	4.96	5.87	2.99	3.54
	Sole soybean	7.45	5.89	4.14	2.28	3.03	3.90	2.32
Embu	Maize-Soybean (1:1)	7.64	3.86	3.96	2.99	7.63	6.06	2.52
	Maize-Soybean (2:2)	7.31	4.78	4.61	3.41	3.77	4.14	3.75
	Maize-Soybean (2:4)	8.67	4.69	6.26	2.56	5.64	5.16	6.32
	Maize-Soybean (2:6)	9.31	5.23	8.67	6.36	4.91	3.80	2.59
p-value		ns	ns	ns	ns	ns	ns	ns
LSD(0.05)		6.92	2.91	4.29	3.12	5.06	4.57	4.63
	Sole maize	6.42	5.11	4.84	3.25	3.53	1.72	3.78
	Sole soybean	6.86	5.29	2.39	5.59	6.28	5.62	4.60
Kamujine	Maize-Soybean (1:1)	5.84	4.33	6.95	5.42	3.49	5.17	3.45
	Maize-Soybean (2:2)	3.96	3.71	3.79	4.62	6.99	4.77	2.89
	Maize-Soybean (2:4)	7.51	6.53	6.85	1.27	5.16	5.49	3.12
	Maize-Soybean (2:6)	6.11	5.66	4.73	4.47	6.48	3.98	4.10
p-value		ns	ns	ns	ns	ns	ns	ns
LSD(0.05)		4.41	3.97	5.87	3.56	4.91	3.88	2.38

ns – not significant; *significant at $p \leq 0.05$; **significant at $p < 0.01$; ***significant at $p < 0.001$

At Embu during 2012 LR, no significant differences were observed in soil mineral – N content as affected by the intercropping patterns during all the sampling periods (Table 5). Similarly, Hauggaard-Nielsen, *et al.,* (2001a) did not find significant differences on soil mineral N at harvest in the 0-25cm soil layer under pea sole crop compared to the other treatments. The increase on soil mineral N for sole soybean and some of the intercropping treatments was also reported by Rusinamhodzi (2006) who found that soil mineral N had increased in sole cowpea and cowpea-cotton treatments but not sole cotton cropping system. At Kamujine during 2012 LR, no significant differences were also observed in soil mineral – N content as affected by the treatments during all the sampling periods, except at 20 WAP where sole soybean recorded statistically (p = 0.0131) the highest (12.84 mg kg-1) soil mineral N than all other treatments, excluding 2M:4S treatment (Table 5). Similarly, Hauggaard-Nielsen, *et al.,* (2001b) observed higher soil mineral N at harvest in the 0-25cm soil layer under pea sole crop compared to the other treatments independent of cropping strategy. Hauggaard-Nielsen *et al.,* (2001c) (2001c) reported that the lowest soil inorganic N deficit was observed in pea sole crop and the greatest in barley sole crop. This suggests that legume and non-legume intercrops are not likely to increase soil N in the long term, but rather deplete it (Nielsen *et al*. ,

2001c). As an average of four years experimentation Jensen (1996) equivalently concluded that the N balance was positive for sole cropped pea, whereas it was negative for barley and pea-barley in all years.

Table 5: Soil mineral – N at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu and Kamujine sites

Location	Treatment	Weeks After Planting						
		0	4	6	8	12	16	20
		Soil mineral N (mg kg-1) ………..						
	Sole maize	10.42	11.15	13.61	13.73	11.53	8.08	15.74
	Sole soybean	14.87	15.70	12.76	10.10	8.81	9.66	17.28
Embu	Maize-Soybean (1M:1S)	15.59	15.22	10.01	11.16	12.34	11.07	17.14
	Maize-Soybean (2M:2S)	17.53	13.96	11.16	10.07	10.48	8.73	11.99
	Maize-Soybean (2M:4S)	17.44	14.76	12.86	10.64	14.64	10.68	15.47
	Maize-Soybean (2M:6S)	18.07	13.72	16.16	11.89	9.60	10.96	12.98
p-value		ns	ns	ns	ns	ns	ns	ns
LSD(0.05)		7.38	5.23	6.89	6.64	5.02	5.48	7.34
	Sole maize	19.73	10.86	12.22	9.42	8.66	6.89	7.15
	Sole soybean	19.73	14.66	11.39	13.68	14.34	12.29	12.84
Kamujine	Maize-Soybean (1M:1S)	16.55	12.83	13.20	9.54	7.87	9.25	7.23
	Maize-Soybean (2M:2S)	15.90	10.03	7.93	10.19	10.39	9.07	6.04
	Maize-Soybean (2M:4S)	22.23	12.93	13.23	7.33	10.92	10.81	9.26
	Maize-Soybean (2M:6S)	15.64	13.70	11.35	10.98	10.49	8.91	5.75
p-value		ns	ns	ns	ns	ns	ns	0.0131*
LSD(0.05)		8.08	7.07	7.11	4.81	6.06	4.62	3.88

ns – not significant; *significant at $p\leq0.05$; **significant at $p<0.01$; ***significant at $p<0.001$

Nitrogen uptake by maize and soybean

At Embu during 2012 LR, the N uptake of maize and soybean was significantly affected by the intercropping patterns (Table 6). For instance, at 4 WAP the sole soybean yielded significantly the highest N amount (2.75% N, p=0.0026) than all other treatments, excluding intercropped soybean. This was strongly correlated (r=0.81; p=0.0988) with soil mineral at the same sampling period (4 WAP); however the correlation was not significant at p=0.05. At 16 WAP and at harvest the sole soybean had accumulated significantly the lowest N (0.35 per cent N, p<0.0001 and 0.33% N, p<0.0001, respectively) than all other treatments, except soybean under 2M:2S, 2M:4S and 2M:6S treatments. Also, the N uptake by soybean during this period was positively correlated (r=0.48; p=0.4125) with soil mineral N at the same sampling period. For the grain, monocropped soybean had accumulated significantly the highest amount of N (5.59% N, p<0.0001) than all other treatments, excluding soybean under conventional and MBILI treatments. The N accumulated in maize grain was positively correlated with soil mineral N at 4 and 16 WAP, with r=0.87 (p=0.0543) and r=0.81 (p=0.0995), respectively. In general, the N accumulation by maize under intercropping treatments was generally lower than that for sole cropping, particularly up to 12 WAP. During 2012 LR at Kamujine site, intercropping systems affected significantly the N acquisition by maize and soybean (Table 6). For instance, at 4 WAP the soybean under MBILI treatment had accumulated significantly the highest N (3.26% N, p<0.0001) than maize under different treatments. During this time the N uptake was highly positively correlated (r=0.79; p=0.1089) with soil mineral N of the same sampling

period. At 6 WAP the soybean under conventional treatment yielded significantly the highest N (4.28% N, $p<0.0001$) than all other treatments. At 8 WAP the soybean sole acquired significantly the highest N (3.16% N, $p=0.0102$) than sole maize and maize under conventional, MBILI, and 2M:6S treatments. At this time the N uptake by maize was significantly positively correlated ($r=0.88$; $p=0.051$) with soil mineral N of the same period. At 12 WAP still the sole soybean observed significantly the highest N (3.31% N, $p=0.0031$) than all other treatments, excluding soybean under 2M:4S treatment. During this sampling period, the amount of N accumulated by soybean was highly significantly positively correlated ($r=0.91$; $p=0.0301$) with soil mineral N of the same period and soil mineral N at 16 WAP ($r=0.89$; $p=0.0437$), respectively. Whereas towards the end of season (at 16 WAP) the maize under MBILI treatment acquired statistically the highest N (1.75% N, $p=0.0053$) than all other intercropping patterns. At harvest, still the maize under MBILI treatment accumulated significantly the highest N (1.68% N, $p=0.0176$) than all other treatments, except sole maize, sole soybean and maize under conventional treatments. At this moment the amount of N yielded by soybean was strongly correlated ($r=0.78$; $p=0.1201$) with the soil mineral N for the period. For the grain, the maize under various treatments had accumulated significantly ($p<0.0001$) the lowest N level than the entire soybean, sole and intercropped (Table 6).

Table 6: Effects of intercropping patterns on N uptake (%) by maize and soybean during 2012 LR at Embu and Kamujine sites

Location	Treatment	Crop	Weeks After Planting						
			4	6	8	12	16	20	
			Stover						Grain
Embu	Sole maize	Maize	1.69	1.73	2.79	2.52	1.78	1.67	1.13
	Sole soybean	Soybean	2.75	1.96	2.88	1.48	0.35	0.33	5.59
	Maize-Soybean (1M:1S)	Maize	1.30	1.69	2.67	2.18	1.95	1.83	1.66
		Soybean	2.59	2.02	2.98	2.19	1.21	1.17	5.44
	Maize-Soybean (2M:2S)	Maize	1.38	1.39	2.80	2.02	2.16	2.03	1.62
		Soybean	2.43	2.02	3.34	2.08	0.53	0.50	5.17
	Maize-Soybean (2M:4S)	Maize	1.82	1.87	2.72	2.45	1.88	1.77	1.90
		Soybean	2.25	2.07	3.53	2.07	0.60	0.57	4.21
	Maize-Soybean (2M:6S)	Maize	1.02	1.34	2.33	2.39	1.90	1.71	1.77
		Soybean	2.20	1.90	2.93	1.99	0.45	0.44	4.66
p – value			0.0026**	ns	ns	ns	<0.0001***	<0.0001***	<0.0001***
LSD(0.05)			0.86	0.74	0.80	0.94	0.73	0.68	0.71
Kamujine	Sole maize	Maize	1.60	1.66	197	1.43	1.07	1.03	0.98
	Sole soy	Soybean	3.00	2.60	3.16	3.31	0.69	1.10	5.07

bea n									
	Maize-Soybean (1M:1S)	Maize	1.24	1.61	1.78	1.43	1.04	1.00	1.40
		Soybean	2.87	4.28	2.97	2.22	0.26	0.26	5.39
	Maize-Soybean (2M:2S)	Maize	1.31	1.33	2.05	1.77	1.75	1.68	1.10
		Soybean	3.26	2.79	2.68	1.72	0.38	0.37	4.88
	Maize-Soybean (2M:4S)	Maize	1.73	1.79	2.43	1.79	0.61	0.59	0.89
		Soybean	2.79	2.12	2.98	2.84	0.71	0.71	4.91
	Maize-Soybean (2M:6S)	Maize	0.97	1.28	2.27	1.09	0.86	0.83	1.47
		Soybean	3.20	3.19	2.72	1.78	0.99	0.70	4.65
p – value			<0.0001 ****	<0.0001*	0.0102 **	0.0031**	0.0053 **	0.0176*	<0.0001 ***
LSD(0.05)			0.87	0.99	0.78	1.00	0.65	0.70	0.78

ns – not significant; *significant at p≤0.05; **significant at p<0.01; ***significant at p<0.001

The greater N acquisition by a non-legume crop intercropped with a legume is frequently reported in literature (Francis, 1986; Vandermeer, 1989; Stern, 1993; Li *et al.,* 2001; Shata *et al.,* 2007). In cereal-legume intercropping, an increase in N acquisition may be derived in two ways. First, the difference in competitive abilities of component species may increase N uptake by cereal, which in most cases has higher competitive ability relative to legume. This may conversely stimulate nodulation in legume, as noted Rerkasem *et al*. (1988) for beans intercropped with maize. Second, an increase in N acquisition may also be attributed to N transfer to cereal from legume (Brophy, Heichel, and Russelle, 1987). The higher N facilitation may enable cereal to absorb more N in intercropping systems than in sole cropping systems, or it may increase the N fixation ability of legumes and may transfer from legume to cereal (Ning *et al.,* 2012). However, in the experimental sites of this study the soils are moderately acidic (pH=5.33 and pH=5.46, at Embu and Kamujine sites, respectively), limiting phosphorus availability which affect the BNF process and therefore lessen the N contribution of the legume component to system. Furthermore, according to Jones and Giddens (1985) there are a number of factors that affect N2 fixation by legume in acid soil. The number of compactible rhizobia in the rhizosphere and the degree of infection of the root by the bacteria are important factors which are controlled by environmental conditions such as soil pH. Thus, in cereal-legume intercropping, without N-fixing and transfer, the N demand of each intercrop may also increase N competition, particularly when relatively low amount of fertilizer-N and soil-N are used (Li *et al*., 2003a; Li *et al*., 2003b). Simpson (1965) stated that in some of the intercropping systems, competition by the legume for N is high and results in reduced N uptake by the cereal, and in this study it resulted in higher uptake by soybean as compared to the maize component. On the other hand, the higher N uptake by maize observed under MBILI treatment at Kamujine site could be due to the fact that during that time the legume component had accomplished its N requirements and about to be harvested. Therefore, the competition for N could be reduced to its minimum.

Effects of maize – soybean intercropping patterns on chemical soil properties

At Embu site, before planting the pH values were not significantly different (p=0.6585) from one treatment to another, and were ranging between 5.30 (for conventional and MBILI treatments) and 5.37 (for sole soybean treatment). After harvesting the first (2012 LR) and second (2012 SR) seasons they were not significantly (p=0.5581 and p=0.7956, respectively) affected by the treatments. However, they experienced a general decrease from the preseason to post second season; the highest and lowest reduction was

observed in the sole maize (2.49%) and the conventional (0.57%) treatments, respectively. This situation was not expected because manure that was applied as blanket was supposed to have increased the soil pH in all the treatments due to its buffer capacity; but, probably the exchangeable cations were leached from the topsoil (0-15 cm) because of the heavy rains that were registered during the seasons. At Kamujine site, although there were also no significant differences in the three sampling periods (p=0.3046, p=0.1946 and p=0.0835, respectively), the situation was slightly different from Embu site because the pH values increased from the preseason to post second season, where the sole maize recorded the highest increase (8.31%) and 2M:6S treatment with the lowest value of 4.03% (Table 7).

At Embu site, the available phosphorus values did not show any significant differences (p=0.2373, p=0.6963, p=0.3224, respectively) among the treatments, during all the sampling periods. However, the P values were generally decreased from the preseason to the post second season, varying from 66.83 in the 2M:6S treatment to 35.82% (in the conventional treatment). Similar situation was observed at Kamujine site, where P values were also not significantly different in the three sampling periods (p=0.7243, p=0.6508 and p=0.6775, respectively). However, they also decreased from the preseason to post second season, with values varying from 57.56% (conventional treatment) to 37.74% in the MBILI treatment (Table 7).

Table 7: Effect of intercropping patterns on soil chemical properties during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Treatment	pH (water, 1:2.5)			P (ppm)		
		Before	2012LR	2012SR	Before	2012LR	2012SR
	Sole maize	5.36	5.20	5.23	12.85	12.81	8.43
	Sole soybean	5.37	5.20	5.26	13.21	13.74	7.94
Embu	Maize-Soybean (1M:1S)	5.30	5.32	5.27	12.21	15.03	8.99
	Maize-Soybean (2M:2S)	5.30	5.34	5.26	12.65	13.39	8.93
	Maize-Soybean (2M:4S)	5.36	5.32	5.30	15.78	13.62	9.31
	Maize-Soybean (2M:6S)	5.31	5.25	5.22	13.68	13.46	8.20
p-value		0.6585	0.5581	0.7956	0.2373	0.6963	0.3224
LSD(0.05)		0.12	0.21	0.13	3.09	2.86	1.40
	Sole maize	5.41	5.62	5.90	9.50	10.84	6.21
	Sole soybean	5.43	5.51	5.71	9.50	12.15	6.64
Kamujine	Maize-Soybean (1M:1S)	5.55	5.63	5.91	10.21	12.20	6.48
	Maize-Soybean (2M:2S)	5.41	5.55	5.73	8.76	13.01	6.36
	Maize-Soybean (2M:4S)	5.49	5.62	5.87	9.18	10.27	6.37
	Maize-Soybean (2M:6S)	5.48	5.49	5.71	10.02	12.56	7.20
p-value		0.3046	0.1946	0.0835	0.7243	0.6508	0.6775
LSD(0.05)		0.15	0.15	0.19	2.13	3.88	1.33

ns – not significant; *significant at $p \leq 0.05$; **significant at $p<0.01$; ***significant at $p<0.001$

At Embu site, at preseason the N03- - N values were not significantly different (p=0.4638) from one treatment to another; however, the highest value was in the MBILI treatment (10.22 mg kg-1) and the sole maize had the lowest value of 5.19 mg kg-1 N03- - N. After the harvest of the second seasons (2012 SR), they still did not show any significant differences (p=0.4249) among the treatments, where the conventional treatment observed the lowest value of 5.50 mg kg-1 N03- - N and the highest (9.05 mg kg-1 N03- - N) was

observed in the 2M:4S treatment. The situation was slightly different at Kamujine site, where during the preseason the N03- - N was not statistically different (p=0.6283) from one treatment to another at the preseason; but, after harvesting the second season (2012 SR), intercropping patterns affected significantly (p=0.0038) the N03- - N, and the sole soybean treatment had recorded statistically the highest N03- - N of 10.78 mg kg-1 than all other treatments. This could be due to senescent nodules from the roots and decomposed organic matter of two seasons.

During the preseason at Embu site, the amount of NH4+ - N was not significantly different (p=0.8610) from one treatment to another; and, it remained not statistically different (p=0.9119) after harvesting the second season. However, the NH4+ - N values experienced a general decrease from the preseason to post second season; the lowest and highest reduction was observed in the sole maize (50.57%) and the 2M:4S (116.75%) treatments, respectively. At Kamujine site, there was also no significant differences during the two sampling periods (p=0.6406, and p=0.1446, respectively). However, the sole maize treatment showed the highest NH4+ - N reduction of 166.39% and the MBILI treatment observed the lowest reduction of about 30% (Table 8).

During the preseason and 2012 SR at Embu site, the mineral – N values did not show any significant differences (p=0.2846, p=0.3474, respectively) among the treatments, during the two the sampling periods. However, the mineral – N values were generally decreased from the preseason to the post second season, varying from 60.68 in the conventional treatment to 15.36 percent in the sole soybean, excluding for the sole maize treatment which observed unexpectedly increase in mineral – N values of 11.69%. The situation was slightly different at Kamujine site, where mineral - N values were only not significantly different (p=0.4582) during the preseason; but during 2012 SR, soil mineral – N was significantly (p=0.0112) affected by the intercropping patterns; and, sole soybean treatment had observed statistically the highest amount of soil mineral – N of 13.81 mg kg-1 than all other treatments (Table 8).

Table 8: Effect of intercropping patterns on soil chemical properties (mineral – N) during 2012 SR at Embu and Kamujine sites

Location	Treatment	N03- (mg kg-1)		NH4+ (mg kg-1)		Mineral N (mg kg-1)	
		Before	2012 SR	Before	2012 SR	Before	2012 SR
Embu	Sole maize	5.19	8.32	5.24	3.48	10.42	11.80
	Sole soybean	7.42	8.73	7.45	4.16	14.87	12.89
	Maize-Soybean (1M:1S)	6.95	5.50	7.64	3.59	14.59	9.08
	Maize-Soybean (2M:2S)	10.22	7.17	7.31	4.47	17.53	11.64
	Maize-Soybean (2M:4S)	8.77	9.05	8.67	4.00	17.44	13.05
	Maize-Soybean (2M:6S)	8.76	8.25	9.31	4.45	18.07	12.70
p-value		ns	ns	ns	ns	ns	ns
LSD(0.05)		5.35	3.85	6.92	2.36	7.38	4.04
Kamujine	Sole maize	13.31	6.33	6.42	2.41	19.73	8.74
	Sole soybean	12.87	10.78	6.86	3.04	19.73	13.81
	Maize-Soybean (1M:1S)	10.71	5.55	5.84	2.73	16.55	8.27
	Maize-Soybean (2M:2S)	11.94	5.12	3.96	3.05	15.90	8.17
	Maize-Soybean (2M:4S)	14.72	7.47	7.51	3.14	22.23	10.62
	Maize-Soybean (2M:6S)	9.53	6.54	6.11	3.45	15.64	9.99
p-value		ns	0.0038**	ns	ns	ns	0.0112**
LSD(0.05)		6.70	2.57	4.41	0.78	8.08	3.06

ns – not significant; *significant at $p \leq 0.05$; **significant at $p < 0.01$

At Embu site, before planting the Ca2+ values were not significantly different (p=0.2670) from one treatment to another, and were ranging between 0.26 Cmol kg-1 for 2M:4S treatment and 0.18 Cmol kg-1 for MBILI treatment. After harvesting the first (2012 LR) and second (2012 SR) seasons they were not significantly (p=0.4209 and p=0.7795, respectively) affected by the treatments. However, they experienced a general decrease from the preseason to post second season; the highest and lowest reduction was observed in the sole maize (212.50%) and in the MBILI and 2M:6S treatments (100.0%), respectively. At Kamujine site, there were also no significant differences in the three sampling periods (p=0.6791, p=0.4224 and p=0.1715, respectively); and, similarly the Ca2+ values observed reduction at the end of 2012 SR, where the highest reduction was recorded in the MBILI treatment (214.29 per cent) and the lowest in the conventional treatment with 37.50 percent less Ca2+ than its preseason (Table 9).

At Embu site, the Mg2+ values did not show any significant differences (p=0.5922, p=0.5326, p=0.4484, respectively) among the treatments, during all the sampling periods. However, the values were slightly decreased from the preseason to the post second season, varying from 17.02 percent in the sole maize treatment to 1.89% in the sole soybean treatment. Slightly different situation was observed at Kamujine site, where Mg2+ values were only significantly (p<0.0001) affected by the treatment during 2012 SR, having sole maize treatment observed statistically the highest Mg2+ value of 0.37 Cmol kg-1 than all other treatments (Table 9).

At Embu site, the K+ values did not show any significant differences (p=0.6801, p=0.5579, p=0.3850, respectively) among the treatments, during all the sampling periods. However, the K+ values were generally decreased from the preseason to the post second season, varying from 225% in the sole maize treatment to 50% in the sole soybean treatment. Similar situation was observed at Kamujine site, where K+ values were also not significantly different in the three sampling periods (p=0.4306, p=0.3612 and p=0.4704, respectively). But differently from Embu site, at Kamujine site they showed three different trends, where in the sole maize and 2M:6S treatments the values remained constant; in the sole soybean and conventional treatments the values were slightly increased; and in the MBILI and 2M:4S treatments the values decreased from the preseason to post second season (Table 9).

Table 9: Effect of intercropping patterns on soil chemical properties (exchangeable cations) during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Treatment	Ca2+ (Cmol kg-1)			Mg2+ (Cmol kg-1)			K+ (Cmol kg-1)		
		Before	2012LR	2012 SR	Before	2012LR	2012 SR	Before	2012LR	2012 SR
Embu	Sole maize	0.25	0.24	0.08	0.55	0.49	0.47	0.13	0.10	0.04
	Sole soybean	0.20	0.19	0.07	0.54	0.54	0.53	0.12	0.12	0.08
	Maize-Soybean (1M:1S)	0.25	0.24	0.09	0.53	0.49	0.48	0.11	0.11	0.05
	Maize-Soybean (2M:2S)	0.18	0.16	0.09	0.50	0.46	0.46	0.10	0.08	0.06
	Maize-Soybean (2M:4S)	0.26	0.20	0.10	0.55	0.53	0.52	0.12	0.11	0.07

Location	Treatment	Ca2+ (Cmol kg-1)			Mg2+ (Cmol kg-1)			K+ (Cmol kg-1)		
		Before	2012LR	2012 SR	Before	2012LR	2012 SR	Before	2012LR	2012 SR
	Maize-Soybean (2M:6S)	0.20	0.18	0.10	0.51	0.44	0.44	0.11	0.10	0.05
p-value		ns	ns	Ns	ns	ns	ns	ns	ns	Ns
LSD(0.05)		0.07	0.10	0.04	0.09	0.13	0.10	0.05	0.04	0.04
Kamujine	Sole maize	0.21	0.20	0.15	0.50	0.46	0.37a	0.08	0.08	0.08
	Sole soybean	0.27	0.22	0.15	0.50	0.50	0.28cd	0.06	0.08	0.07
	Maize-Soybean (1M:1S)	0.22	0.26	0.16	0.54	0.49	0.29c	0.07	0.08	0.08
	Maize-Soybean (2M:2S)	0.22	0.22	0.07	0.53	0.52	0.26d	0.09	0.08	0.07
	Maize-Soybean (2M:4S)	0.22	0.17	0.09	0.57	0.54	0.34b	0.08	0.06	0.06
	Maize-Soybean (2M:6S)	0.18	0.22	0.10	0.49	0.58	0.33b	0.07	0.08	0.07
p-value		ns	ns	Ns	ns	ns	<0.0001***	ns	ns	Ns
LSD(0.05)		0.11	0.09	0.08	0.09	0.14	0.03	0.02	0.02	0.02

ns – not significant; *significant at p≤0.05; **significant at p<0.01; ***significant at p<0.001

During 2012 SR at Embu site, there were significant differences in soil total N as affected by intercropping patterns. For instance, the MBILI treatment observed the highest N value of 0.05 % (p=0.0530) than all other intercropping patterns, excluding the 2M:4S treatment. Whereas, the soil organic carbon was not affected by the intercropping patterns (p=0.2460); however, the 2M:6S treatment observed numerically the highest SOC value of 2.56% than all other treatments. In general, the SOC was higher under intercropping treatments than under sole cropping systems, probably due to higher crop residues produced under intercropping compared to sole cropping systems. Different situation was observed at Kamujine site, where the soil total N was not affected by the intercropping patterns (p=0.0800). This could be due to relatively slow turnover times for SOM, making the incorporation of residue into total N small. Whereas, the SOC was significantly affected by the intercropping and the conventional treatment recorded the highest value of 2.46%, p=0.0020 (Table 10). In general, the SOC at this site was not expected to be relatively low under intercropping treatments than under sole crop treatments. The higher SOC values observed at Embu site compared to Kamujine site could be due to relatively higher precipitation recorded at first location which resulted in lower mineralization rate and therefore higher SOC.

Table 10: Effect of intercropping patterns on soil chemical properties (soil total N and SOC) during 2012 SR at Embu and Kamujine sites

Location	Treatment	Soil total N (%N)	Soil Organic C (%C)
Embu	Sole maize	0.01	2.48
	Sole soybean	0.02	2.48
	Maize-Soybean (1M:1S)	0.02	2.50
	Maize-Soybean (2M:2S)	0.05	2.53
	Maize-Soybean (2M:4S)	0.03	2.48
	Maize-Soybean (2M:6S)	0.02	2.56
p-value		0.0530*	0.2460
LSD(0.05)		0.02	0.09
Kamujine	Sole maize	0.03	2.31
	Sole soybean	0.00	2.14
	Maize-Soybean (1M:1S)	0.02	2.46
	Maize-Soybean (2M:2S)	0.02	2.03
	Maize-Soybean (2M:4S)	0.02	2.30
	Maize-Soybean (2M:6S)	0.005	1.96
p-value		0.0800	0.0020**
LSD(0.05)		0.02	0.22

ns – not significant; *significant at p≤0.05; **significant at p<0.01

The increase in the soil pH values in intercropped systems compared with sole cropping systems as encountered at Kamujine site, demonstrates that intercropping lead to reduction in soil acidity compared to monocropping systems, probably due to higher organic material generation. Similarly, Esekhade and Idoko (2009) and Esekhade *et al*., (2000) observed higher soil pH in intercropping treatments compared with soil under monocropping. Yasin *et al*., (2010) argued that, decomposition product of organic matter (maize) in the soil can play a role as soil pH regulator. Contrarily to the findings in this study, Dahmardeh *et al*. (2010) found that intercropping of maize-cowpea had significantly increased the phosphorus and potassium in soil, and that the lowest P level was observed in the sole maize treatment. Although not significantly different from other treatments, the lowest P level in sole maize was also observed in this study at Kamujine site. Similarly, Suwanarit *et al*. (1998) did not find significant effect of corn-groundnut intercropping system on available phosphorus. The soil mineral – N observed under sole legume treatment at Kamujine site was also reported by Dahmardeh *et al*. (2010), who found that soil mineral – N was significantly higher under sole cowpea treatment than in the other treatments.

The higher SOC observed in this study under intercropping treatments compared to their sole crops was also reported by several other authors (Bichel, 2013; Dyer, 2010; Sainju *et al*., 2009; Nzabi *et al*., 2000). Bambrick (2009) reported that tree based intercropping systems had greater potential for carbon storage than conventional cropping systems due to the fact that carbon is stored in the biomass of growing trees and trees provide additional carbon inputs (leaves, roots) that contribute to the SOC pool. As reported at Embu site, Zhang *et al*. (2007) also did not find significant differences on SOC under intercropping treatments compared to their pure stands. On the other hand, the absence of differences in soil total N observed at Kamujine site was also reported by Dyer (2010) and Bichel (2013) in Argentina under maize-soybean intercropping systems. Mazzoncini *et al*. (2011) reported that soil total N stocks significantly changed after 15 years, and recommended long-term studies, especially when focusing on the SOM pool. The SOM have been used as indicators of the effects related to biomass source and amounts on soil organic

matter dynamics in cropping systems (Bayer *et al*., 2009). Soil chemical properties in terms of macro-, meso- and micro-nutrients after a cropping period depends on the type of crops planted and cropping systems used (Ibeawuchi, 2007).

Conclusions

The maize-soybean intercropping patterns affected significantly soil nitrate-N only at harvest (20 WAP) at both locations, and at 12 WAP at Embu site. But in general, the soil nitrate-N was reduced due to intercropping patterns. At both locations, the soil ammonium-N was not significantly affected by the maize-soybean intercropping patterns. The soil mineral-N was not significantly affected by the maize-soybean intercropping patterns at Embu site; and at Kamujine site it was only affected at harvest (20WAP).

The N uptake of maize and soybean was significantly affected by the intercropping patterns, at both localities. The sole soybean treatment yielded the highest N amount. The N acquired by both crops was highly significantly positively correlated with soil mineral N.

The maize-soybean intercropping patterns had no significant effect on soil pH, extractable phosphorus, exchangeable calcium and potassium, and extractable ammonium at both locations. But, the nitrate-N and mineral-N that were significantly higher under sole soybean treatment at Kamujine site during 2012 SR; the exchangeable magnesium was significantly higher under maize sole crop at Kamujine site during 2012 SR. At Embu site during 2012 SR, the soil total N was significantly affected by the intercropping patterns, whereas at Kamujine site was not affected. The MBILI treatment observed the highest soil total N. The soil organic carbon was significantly affected by the intercropping patterns at Kamujine site where the conventional treatment observed the highest SOC, but it was not affected at Embu site.

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Effects of different maize, soybean intercropping patterns on yields and its economics

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Abstract

In central highlands of Kenya, the low soil fertility and inability to replenish it are amongst the major constraints affecting the productivity of maize and cash crops, leading to hunger and poverty. The adoption of ISFM technologies such as maize-soybean intercropping system is being promoted as one of the options to address low crop productivity among the farmers. This study intended to determine the effects of maize-soybean intercropping patterns on yields and to assess the economics of different maize–soybean intercropping patterns in two the contrasting sites. The experiment was arranged in a randomized complete block design (RCBD) with four replications. The treatments were four maize (M) – soybean (S) intercropping patterns (conventional=1M:1S; MBILI-MBILI=2M:2S; 2M:4S; 2M:6S) and two sole crops of maize and soybean, respectively. The results showed that in both sites during the both seasons maize stover and grain yields ware significantly affected by the intercropping pattern. During 2012 LR at Embu site the MBILI treatment produced significantly higher stover and grain yields (13.12 t ha^{-1}, p=0.0001 and 6.11 t ha^{-1}, p<0.0001, respectively) than all other treatments. During 2012 SR, still the MBILI treatment had recorded significantly the highest stover and grain yield (7.62 t ha^{-1}, p<0.0001 and 5.62 t ha^{-1} p=0.0467, respectively) than all other treatments. During 2012 LR at Kamujine site the conventional treatment produced significantly the highest stover yield (3.87 t ha^{-1}, p=0.0461) than only the 2M:6S treatment. During 2012 SR at Kamujine site, the MBILI treatment had recorded significantly the highest stover and grain yield (6.55 t ha^{-1}, p=0.0005 and 3.55 t ha^{-1} p=0.0006, respectively) than all other treatments. During both seasons in both sites, the soybean yield was significantly affected by the intercropping pattern. During the 2012 LR, the yields were reduced by 60 and 81% due to the intercropping with maize, at Embu and Kamujine, respectively; whereas, during the 2012 SR, the yields were reduced by 52 and 78% as effect of intercropping with maize, at Embu and Kamujine, respectively. At Embu site during the both seasons, the MBILI treatment was more profitable. At Kamujine site during the 2012 LR maize sole crop was the most profitable; whereas during 2012 SR the MBILI treatment was the most profitable.

Key words: maize-soybean yields, economics, intercropping patterns, central highlands, Kenya.

Introduction

Smallholder farmers are the most important food security stakeholders in sub-Saharan Africa (FAO, 2011), who mainly practice subsistence agriculture characterized by low crop productivity due to the soil nutrient depletion (Mugwe *et al*., 2007). The majority of these farmers lack financial resources to purchase sufficient amount of mineral fertilizers to replace soil nutrients removed through harvested crop products (Jama *et al*., 2000), crop residues, and through loss by runoff, leaching and as gases (Bekunda *et al*., 1997). Consequently, poor soil fertility has emerged as one of the greatest biophysical constraint to increasing agricultural productivity hence threatening food security in this region (Mugwe *et al*., 2009; Mugendi, 1997). Therefore, it is necessary to adopt improved and sustainable technologies in order to guarantee improvements in food productivity and thereby food security (Landers, 2007; Gruhn *et al*., 2000). Such technologies include the use of integrated soil fertility management practices (ISFM) such as intercropping cereals with grain legumes as one of its main components (Mucheru-Muna *et al*., 2010; Sanginga and Woomer, 2009). Cereal – grain legume intercropping has potential to address the soil nutrient depletion on smallholder farms (Sanginga and Woomer, 2009). The legumes play an important role in nitrogen fixation (Peoples and Craswell, 1992), and are important source of nutrition for both humans and livestock

(Nandwa *et al.,* 2011). In the central highlands of Kenya, cereal – legume intercropping is already being widely practiced by the smallholder famers. According to Sanginga and Woomer (2009) intercropping cereal and grain legume crops helps maintain and improve soil fertility, because crops such as cowpea, mung bean, soybean and groundnuts accumulate from 80 to 350kg nitrogen (N) ha^{-1} (Peoples and Craswell, 1992). For instance, soybean can positively contribute to soil health, human nutrition and health, livestock nutrition, household income, poverty reduction and overall improvements in livelihoods and ecosystem services, than many others leguminous grain crops (Rakasi, 2011; Raji, 2007). Improved intercropping systems are part of ISFM technologies (Mucheru-Muna *et al.,* 2010; Sanginga and Woomer, 2009) and in central highlands of Kenya the information is scarce regarding to optimum cropping pattern of maize-soybean intercropping system and on its economics.

Materials and methods

Study area

The experiment will be carried out in two sub counties of central highlands of Kenya, namely Embu West and Tigania East sub counties.

Embu West Sub County

Embu West District is located in Embu County, in the central highlands of Kenya, and occupies an area of 708 Km^2 and is bordered by Mbeere district to the East and South East, Kirinyaga to the West and Meru South to the North. The experimental site lies within N 0° 31´ 4.2´´ E 37^0 27´ 20´´ and at the altitude of 1468 m above the sea level (ASL), at Embu Agricultural Staff Training College (Jaetzold *et al.,* 2006). Diagnosis study carried out in the central highlands of Kenya have reported soil fertility constraints, particularly N and P deficiencies, low carbon content and low soil pH (Gachimbi *et al.,* 2002). The major agro-ecological zone (AEZ) is Upper Midland 2 (UM 2), the soils are humic nitisols and the total arable land area is 478 Km^2 with total available agricultural land area covering 371 Km^2. Table 3.1 shows the soil characteristics of the soils in Kamujine. The average annual rainfall varies from 1230 to 909 mm with long rainy season between March and June and short rainy season between October and December, respectively. Rainfall for the two seasons in which the experiment was conducted is presented Figure 1.

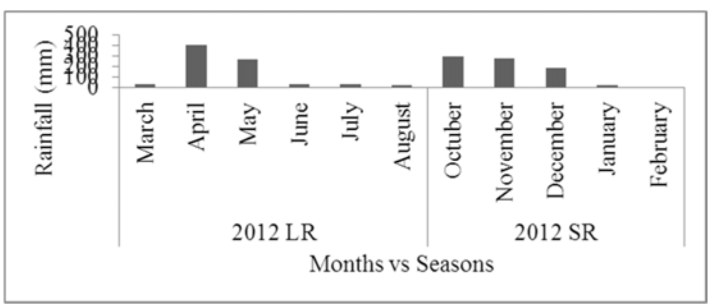

Figure 1: Rainfall amount during 2012 LR and 2012 SR at Embu-ATC, Embu west sub county, Kenya

Tigania East Sub County

Tigania East Sub County is located in Meru County, in the central highlands of Kenya and it occupies 108.6 km^2. The experimental site lies within N 0° 6´ 19.5´´ E 037° 64´ 39.6´´ and at the altitude of 935 m above the sea level (ASL), at Kamujine Dispensary in Mikinduri Division. The major agro-ecological zones are Lower Midlands 3 and Upper Midland 3 (LM 3 and UM 3), the soils are mainly eutric Nitisols and humic

Cambisols. The annual average temperature varies from 19.2 ˚C to 22.9 ˚C (Jaetzold *et al.,* 2006). Table 1 shows the soil characteristics of the soils in Kamujine.

Table 1: Soil characteristics at Embu – ATC and Kamujine sites, Kenya

Soil parameter	Embu – ATC Site	Kamujine Site
pH in water (1:2.5)	5.30	5.50
Total N (%)	0.03	0.01
Total soil organic carbon (%)	2.64	1.88
Extractable P (ppm)	13.40	9.54
Exchangeable Ca (C mol kg-1)	0.22	0.21
Exchangeable Mg (C mol kg-1)	0.53	0.53
Exchangeable K (C mol kg-1)	0.12	0.08
Clay (%)	65	45
Sand (%)	17	20
Silt (%)	18	35

The average annual rainfall varies from 1000 to 2200 mm with long rainy season between March and June and short rainy season between October and December, respectively (Jaetzold *et al.,* 2006). Rainfall for the two seasons in which the experiment was conducted is presented Figure 2.

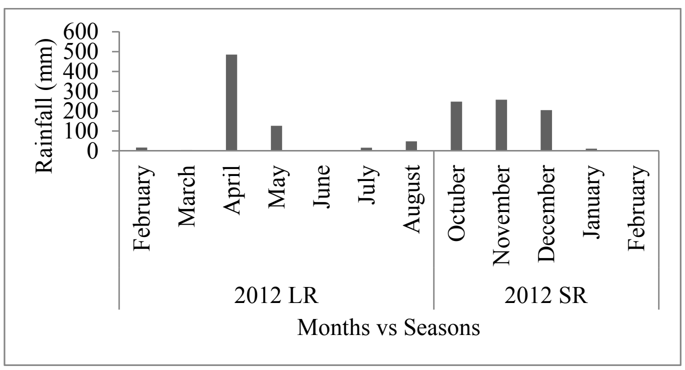

Figure 2: Rainfall amount during 2012 LR and 2012 SR at Kamujine site, Tigania East Sub county, Kenya

Management of the experiment

The fields were ploughed using hand hoe and left as such for two weeks. Plots measuring 7.0 by 4.5 m were marked just before planting. Pathways measuring 3.0 m and 2.0 m were left between the blocks and plots, respectively. At Embu-ATC, planting was done on the 23rd of March and 12th of October 2012 for the 1st and 2nd seasons, respectively. At Kamujine, planting was done on the 26th of March and 15th of October 2012 for the 1st and 2nd seasons, respectively. The sole maize (*Zea mays* L.) var. DK 8031 was planted at a spacing of 0.75 m 0.50 m inter and intra-row, respectively. The number of hills per row was 10 with three seeds per hill in order to ensure maximum plant population and to account for germination failure; and two weeks after germination the excess plants were thinned out to remain with two plants per hill. The sole soybean (*Glycine max* (L.) Merrill) var. Gazelle was hand drilled at a spacing of 0.45 × 0.10 m in inter and intra – row

spacing resulting to 62 plants per row to ensure maximum germination/population and the excess plants were thinned out to remain with the recommended population of 31 plants per row after 2 weeks of emergence. The following external nutrient replenishment inputs were applied per plot: 6kg of manure equivalent to 30 kg N ha^{-1}, applied two weeks before planting; 94.5 grams of CAN as source of N, equivalent to 30 kg N ha^{-1}, for soybean the Nitrogen (starter N) was applied at sowing while for maize it was applied when the crop has six leaves, as topdressing; 189 grams of TSP as source of P, equivalent to 60 kg P ha^{-1}, which was applied at sowing. The fertilizers were applied accordingly to the recommendation from FURP (1987). Management practices were the same for both the monocrop and the maize – soybean intercrop.

Experimental design and management

First, soil samples from the experimental sites were collected at 0 – 15 cm depth for analysis for organic carbon, total nitrogen using standard methods (Okalebo *et al.,* 2002), extractable P, Ca, Mg, K, Na using Mehlich-1 (M1) extraction method, where P and Mg^{2+} were determined colourimetrically in a spectrophotometer and Ca^{2+}, and K^+ were determined using flame photometer. The experiment was established in Embu-ATC (Embu West district) and in Kamujine (Tigania East district) and it was laid out as a randomized complete block design (RCBD) with four replicate blocks and plot sizes measuring 7 x 4.5 m. The cropping system was of sole maize (*Zea mays* L.), sole soybean (*Glycine max* (L.) Merrill) and maize (M) – soybean (S) intercropping with cropping patterns (Table 2).

Table 2: Treatments in the two sites (ATC-Embu and Kamujine)

Treatment	Cropping system	Treatment	Cropping system
T1	Sole maize	T4	Maize-soybean (2:2)
T2	Sole soybean	T5	Maize-soybean (2:4)
T3	Maize-soybean (1:1)	T6	Maize-soybean (2:6)

Maize and soybean harvest and yields

Maize and soybean grain and stover was harvested at maturity from a net area of each treatment demarcated after leaving out two rows on each side of the plot and the first two and the last two maize/soybean plants on each row to minimize the edge effect (Table 3). The entire plants on the plots was harvested by cutting at the ground level and weighted to represent the total fresh weight. Maize/Soybean cobs/pods were manually separated from the stover, sun-dried, and packed in sacks before threshing. After threshing, moisture content of the grains was determined using a moisture meter and grain yield adjusted to 12 per cent moisture content using the following formula. Similarly, the yields and harvest index were calculated using the following formulas.[formulae]

$$Adjusted\ yield = measured\ yield * \frac{(100 - sample\,moisture\,content)}{(100 - s\tan dard\ moisture\,content)} \quad (1)$$

$$Yield\,(t/ha) = 10 * \frac{Dry\,weight\,(kg/m^2)}{Net\,area\ (m^2)} \quad (2)$$

$$Harvest\,Index\,(HI)\,(\%) = \frac{Grain\,yield\ (t/ha)}{Total\,biomass\,yield\,(t/ha)} * 100 \quad (3)$$

Table 3: Net plot area per treatment in both sites

Intercropping pattern	Total plot size (m^2)	Net plot (m^2)
Sole maize	7.0m×4.5m=31.5	6.0m×3.5m=21.0
Sole soybean	7.0m×4.5m=31.5	4.95m×3.9m=19.3
Maize-Soybean (1M:1S)	7.0m×4.5m=31.5	5.25m×3.5m=18.4
Maize-Soybean (2M:2S)	7.0m×4.5m=31.5	4.8m×3.5m=16.9
Maize-Soybean (2M:4S)	7.0m×4.5m=31.5	5.3m×3.5m=18.7
Maize-Soybean (2M:6S)	7.0m×4.5m=31.5	4.5m×3.5m=15.8

Data analysis

Data of maize – soybean yields was subjected to analysis of variance using SAS version 8. To test the differences between different cropping pattern and conventional intercropping systems, the yields were subjected to *t-student* test at 95 per cent of significance level ($p<0.05$).

Economic analysis

The information that was collected at each time of given activity in the course of each season was used for cost-benefit analysis. The labour was valued at the local wage of US$ per man day, equivalent to 8 hours. All other biomass was accounted for as a benefit in addition to the grain yields. Also, was collected information about the prices of CAN, TSP, labour cost, soybean, maize and stover (Table 4). The data was then be subjected to analysis of variance using SAS version 8.

Table 4: Parameters used in the economic analysis of the different intercropping patterns during 2012 LR and 2012 SR at Embu and Kamujine sites

Parameter	Embu site		Kamujine site	
	2012 LR	2012 SR	2012 LR	2012 SR
Price of maize seed (USD kg^{-1})	0.30	0.29	0.30	0.29
Price of soybean seed (USD kg^{-1})	0.71	0.69	0.71	0.69
Price of TSP (USD kg^{-1})	0.95	0.93	0.95	0.93
Price of CAN (USD kg^{-1})	0.62	0.61	0.62	0.61
Price of goat manure (USD kg^{-1})	0.38	0.37	0.38	0.37
Labour cost (USD day^{-1})	3.93	3.84	1.76	2.33
Price of maize grains (USD kg^{-1})	0.42	0.41	0.42	0.41
Price of soybean grains (USD kg^{-1})	0.71	0.69	0.71	0.69
Price of maize stover (USD t^{-1})	44.60	43.59	44.60	43.59

Exchange rate: 1USD= 84 KES (September, 2012) and 1USD=85.95 Khs (March, 2013). Price of legume grains and seed were considered equal as farmers generally recycle seed from the harvest obtained

Results and discussion

Maize yields

At Embu during the both seasons, maize stover and grain yields ware significantly affected by the intercropping pattern. For instance, during 2012 LR the MBILI treatment produced significantly higher stover and grain yields (13.12 t ha^{-1}, p=0.0001 and 6.11 t ha^{-1}, $p<0.0001$, respectively) than all other treatments, excluding the conventional (for the grain yield and stover yield) and also sole maize treatment (for the stover yield). During 2012 SR, still the MBILI treatment had recorded significantly the highest stover and grain yield (7.62 t ha^{-1}, $p<0.0001$ and 5.62 t ha^{-1} p=0.0467, respectively) than all other treatments, except sole maize and conventional treatments. Only during 2012 LR that the harvest index was

significantly affected by the intercropping patterns, where the 2M:6S treatment observed the highest HI of 37.30% than all other treatments. Slightly different situation was observed during 2012 SR, where although not significantly different (*p*=0.5398) from other treatments, the MBILI treatment recorded numerically the highest HI of 42.22%. These differences between two the seasons in term of HI may be related to variations in rainfall and/or differences in weed pressure.

During both season at Kamujine site, maize stover yield was significantly affected by the intercropping pattern. For instance, during 2012 LR the conventional treatment produced significantly the highest stover yield (3.87 t ha^{-1}, *p*=0.0461) than only the 2M:6S treatment. In this season, the grain yield was not significantly affected by the intercropping patterns (*p*=0.0704); however, the sole maize treatment had recorded numerically the highest value of 3.36 t ha^{-1} and 2M:6S treatment with the lowest. The lower maize yields under 2M:6S treatment could be related to the lower plant density compared to other treatments. During the 2012 LR, the maize stover yields was strongly significantly ($p \leq 0.05$) positively correlated with the N uptake at all the sampling periods, excluding at 16 WAP and 20WAP. During 2012 SR, the MBILI treatment had recorded significantly the highest stover and grain yield (6.55 t ha^{-1}, *p*=0.0005 and 3.55 t ha^{-1} *p*=0.0006, respectively) than all other treatments, except sole maize and conventional treatments. Differently from Embu site, the harvest index was not significantly affected by the intercropping patterns during both seasons (*p*=0.4243 and *p*=0.4908, respectively); however, the MBILI (during 2012 LR) and 2M:4S (during 2012 SR) treatments observed numerically the highest HI of 51.40 and 37.29%, respectively (Table 4).

Table 4: Effect of intercropping pattern on maize yields and harvest index during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Treatment	Stover yield (t/ha)		Grain yield (t/ha)		Harvest Index (%)	
		2012 LR	2013 SR	2012 LR	2013 SR	2012 LR	2013 SR
Embu	Sole maize	11.73	8.14	4.95	4.58	29.95	36.02
	Maize-Soybean (1M:1S)	12.64	7.74	5.49	5.16	30.45	39.27
	Maize-Soybean (2M:2S)	13.12	7.62	6.11	5.62	31.80	42.22
	Maize-Soybean (2M:4S)	8.89	4.91	4.05	3.48	31.30	41.43
	Maize-Soybean (2M:6S)	5.26	4.45	2.74	3.16	37.30	41.52
p-value		0.0001***	<0.0001***	<0.0001***	0.0467*	0.0168*	0.5398
$LSD_{(0.05)}$		2.59	1.31	0.87	1.79	4.23	8.63
Kamujine	Sole maize	3.81	6.00	3.36	2.98	47.05	32.90
	Maize-Soybean (1M:1S)	3.87	6.34	3.09	3.44	44.59	35.03
	Maize-Soybean (2M:2S)	2.95	6.55	3.07	3.55	51.40	35.14
	Maize-Soybean (2M:4S)	2.59	4.83	2.47	2.86	49.23	37.29
	Maize-Soybean (2M:6S)	1.90	3.97	1.9	1.82	50.39	32.19
p-value		0.0461*	0.0005***	0.0704ns	0.0006***	0.4243	0.4908
$LSD_{(0.05)}$		1.43	1.00	1.07	0.64	8.24	6.55

ns – not significant; *significant at $p \leq 0.05$; **significant at $p<0.01$; ***significant at $p<0.001$

Increased maize yield under MBILI treatment found at Embu site was also reported by Undie *et al*. (2012) in Nigeria under maize-soybean intercrop, Mucheru-Muna *et al*. (2010) in the central highlands of Kenya and Woomer *et al*. (2004) in western Kenya with maize-beans, and Solanki *et al*. (2011) in India with maize-blackgram. This, could be due to the fact that the MBILI intercrop arrangement offers better opportunities to the components to utilize available resources more effectively than the conventional (1M:1S) intercropping pattern. Rajat De and Singh (1979) stated that the modified 2M:2S system affords a better solar energy harvest than the 1M:1S crop arrangement, due to the fact that the former might have provided sufficient light to the lower leaves to continue photosynthesis. Furthermore, Brintha and Seran (2009) stated

that productivity rates increases with LAI because of increased total light interception, but larger LAI values often cause no more increases and then decreases on a ground basis, probably due to respiratory CO_2 loss from heavily shaded leaves and stems. However, when the plant population is different the yield difference is determined by population density rather than crop arrangement (Rajat De and Singh, 1979), which was not the case in this particular situation. Similarly, Sikirou and Wydra (2008), Dapaah *et al.* (2003), Mpairwe *at al.* (2002) and Olufemi *et al.* (2001) reported higher cereal grain yield under intercropping system compared to its sole crop. Nzabi *et al.* (2000) stated that maize grain yield differs with different legume species and intercropping produces higher maize grain yield than in pure stand.

On the other hand, Thobatsi (2009) in RSA, Silwana and Lucas (2002) also observed reduction in maize yield under intercropping system compared to its monocrop, under similar environment of limited rainfall conditions, as it was observed at Kamujine site during 2012 LR. In this site it was necessary to supplement with irrigation water because the crop had started to suffer for water stress due to lack of rainfall during flowering period, as it can be seen in the Figure 3.3. Amede (1995) stated that one of the factors that reduces maize grain yield is dry conditions that occur specially during the flowering period. More total populations under intercrops compared to monocrop under stress conditions might result in intercrop yields than sole crop yields due to increased competition for moisture (Natarajan and Willey, 1986). Yield reductions involving one or all intercropping components in intercropping could be associated to inter-specific competition for nutrients, moisture and/or space (Adaniyan *et al.,* 2007). Moreover, Kamujine has a light texture soil, which has low moisture holding capacity (Jaetzold *et al.,* 2006), resulting therefore in reduced yields under intercropping (Natarajan and Willey, 1986).

The efficiency of a crop variety to convert the dry matter into economic yield is determined by its harvest index. The higher the value, the higher will be dry matter conversion efficiency. The absence of significant differences in HI of maize observed during 2012 SR at Embu and Kamujine sites was also reported by Haseeb-ur-Rehman *et al*. (2010) and Egbe, Alibo and Nwueze (2010) in maize-cowpea intercropping; Saleem *et al.* (2011) in maize-legume intercropping systems; and, Carruthers *et al.* (2000) in maize-soybean intercropping.

Soybean yields and components

During both seasons in both sites, the soybean yield was significantly affected by the intercropping pattern. During the 2012 LR, the yields were reduced by 60 and 81 per cent due to the intercropping with maize, at Embu and Kamujine, respectively; whereas, during the 2012 SR, the yields were reduced by 52 and 78 per cent as effect of intercropping with maize, at Embu and Kamujine, respectively (Table 4.5). For instance, at Embu during 2012 LR, the sole soybean observed significantly the highest stover yield (1.41 t ha^{-1}, p=0.0015) than all the intercropping patterns, followed by the 2M:6S intercrop pattern with 1.03 t ha^{-1} which was statistically different from MBILI (0.53 t ha^{-1}, p = 0.0015) and conventional (0.40 t ha^{-1}, p = 0.0015) intercropping patterns, but not significantly different from the 2M:4S intercropping pattern. Still at the same site and season, the sole soybean observed statistically the highest grain yield (1.44 t ha^{-1}, p=0.0002) than all the intercropping patterns, followed again by the 2M:6S treatment (0.88 t ha^{-1}, p=0.0002), which was significantly different from other intercropping patterns (conventional, MBILI and 2M:4S), and these were not statistically different among them. Similar situation was also observed during 2012 SR, where sole soybean treatment recorded statistically the highest stover yield (1.45 t ha^{-1}, p<0.0001) than all other treatments, followed by the 2M:6S treatment (1.17 t ha^{-1}, p<0.0001), which was statistically different from the rest of the intercropping patterns. Although the conventional treatment observed 28 per cent higher stover yield than the MBILI treatment, they were not statistically different (p>0.05) among them. The monocropped soybean observed also the highest grain yield (1.65 t ha^{-1}, p<0.0001) than all other treatments, followed by the 2M:6S treatment with 1.01 t ha^{-1} (p<0.0001), which significantly different from the rest of the treatments. During this season, there was significant positive correlation between the soybean grain yield and soil nitrates, and soil mineral N, with r=0.56 (p=0.0109) and r=0.45 (p=0.047), respectively. During both seasons, the harvest index of soybean was significantly (p=0.0004 and p=0.0003, respectively) reduced by the intercropping patterns. For instance, during 2012 LR the sole soybean treatment observed the highest HI of 50.28 per cent which was significantly (p=0.0004) different from all other treatments. Similar situation

was observed during 2012 SR, where still sole soybean recorded significantly (p=0.0003) the highest HI (53.52%) than all other treatments, excluding the 2M:4S treatment.

At Kamujine during 2012 LR, the sole soybean observed statistically the highest stover and grain yields (1.09 t ha^{-1}, p<0.0001 and 0.56 t ha^{-1}, p=0.0007, respectively) than all other treatments, followed by the 2M:6S treatment with 0.78 t ha^{-1} for the stover yield, which was significantly different (p<0.0001) from the other intercropping patterns; but the MBILI intercrop pattern was not statistically different from the conventional intercropping pattern. For the grain yield, there were no significant differences among the intercropping patterns; however, the 2M:6S observed the highest yield (0.24 t ha^{-1}) than all the others. During this season, there was significant positive correlation between the soybean grain yield and soil nitrates, and soil mineral N, with r=0.73 (p=0.0002) and r=0.76 (p<0.0001), respectively. During 2012 SR, monocropped soybean treatment observed also significantly the highest stover yield (1.27 t ha^{-1}, p=0.0004) than all other treatments. Similarly, sole soybean treatment recorded the highest grain yield of 0.72 t ha^{-1} (p<0.0001) than all other treatments. During this season, there was also significant positive correlation between the soybean grain yield and soil nitrates, and soil mineral N, with r=0.61 (p=0.0043) and r=0.60 (p<0.0053), respectively During both season, the harvest index of soybean was not significantly (p=0.0864; p=0.0988) affected by the intercropping patterns; however, it was numerically reduced by the intercropping patterns. In general, the yields were increased about 23 and 26% in the second season compared to the first season, at Embu and Kamujine, respectively. Probably due to the cumulative effects of the goat manure that was applied in the first and second seasons, and also due to root and nodule senescence.

Table 5: Effect of intercropping pattern on soybean yields and harvest index during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Treatment	Stover yield (t ha^{-1})		Grain yield (t ha^{-1})		Harvest Index (%)	
		2012 LR	2012 SR	2012 LR	2012 SR	2012 LR	2012 SR
Embu	Sole S	1.41	1.45	1.44	1.65	50.28	53.52
	1M:1S	0.40	0.76	0.26	0.41	39.26	35.38
	2M:2S	0.53	0.55	0.35	0.42	39.98	43.17
	2M:4S	0.60	0.83	0.46	0.76	42.95	47.98
	2M:6S	1.03	1.17	0.88	1.01	45.99	46.60
p-value		0.0015**	0.0001***	0.0002***	< 0.0001***	0.0004***	0.0003***
$LSD_{(0.05)}$		0.43	0.28	0.39	0.18	4.02	5.73
Kamujine	Sole S	1.09	1.27	0.56	0.72	32.39	36.41
	1M:1S	0.18	0.21	0.05	0.07	19.44	23.74
	2M:2S	0.19	0.24	0.04	0.08	19.29	24.31
	2M:4S	0.52	0.58	0.17	0.30	22.42	36.56
	2M:6S	0.78	0.83	0.24	0.37	22.55	33.65
p-value		< 0.0001***	0.0004***	0.0007***	<0.0001***	0.0864	0.0988
$LSD_{(0.05)}$		0.13	0.39	0.20	0.08	10.17	12.52

ns – not significant; *significant at p≤0.05; **significant at p<0.01; ***significant at p<0.001; M - maize, S - soybean

The reduction on soybean yields under intercropping with maize or sorghum has also been reported by several researchers (Ijoyah and Fanen, 2012; Egbe, 2010; Muoneke *et al.,* 2007; Muneer *et al.,* 2004; Heibsch *et al.*, 1995; Olufajo, 1992; Pal, Oseni, and Norman, 1992; Neupane, 1983). This reduction in soybean yields under intercropping could be due to interspecific competition between the intercrop components for water, light, air and nutrients, and also the aggressive effects maize (C_4 species) on soybean, a C_3 species (Egbe, 2010; Muoneke *et al*., 2007). According to Heibsch *et al.* (1995), crops with C_4 photosynthetic pathways have been known to be dominant when intercropped with C_3 species like soybean. The shading of soybean by

the maize plants (taller) may also have contributed to reduction on the yields of intercropped soybean. Olufajo (1992) reported that shading by the taller plants in mixture could reduce the photosynthetic rate of the lower growing plants and thereby reduce their yields. It was confirmed in this study though the lower soybean yields in the rows closer to the maize plant compared to the middle one, which was positively correlated with the PAR intercepted. In addition, Lesoing and Francis (1999) stated that water stress and shading are probably the two major factors, which contribute to reduced legume component yield under intercropping. Moreover, Natarajan and Willey (1980) and Sivakumar and Virmani (1980) reported that stover yield often shows a positive correlation with the amount of radiation intercepted by crops in intercropping systems. In this study it was observed positive correlation between grain yield with the amount of radiation intercepted by crops in intercropping treatments. The reduction of harvest index of the legume component observed in this study was also reported by other researchers (Alhassan, Kalu and Egbe, 2012; Zaefarian *et al*., 2007). The reduction was due to maize shading effects on soybean, which caused the legume component to allocate its photosynthates to vegetative growth and height increasing for competing with taller maize. On the other hand, the findings of this study at Kamujine site were in agreement with Carruthers *et al*. (2000) who reported that the HI for intercrop soybean was not significantly different from monocrop soybean.

Effects of maize–soybean intercropping patterns on its economics

During both seasons at both locations, the intercropping patterns affected significantly the gross returns, net returns and benefit cost ratio (Table 6). For instance, during 2012 LR at Embu site, the MBILI treatment showed to be significantly more profitable (gross monetary returns = 3,310.10 USD ha^{-1}, $p<0.0001$) than all the other cropping patterns, whereas sole soybean was statistically the lowest remunerable, with gross and net returns of 1,910.10 USD ha^{-1}, $p<0.0001$ and 278.2 USD ha^{-1}, respectively. This result suggests that growing soybean under intercropping is more profitable than as a monocrop. Also, the MBILI treatment observed significantly the highest net monetary returns (2,914.7 USD ha^{-1}, $p<0.0001$) than all the other treatments, except the conventional and sole maize treatments. And, producing sole soybean and 2M:6S treatment showed to be a loss of 1083.9 USD ha^{-1} ($p<0.0001$) and 894.0 USD ha^{-1} ($p<0.0001$), respectively. Although not statistically different from the sole maize and conventional treatments ($p>0.05$), the MBILI system recorded the highest BCR value of 0.26, which was significantly different ($p<0.0001$) from sole soybean, 2M:4S and 2M:6S treatments. During the 2012 SR, the MBILI treatment also observed the highest gross monetary returns (2914.7 USD ha^{-1} $p=0.0012$) than all other treatments, excluding the conventional treatment. Whereas in terms of net monetary returns and BCR, the conventional treatment observed the highest values (371.6 USD ha^{-1}, $p=0.0048$ and 0.15, $p=0.0036$, respectively) than only sole soybean and 2M:6S treatments. Different situation was observed at Kamujine, where during 2012 LR the monocropped maize observed significantly the highest gross monetary returns (1,541.4 USD ha^{-1}, $p=0.0015$) than sole soybean and 2M:6S treatments. In terms of net monetary returns, the sole maize treatment also showed to be more profitable (532.4 USD ha^{-1}, $p<0.0026$) than sole soybean, 2M:4S and 2M:6S treatments. The sole maize treatment also observed the highest BCR value (0.53, $p=0.004$) than all other treatments, excluding the conventional treatment. During 2012 SR, the MBILI treatment observed the highest gross monetary returns (1,789.5 USD ha^{-1}, $p<0.0001$) than sole maize, sole soybean and 2M:6S treatments. In terms of net monetary returns and BCR, the sole maize treatment observed the highest values (197.8 USD ha^{-1}, $p<0.0001$ and 0.16, $p<0.0001$, respectively) than only sole soybean and 2M:6S treatments (Table 6). The lower maize plant density under 2M:4S and 2M:6S treatments, and the fact that soybean stover was not accounted economically (because most famers in the region do not sell it) could have been the reason for the lowest net monetary returns in these treatments.

Table 6: Monetary returns and BCR of maize-soybean has affected by the intercropping pattern during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Treatment	Gross return (USD ha^{-1})		Net return (USD ha^{-1})		BCR	
		2012 LR	2012 SR	2012 LR	2012 SR	2012 LR	2012 SR
Embu	Sole M	2382.4	2221.7	340.6	226.6	0.17	0.11
	Sole S	1026.6	1148.4	-1083.9	-913.9	-0.51	-0.44
	1M:1S	2825.8	2724.4	417.9	371.6	0.17	0.15
	2M:2S	3310.1	2914.7	688.5	353.1	0.26	0.14
	2M:4S	2310.1	2160.4	-59.2	-154.7	-0.03	-0.07
	2M:6S	1910.1	2189.0	-894.0	-550.9	-0.32	-0.20
p-value		<0.0001***	0.0012**	<0.0001***	0.0048**	<0.0001***	0.0036**
LSD $_{(0.05)}$		472.23	685.81	472.23	685.81	0.20	0.30
Kamujine	Sole M	1541.4	1473.8	532.4	197.80	0.53	0.16
	Sole S	399.3	503.4	-587.5	-776.42	-0.60	-0.61
	1M:1S	1425.9	1722.2	196.8	190.03	0.16	0.12
	2M:2S	1409.9	1789.5	71.8	121.35	0.05	0.07
	2M:4S	1209.3	1585.6	-0.10	78.05	0.00	0.05
	2M:6S	1015.6	1175.1	-415.7	-609.15	-0.29	-0.34
p-value		0.0015**	<0.0001***	0.0026**	<0.0001***	0.004**	<0.0001***
LSD $_{(0.05)}$		480.31	218.78	495.27	141.68	0.39	0.11

ns – not significant; *significant at p=0.05; **significant at p=0.01; ***significant at p<0.001; S – soybean, M - maize

The higher net monetary returns observed with MBILI treatment at Embu site during 2012 LR was also reported by Mucheru-Muna *et al*. (2010) and Woomer and Tungani (2003) with maize-beans. This could be related to higher yields with relatively less input investments that this treatment observed compared to the other treatments. Similarly, Temesgen *et al*. (2011) with maize-cowpea, Egbe (2010) with sorghum-soybean, Haseeb-ur-Rehman *et al*. (2010), Mudita *et al*. (2008) and Muoneke *et al*. (2007) with maize-soybean, also reported higher monetary returns and higher BCR under intercropping system compared to sole cropping of maize/soybean/cowpea. These reports from past studies are in contrast with the findings of this study at Kamujine site during the 2012 LR, where maize sole crop recorded higher monetary returns and higher BCR than intercropping treatments. This could be related to higher maize grain yield recorded by that treatment during the season. Moreover, using the BCR Segun-Olasanmi and Bamire (2010) reported that maize-cowpea intercropping was more profitable than their sole crops. These results suggest that intercropping could improve the system's productivity, increase the income for smallholder farmers, and compensate losses.

Conclusions

The maize-soybean intercropping patterns had significant effect on maize stover and grain yields during both seasons at Embu site. The MBILI treatment recorded the highest stover and grain yields. During 2012 LR at Kamujine site only the maize stover yield was significantly affected by maize-soybean intercropping patterns. The conventional treatment observed the highest stover yield than 2M:6S treatment; but it was statistically a (at) par with the one recorded by the MBILI treatment. And during the 2012 SR, the maize stover and grain yields maize-soybean intercropping patterns affected significantly the MBILI treatment recorded the highest stover and grain yields.

During both seasons at both localities, the soybean yields were significantly affected by the maize-soybean intercropping patterns. During the 2012 LR, the yields were reduced by 60 and 81% due to the intercropping with maize, at Embu and Kamujine, respectively; whereas during 2012 SR, the yields were reduced by 52 and 78% as effect of intercropping with maize at Embu and Kamujine sites, respectively.

During both seasons at both localities, the maize-soybean intercropping patterns affected significantly the gross monetary returns, net returns and benefit cost ratio. At Embu site during the both seasons, the MBILI treatment was more profitable. At Kamujine site during the 2012 LR maize sole crop was the most profitable; whereas during 2012 SR the MBILI treatment was the most profitable.

Recommendations

From the results of this study can be recommended, to the farmers of central high lands of Kenya, the use of MBILI-MBILI maize-soybean intercropping pattern because it gave efficient resources and higher net monetary returns.

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The effect of a dry agroecological zone on selected growth and yield parameters of three elite cassava genotypes grown in Mutomo sub-County of Kitui County in Kenya

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Abstract

Communities in the drylands engage in different farm activities in attempting to make their economic ends meet. Such activities include growing of crops and trees to supplement returns from livestock rearing. The major impediment to agricultural production in the rangelands is lack of sufficient soil moisture and soil nutrients to make crops attain their physiological maturity. Cassava, a crop which is highly drought tolerant is ideal for such environments with sufficient soil moisture. Cassava has a very high potential of becoming a major source of carbohydrates and cash income to farmers in semi-arid regions and in high potential areas of Coast, Central and Western regions of Kenya. KARI-Katumani has bred cultivars tolerant to cassava mosaic disease and acceptable to farmers. Three promising cassava cultivars, EX-Mariakani, I 96/00067, and MM96/5280 were grown onfarm under rainfed conditions in October 2012 in Mutomo Sub-County in Kitui County. The cultivars were subjected to normal farmers' cultural practices. The cassava plants were harvested 12 months after planting and evaluated on selected growth parameters. Cultivar EX-Mariakani, had much taller plants, number of marketable tuberous roots, weight of mother stock and stems per plant, higher stay green ability and leaf retention scores than cultivars I 96/00067 and MM96/5280. Cultivar I 96/00067, though not significantly different, had much higher marketable tuberous roots yield than cultivars EX-Mariakani and MM96/5280. The three cultivars had a moderate cassava mosaic disease infection and white scale infestation scores suggesting that they had similar qualities. Cassava cultivars, EX-Mariakani, I 96/00067, and MM96/5280 performed well in this dry agro-ecological zone and their multiplication and distribution to farmers in Mutomo should continue aggressively. EX-Mariakani seems to have more superior drought tolerance capability than I 96/00067, and MM96/5280.

Key words: cassava seed systems; food security crop, mitigating crop failure, climate change, adaptation, semi-arid, drought prone food deficit areas.

Introduction

According to Keya *et al*. (2006) communities in the drylands engage in different farm activities in attempting to make their economic ends meet. Such activities include growing of crops and trees to supplement returns from livestock rearing (Carlos 2004; Itabari *et al.* 2004). Keya *et al.* (2006) noted that the major impediment to agricultural production in the rangelands is lack of sufficient soil moisture and soil nutrients to make crops attain their physiological maturity. As such, in order to improve crop and tree production in these areas, sustainable improved sustainable onfarm water harvesting and storage methods and integrated soil fertility management programmes are required in order to mitigate effects of drought.

Cassava (*Manihot esculenta* Crantz) is grown widely throughout East Africa and is a major source of calories and cash income to farmers in Coast, Central and Western regions of Kenya and has high potential in the arid and semi-arid regions (EARRNET, 1998; Githunguri, 1995). Cassava has become an important staple food with high potential for livestock and industrial uses in East Africa (EARRNET, 1998). Constraints to cassava production in Kenya include cassava mosaic disease, green mite, bacterial blight, mealybug, lack of adequate disease and pest free planting materials, poor cultural practices, presence of high levels of cyanogenic glucosides in some cassava clones (Githunguri, 2006; Lusweti *et al*., 1997), lack of planting materials and markets (Githunguri *et al*., 2008). While cassava mosaic disease causes appreciable cassava yield reduction, the presence of hydrocyanic acid lowers the quality of cassava roots and has been the major

reason for rejection of cassava cultivars in Eastern Kenya. Communities in Eastern Kenya eat either raw or boiled cassava (Githunguri, 1995). KARI-Katumani has bred cultivars tolerant to cassava mosaic disease and acceptable to end-users (Githunguri *et al,* 2003). As such, it was deemed necessary to use some of these cassava cultivars to mitigate the rampant food insecurity in the arid and semi-arid areas. The objective of this work was to subject some of the elite cassava cultivars and clones to participatory field evaluation, multiply and distribute the best to farmers within Mutomo sub-county in Kitui County and other selected semi-arid areas.

Materials and methods

Three promising cassava cultivars, EX-Mariakani, I 96/00067, and MM96/5280 were grown onfarm under rainfed conditions in October 2012 in Mutomo Sub-County in Kitui County. The cassava cultivars were planted in non-replicated plots of 15 x 15m in eight farms. The cultivars were subjected to normal farmers' cultural practices. The cassava plants were harvested in October 2013 and evaluated on selected growth parameters. The exercise was conducted under the guidance of research staff. The selected growth parameters included plant height (cm), number and weight of marketable and unmarketable tuberous roots, and weight of mother stock and stems per plant. Stay green ability and leaf retention were evaluated using a scoring scale of 1- 5 where 1, 2, 3, 4 and 5 represented very good, good, moderate, poor and very poor, respectively. Cassava mosaic disease infection and white scale infestation were evaluated using a scoring scale of 1- 5 where 1, 2, 3, 4 and 5 represented no apparent, mild, moderate, severe, and very severe field symptoms seen, respectively. The data collected was subjected to analysis of variance using the method described by Gomez and Gomez (1984) and the treatments means were separated using the Least Significant Difference (LSD) test using the SAS statistical package (SAS 1990).

Results and discussion

According to Tables 1, 2 and 3, even though the differences were not statistically significant, cultivar EX-Mariakani, had much taller plants, number of marketable tuberous roots, weight of mother stock and stems per plant, higher stay green ability and leaf retention scores than cultivars I 96/00067 and MM96/5280. According to Table 3, cultivar I 96/00067, though not significantly different, had much higher marketable tuberous roots yield than cultivars EX-Mariakani and MM96/5280. Table 4 shows the three cultivars had a moderate cassava mosaic disease infection and white scale infestation scores suggesting that they had similar qualities.

Table 1: The effect of a dry AEZ on cassava in Mutomo sub-County of Kitui County in Kenya in 2012-2013

Treatment	Plant ht (cm)	Stay Green Ability	Leaf Retention Score
EX-Mariakani	73.3	2.75	3.0
I 96/00067	50.8	2.00	2.0
MM96/5280	46.6	2.00	2.0
Means	56.9	2.25	2.0
E.S.E.	9.19	0.323	0.5
S.E.D.	13.00	0.456	0.6
LSD	31.81	1.117	1.6
S.E.	18.39	0.645	0.9
CV (%)	32.3	[redacted]	39.3

Table 2: The effect of a dry AEZ on tuberous roots of cassava in Mutomo Sub-County of Kitui County in Kenya in 2012 -2013

Treatment	Number of marketable tuberous roots	Number of unmarketable tuberous roots
EX-Mariakani	7.25	4.0
I 96/00067	5.25	5.0
MM96/5280	4.75	5.0
Means	5.75	4.0
E.S.E.	1.537	1.1
S.E.D.	2.173	1.6
LSD	5,317	3.9
S.E.	3.073	2.3
CV (%)	53.4	51.5

Table 3: The effect of a dry AEZ on yield (kg) of cassava in Mutomo sub-County of Kitui County in Kenya in 2012-2013

Treatment	Marketable tuberous roots	Unmarketable tuberous roots	Mother stock / plant	Stems / plant
EX-Mariakani	2.2	0.9	0.6	3.0
I 96/00067	3.9	1.2	0.4	2.5
MM96/5280	1.8	1.5	0.4	2.5
Means	2.6	1.2	0.4	2.7
E.S.E.	0.88	0.59	0.17	0.20
S.E.D.	1.25	0.83	0.24	0.28
LSD	3.06	2.03	0.59	0.69
S.E.	1.77	1.17	0.34	0.40
CV (%)	67.7	100.1	76.9	14.9

Table 4: The effect of a dry AEZ on cassava mosaic disease infection and white scale infestation scores on cassava in Mutomo sub-County of Kitui County in Kenya

Treatment	Cassava mosaic disease infection score	Cassava white scale infestation score
EX-Mariakani	3	3.0
I 96/00067	3	3.3
MM96/5280	3	3.0
Means	3	3.1
E.S.E.	0.4	0.1491
S.E.D.	0.6	0.2108
LSD	1.5	0.5419
S.E.	0.9	0.2981
CV (%)	30.5	9.6

This means that three cassava cultivars, EX-Mariakani, I 96/00067, and MM96/5280 seem to be performing well in this dry agro-ecological zone and their multiplication and distribution to farmers in Mutomo should

continue aggressively. Special attention should be given to EX-Mariakani which seems to have more superior drought tolerance capability than I 96/00067, and MM96/5280. There is need to investigate further the culinary differences if any, between the three cultivars**.**

Conclusions

Cultivar EX-Mariakani seems to be more drought tolerant than the improved I 96/00067, and MM96/5280. Its multiplication and distribution to farmers in Mutomo should continue aggressively. There is need to investigate further the culinary differences if any, between the three cultivars**.**

Recommendations and way forward

It is important to involve farmers in varietal evaluation and selection right from the start. Breeders should consider incorporating the highly desirable culinary qualities in local cultivars in the high yielding early maturing disease resistant improved clones in order to accelerate adoption of improved cultivars. There is need to multiply the three cultivars and distribute them to farmers in Mutomo and other areas in semi-arid eastern Kenya.

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Drought mitigating technologies: lessons learnt from sorghum and cowpea production in semi-arid areas of Embu County, eastern Kenya

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Abstract

The lower parts of Embu County in eastern Kenya are characterised by poor harvest due to poor rainfall distribution, among other factors leading to declining poverty levels. Rainfed agricultural productivity has continually declined due to unpredictable and unreliable rainfall patterns. The decline in crop productivity has been as a result of inadequate understanding of intra-seasonal rainfall variability to develop optimal cropping calendar. A study was conducted to access the effect of various water harvesting and integrated soil fertility management technologies for enhanced sorghum (*Sorghum bicolor* L.) Moench) and cowpea (*Vigna unguiculata* L.) productivity in Mbeere South sub-County. The field experiment was laid out in Partially Balanced Incomplete Block Design (PBIBD) with 36 treatments replicated three times. The treatments of tied-ridges and contour furrows under sorghum alone and intercrop plus external soil amendment of 40 K kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1} had the highest grain yield of 3.1 t ha^{-1}. The soil fertility levels differed significantly from one another (p=0.0001) in terms of sorghum and cowpea grain yield. Generally, all experiment controls had the lowest grain yields as low as 0.3-0.5 t ha^{-1}. Therefore, integration of minimal organic and inorganic inputs under various water harvesting technologies could be considered as an alternative food security initiative towards climate change mitigation for Mbeere South sub-County, Embu County in eastern Kenya.

Key words: climate change, food security, soil amendments, Mbeere south sub-county, eastern Kenya.

Introduction

Agricultural productivity is constrined by climate change, declining soil fertility, degradation of natural resources, inefficient markets, weak institutions and policies in semi-arid areas of Kenya. More than 13 million of the 38 million people live below the poverty line of less than one USD a day. Agriculture is the mainstay of the Kenyan economy contributing about 55% of the gross domestic production (GDP). The sector further provides 80% employment, accounting for 60% of the exports and 45% of the government revenue (Ragwa *et al.,* 1998). The Government of Kenya (GoK) has put in place the Agricultural Input Subsidy Program (AISP) to support farmers so that they can access inputs such as inorganic fertilisers. In its “Vision 2030”, the government also spells out the desire to use agriculture as the vehicle to transform the country to industrialisation (CAADP, 2008). However, more than 80% of Kenya is classified as arid and semi-arid which is characterised by low and erratic rainfall, high evaporation rates and fragile soils that are unsuitable for sustainable rainfed agriculture (Miriti *et al.,* 2012; McCown and Jones, 1992). Rainfed productivity has continually declined due to unpredictable and unreliable rainfall patterns in Embu County. The decline in food productivity has been as a result of inadequate understanding of intra-seasonal rainfall variability to develop optimal cropping calendar. Understanding spatio-temporal rainfall patterns

rainfall has been directly implicated to combating poverty and hunger through agricultural enhancement (IPPC, 2007). The amount of soil-water available to crops depends on rainfall onset, length and cessation which influence the successfulness or failure of a crop. This is particularly important in sub-Sahara Africa (SSA) where agricultural productivity is principally rainfed yet highly variable (Jury, 2002).

The drier parts of Mbeere sub-County of Embu in Kenya experiences elevated rainfall variations, persistent dry spells, prolonged droughts and high annual potential evapotranspiration (2000-2300 mm $year^{-1}$) (Micheni *et al.*, 2004). There is generally enough water on the total. However, it is poorly distributed over time (Kimani *et al.*, 2003) with 25% of the annual rain often falling within rainstorms, that crops suffer from water stress, often leading to crop failure (Meehl *et al.*, 2007). Quite often, analyses on rainfall patterns have been based on annual averages, thus missing on characteristics of seasonal variations (Barron *et al.*, 2003). Sivakumar *et al.* (1993) reported that understanding the average amount of rain per day is essential in assessing inter- and intra-seasonal variability. Evaluating mean duration between successive rain events also aids in understanding these variability (Akponikpè *et al.*, 2008). Recha *et al.* (2011) noted that most studies do not provide information on the much-needed character of within-season variability despite its implication on soil-water distribution and productivity. There has been interest in understanding seasonal rainfall patterns by evaluation of its variables including rainfall amount, rainy days, lengths of growing seasons and even dry-spell frequencies. Studies done by Tilahun (2006) noted high variations in annual and seasonal rainfall totals and rainy days in Ethiopia and Sudano-Sahelian regions. Mugalavai *et al.* (2008) analysed onset and cessation of rainfall in Kenya and linked their variation to atmospheric, oceanic and local geographic conditions. Hitherto, the much-needed information on inter- and intra-seasonal variability of rainfall in Embu County is still inadequate despite its critical implication on soil-water distribution, water use efficiency (WUE), nutrient use efficiency (NUE) and crop yield. Recent studies have yielded little evidence on occurrence of dry spells to increase the frequency of rain water use efficiency in semi-arid areas of Africa (Stroosnijder, 2009). This has been contributed by mixed crop-livestock systems being projected to see reduction in crop production as a result of drought throughout most East Africa regions due to climate change by 2050 (Thornton *et al.*, 2010)

The challenge now remains on how to maximise any drop of rain water which falls on the ground to increase agricultural production in semi-arid areas of Embu County. The low crop production in central Kenya is also often associated with lack of appropriate farming practices that are suited to the fragile ecosystems (Bationo *et al.*, 2004; Mbogoh, 2000). Most of the smallholder farms are characterised by nutrient mining as a result of crop harvest and residue removal (Mugendi *et al.*, 2003; Bielders *et al.*, 2002) as well as lack of resources to invest in mineral fertilisers or very little nutrient replenishment is practiced (Mugendi *et al.*, 2010). The recommendation of African Fertiliser Summit (2006) '*to increase the fertiliser use from the current 8 to 50 kg ha^{-1} nutrient by 2015*' reinforces the role of fertiliser as a key entry point for increased crop productivity and attaining food security and rural well being in SSA. Alternatively most farmers cannot afford to buy inorganic fertilisers due to their high prices (Sanginga *et al.*, 2009; Crew and People, 2004). Many agricultural systems revolve around inorganic fertiliser use rates and concentration of nutrients in manure. Inorganic fertilisers and high quality manure are often expensive for most smallholder farmers. Due to these inappropriate farming systems, they lead to land degradation as a result of soil erosion and soil fertility decline in cultivated areas resulting to low crop yields (Njeru *et al.*, 2011a; Kimani *et al.*, 2007). The soil fertility decline is as a result of a combination of processes such as high rates of soil erosion, nutrient leaching, removal of crop residues, continuous cultivation of the land without adequate fertilisation and fallowing (Njeru *et al.*, 2011b; Okalebo *et al.*, 2006). The average annual loss in soils nutrients of 42 kg Nitrogen (N), 3 kg Phosphorus (P) and 29 kg Potassium (K) ha^{-1} in Kenya is among the highest in Africa (Smaling *et al.*, 1997). The rising cost of inputs has lead to many smallholder farmers reducing or abandoning the use of chemical fertiliser altogether (Gachimbi, 2002).

Therefore, food security situation is expected to continue deteriorating and could worsen in future if water harvesting and integrated soil fertility technologies are not taken up quickly in semi-arid areas of Embu County. Improving agricultural productivity is crucial for resolving food crises, enhancing food security and accelerating pro-poor growth. Yet, sorghum and cowpea are locally important for food and household

nutrition, and provide income opportunities for the most vulnerable people and women in particular. These premium crops have potential to diversify the farming systems, adapt to spread risks and are more resilient to climatic variations and climate change variability. This study assessed the effect of various water harvesting and integrated soil fertility management technologies for enhanced sorghum and cowpea productivity in Mbeere South sub-County.

Materials and methods

Site description

The study was conducted in Kiritiri Division (S0.91672 and 37.47680 N; S0.47330 37.91238 E at 800 m) in Mbeere South District which lies in the southeastern slopes of Mt. Kenya. It receives an average rainfall of 700-900 mm and has temperatures of 21.7-22.5^{o} C. The soil type is ferralsols. Besides differences in agroecological zones along the altitudinal gradient, agricultural systems differ from upper to lower zones. Kiritiri Division, Mbeere South District is generally a low potential dry zone. It is covered by three agroecological zones; the marginal cotton zone (LM4); the lower midland livestock-millet zone (LM5); and the lowland livestock millet zone (L5). The study was conducted in agroecological zone (LM4/5) during the 2012 long rains (Jaetzold *et al.*, 2007).

Experimental design

The treatments were arranged in a factorial structure with each treatment being a combination of one of the three levels of water harvesting techniques (tied-idges, contour furrows and conventional tillage-farmers' practice), two levels of cropping systems (sole sorghum-Gadam, sorghum and cowpea (M66) intercrop and six levels of soil fertility amendment options (control, 40 kg P ha^{-1} + 40 kg N ha^{-1}, 40 Kg P ha^{-1} + 20 kg N ha^{-1}, 40 kg P ha^{-1} + 40 kg N ha^{-1} + manure 5 t ha^{-1}, 40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1} and manure 5 t ha^{-1} thus giving a total of 36 treatments. They were laid out in a Partially Balanced Incomplete Block Design (PBIBD) with six incomplete blocks per replicate each containing six treatments, replicated 3 times making a total of 108 plots. Treatments were assigned to blocks randomly with plot size of 6 × 4 m. The dryland sorghum (Gadam) and cowpea (M66) varieties were used as the test crops. Farmers were invited to evaluate each plot by scoring on a scale of good, fair and poor according to their own observation on crop performance and this was compared with scientific data collected on crop productivity at the end of the 2011 long rains. They were all given equal opportunity to evaluate 108 plots in the field experiment. They were also asked the kind of water harvesting and soil fertility management they used in their farms.

Data analysis

The difference between treatment scores and gender was significant ($P \leq 0.05$). The biophysical data on crop yield was analysed using statistical Analysis of Variance (ANOVA) using SAS version 8. Differences between treatment effects were declared significant ($P \leq 0.05$).

Field experiment results

The results (Table 1) underscore the scientific crop evaluation from the field experiment during the 2011 long rains.

Three types of water harvesting, two cropping system and six fertility amendment levels but only fertility levels that differed significantly from one another (p=0.0001) in sorghum grain yield (Table 1). The three levels of water harvesting and the two cropping systems did not differ significantly in grain yield among themselves (p=0.8513) and (p=0.7001), respectively. The total dry matter amount varied significantly among levels of cropping system and fertiliser application (p= 0.0111 and 0.0001), respectively. However the total dry matter amount did not vary significantly across water harvesting methods (p=0.5333). The sorghum biomass were significantly different among cropping system (p=0.0020) while water harvesting and fertility levels did not differ significantly (p=0.3820 and 0.0854).

Table 1: The effects of water harvesting, cropping system and soil fertility regimes on sorghum yields in Kiritiri Division

Water harvesting	Cropping system	Soil fertility management regimes	Total DM (t ha^{-1})	Biomass + husks (t ha^{-1})	Grain yield (t ha^{-1})
Tied-ridges	Sole crop	40 kg P ha^{-1} +20 kg N ha^{-1} + manure 2.5t ha^{-1}	6.1	3.0	3.1
Contour furrows	"	"	6.1	3.0	3.1
Tied-ridges	Intercrop	"	6.1	3.0	3.1
Contour furrows	"	"	6.1	3.0	3.1
Tied-ridges	"	40 kg P ha^{-1} + 20 kg N ha^{-1}	5.9	2.9	3.0
Contour furrows	"	Manure 5 t ha^{-1}	5.9	2.9	3.0
Tied-ridges	"	40 kg P ha^{-1}+40 kg N ha^{-1}+ manure 5 t ha^{-1}	5.9	2.9	3.0
"	"	40 kg P ha^{-1}+40 kg N ha^{-1}	5.8	2.8	3.0
Contour furrows	"	40 kg P ha^{-1}+40 kg N ha^{-1} + manure 5 t ha^{-1}	5.7	2.8	2.9
Tied-ridges	Intercrop	"	5.6	2.7	2.9
Contour furrows	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1}	5.6	2.7	2.9
"	"	40 kg P ha^{-1} + 20 kg N ha^{-1}	5.4	2.6	2.8
Tied-ridges	Intercrop	"	5.4	2.6	2.8
Contour furrows	"	40 kg P ha^{-1}+40 kg N ha^{-1} + manure 5 t ha^{-1}	5.2	2.5	2.7
Tied-ridges	"	40 kg P ha^{-1}+40 kg N ha^{-1}	5.2	2.5	2.7
Contour furrows	"	"	5.1	2.5	2.6
"	"	40 kg P ha^{-1} + 20 kg N ha^{-1}	5.0	2.4	2.6
Tied-ridges	Sole crop	Manure 5 t ha^{-1}	4.9	2.4	2.5
Contour furrows	Intercrop	"	4.8	2.3	2.5
Tied-ridges	"	"	4.8	2.3	2.5
Farmers practice	"	40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5t ha^{-1}	4.6	2.2	2.4
"	Sole crop	40 kg P ha^{-1}+20 kg N ha^{-1}	4.6	2.2	2.4
"	"	40 kg P ha^{-1}+40 Kg N ha^{-1}	4.5	2.2	2.3
"	"	40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1}	4.4	2.1	2.3
"	Intercrop	40 kg P ha^{-1} + 40 Kg N ha^{-1}	4.3	2.1	2.2
"	"	40 kg P ha^{-1} + 20 kg N ha^{-1}	4.2	2.0	2.2

“	Sole crop	40 kg P ha^{-1} + 40 kg N ha^{-1} + manure 5 t ha^{-1}	4.1	1.9	2.2
“	Intercrop	”	3.9	1.8	2.1
“	“	Manure 5 t ha^{-1}	3.9	1.8	2.1
“	Sole crop	“	3.7	1.7	2.0
Tied-ridges	“	Control	1.7	1.2	0.5
“	Intercrop	“	1.6	1.1	0.5
Contour furrows	Sole crop	“	1.5	1.1	0.4
“	Intercrop	“	1.4	1	0.4
Farmers practice	Sole crop	“	1.3	1	0.3
“	Intercrop	“	1.1	0.8	0.3
Means			4.5	2.2	2.3
CV			17	22.8	20.4
LSD			1.92	1.41	0.20

Combination effect

The results further indicated that sorghum without manure did not differ significantly in yield with treatments that did not receive fertiliser. However, plots that received fertiliser and no manure gave slightly higher sorghum yield than plots that received manure and no fertiliser (Table 1). The highest sorghum yield of 3.1 t ha^{-1} was from tied-ridges under sole sorghum and intercrop cropping system with external nutrient replenishment of 40 kg P ha^{-1} + 20 Kg N ha^{-1} + manure 2.5 t ha^{-1}. The top eight treatments yield did not differ significantly ($p<0.05$) from one another. The lowest sorghum yield of less than 2.0 t ha^{-1} was in the control with neither fertiliser nor manure regardless of other intervention (water harvesting methods or cropping systems). The total dry matter and biomass were highest in tied-ridges under sole cropping of soil fertility amendment of 40 kg P ha^{-1} +20 kg N ha^{-1} + manure 2.5 t ha^{-1} (6.1 t ha^{-1}) and (3.0 t ha^{-1}), respectively.

Discussion

Treatment performance

There is a consistency in the results (Table 1) on high grain yields, biomass and total dry matter at 3.1, 3.0 and 6.1 t ha^{-1}, respectively, in tied-ridges under sorghum alone with a minimum combination of organic and inorganic inputs at half dose application of N and manure. This was an indication that minimal nutrient replenishment was required in all the seasons. Studies by Mugendi *et al*. (2010) and Gachimbi (2002) have also reported that farms in central Kenya highlands require nutrient replenishment every season from manures, fertilisers and crop residue return in their farms. It has also been reported by Njeru *et al*. (2010, 2009) and Mairura *et al*. (2007) that soil fertility can also be be accessed through visual observation on crop performance and yield. The results (Table 1) further shown that water harvesting technologies and integrates soil fertility management technologies played a major role in moisture conservation and increased crop productivity. This is in agreement with what Miriti *et al*. (2012) and Mucheru-Muna *et al*. (2009) found that by incorporation of water harvesting and legumes on-farm the can enhance crop productivity in eastern Kenya. The results further shows that the third and the fourth treatments of tied-ridges and contour furrow under sorghum and cowpea intercrop with the same soil fertility management options were dominated by their sole cropping systems. This could be as a result of nutrient competition since cowpeas are heavy nutrient miners as they are associated with interspecific

competition in mixed stands. The same results have been reported by Katsaruware *et al.* (2009) that crop yield reduction can be experienced in intercrops where they are associated with interspecific competition in mixed stands and the absence of interspecific competition in the monocrops. The results further indicate that intercropping sorghum with cowpea depressed sorghum yields. This influenced farmers' decision on crop performance. This outcome for sorghum (Table 1) could be in line with reports for maize from Kenya (Nadar, 1984) and in Tanzania (Jensen *et al.,* 2003) where maize grain yields reduction of 46-57% and 9% occurred when maize was intercropped with cowpea due to the competition for moisture between the two crops. Alternatively, due to slow mineralisation of manure which needed several seasons to meet the level of nutrient competition (Lekasi *et al*., 2003). The results by Miriti (2011) have also shown that cowpea was a nutrient competitor for maize production in semi-arid areas of eastern Kenya. The experiment control farmers practice under sorghum and cowpea intercrop was the lowest in grain yield. This is in line with continuous cultivation of the same piece of land as this will lead to nutrient depletion and requires nutrient replenishment (Mugwe *et al*., 2009; Miriti *et al.,* 2003). This has lead to land degradation contributing to reduced crop production as a result of failure of rainfall distribution in semi-arid areas of Kirinyaga West County. However, farmers are discouraged from adopting these water conservation structures because they are labour-intensive in and land tenure uncertainty (Demelash and Stahr, 2010). Therefore, land productivity can be improved by using appropriate agricultural technologies which suit these semi-arid areas of Mbeere south sub-County, eastern Kenya.

Conclusion

The results reported here demonstrate that there is need to incorporate water harvesting and integrated soil fertility management technologies in sorghum and cowpea productivity. This will also suggests that only low-input technologies are suitable and need to be adopted through a known crop intensification technologies that could be enhanced. The results have also demonstrated that there is need for nutrient replenishment on-farm every season to enhance sorghum and cowpea productivity. Therefore, integration of minimal organic and inorganic inputs under various water harvesting technologies could be considered as an alternative food security initiative towards climate change mitigation for Mbeere South sub-County, Embu County in Eastern Kenya.

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Farmers' up-take response to soil fertility management practices in Pallisa District, eastern Uganda

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Abstract

The growing decline of soil fertility in sub-Sahara Africa is reflected declining crop yields per unit area, increasing food insecurity and poverty. The problem is multi-faceted and requires many dimensions to tackle it. This study identified different practices farmers use to maintain soil fertility and changes that these practices have undergone over the last 60 years and, how different extension methods by the National Agricultural Research Organistion are used to disseminate research recommended soil fertility management practices influence their uptake/adoption by the target beneficiaries. Focus group, individual discussions and with field observations and a survey among participants in the training were methods used for data collection in Pallisa District. Qualitative and quantitative data were analysed using SPSS (16.0) software. Crop rotation, grass strips; rotation of Kraals, land fallow, returning residues to the field were the indigenous practices used. These have undergone changes and becoming less practicable. Use of animal manure and Inorganic fertilisers were the most adopted introduced practices with 72.3 and 7.4% adopters, respectively. Demonstrations using the mother-baby approach (entails a two-stage demonstration of recommended soil fertility improvement practices, field days and workshops for participants) worked better for farmers than use of print materials in promoting uptake of use of soil practices. Major constraints to the application of these practices by the beneficiaries include poor accessibility/scarcity, high labour and monitory costs involved, drought, poor handling and transportation facilities (for animal manure) and low farm-gate prices of farm products. Indigenous methods are being abandoned due to growing land shortage; methods that involve hands-on training are most preferred by farmers; uptake of introduced practices, especially inorganic fertilisers and animal manure is most constrained by low and unstable farm-gate prices, drought, inaccessibility, high monitory and labour costs involved and limited capital aggravated by lack of saving culture and poor prioritisation. Therefore, farmers should adopt integrated soil management approaches, and policies that facilitate application of ISFM should be in place, soil information dissemination should take a more practical approach like in the case of mother-baby. Sensitisation of farmers on the value of sharing soil information and mechanism for reward be put in place.

Introduction

Soil fertility depletion is one of the most important biophysical constraints to food security in sub-Sahara Africa (Kimaru and Jama, 2006; Verchot *et al.,* 2007; CIAT 2001) in Uganda and other African countries (World Bank, 2004; CIAT, 2001). The population increase estimated at the rate of one million per year and expected to reach 35 million by 2015 (UBOS, 2006; 2010) will immensely increase demand for food and fibre. According to IFPRI (2004), soil fertility in Uganda is drastically declining and limiting crop yields.

Soil fertility is caused by continuous cropping, burning of crop residues, overgrazing, soil erosion, leaching and nutrient mining, among others. On average -21, -8 and -43 kg ha^{-1} $year^{-1}$ of nitrogen (N), phosphorus (P) and K are lost per year (Wortmann and Kaizzi, 1998; Nkonya *et al.,* 2005).

Low adoption of recommended soil fertility management practices in Pallisa District is responsible for the growing decline in soil fertility. Limited access to extension services and inputs, high input costs, poor attitudes, low farm-gate prices among other factors have been advanced for the failure (NARO/DFiD, 2001). There has been little attention on how dissemination methods used contribute to this problem. Therefore this study was instrumental in informing researchers on what adjustments to make on

recommendations to smallholder farmers on different soil fertility enhancement practices, extension workers on better options/methodologies to enhance dissemination, subsequent uptake and adoption of appropriate soil technologies. Furthermore, it was to provide a basis for formulation of favourable policies by policy makers.

The objectives of the study were to describe the trend in the soil fertility management practices, different extension methods used by NARO with their influence on adoption of disseminated recommended soil fertility management practices and other factors that influence farmers' decisions to learn, use and or share soil fertility management information with other farmers in Pallisa district.

Materials and methods

Site description and sampling

This study took a descriptive approach, focusing mainly of qualitative information with limited quantitative data. This was meant to dig out detailed information using a number of methods including observation of things as they are in farmers' conditions. The scope was limited to the project area. Butebo and Opwateta sub-Counties with Opwateta, Kapwai, Kadesok and Butebo parishes were selected and purposefully sampled. Farmer groups that participated in the training were purposefully sampled in each parish. Purposeful sampling method was used to identify farmers who participated (both adopters and none adopters) in the training for the focus group discussions. At household levels, observations of practices were made and photographed. A survey was then conducted, with the study population comprising of all those who participated in the dissemination processes. Participating farmers in all the parishes were identified, registered and given numbers. A sample size of 100 farmers was drawn through a simple sampling technique involving a raffle with replacement. Semi-structured interviewer-administered questionnaires were used to capture information. Survey data was analysed using SPSS computer software while qualitative data was analysed by content.

Results

Figure Trend of soil fertility in Opwateta and Kanyum sub counties, Pallisa District

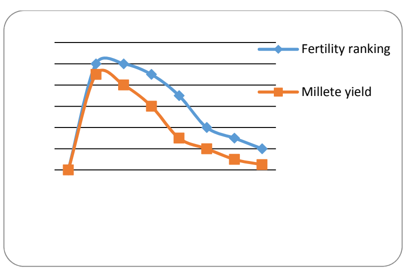

Figure 1a : Opwateta village, Opwateta Parish

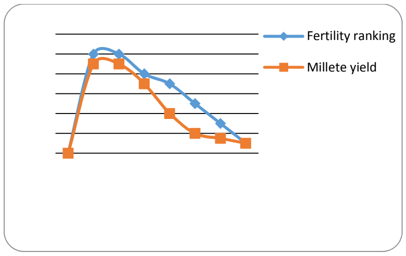

Figure 1b : In Kituba village, Kanyum parish,

Table 1: Indigenous soil fertility management practices and their level of usage

Practice	Distribution of the practice (%)	Challenges
Crop rotation	100	Growing over reliance by farmers on few crops (especially cereals) for food and income as land become limited with growing human population.
Grass strips	88	Growing land shortage causing encroachment
Land fallow	15	Land shortage
Rotation Kraals on farm land	13	Limited number of cattle due to limited land
Maintaining crop residues in the field	83	Growing demand from non-farm use like hut thatching and fuel wood

Ranking

Figure 2: Changes in level of frequencies of crops /practices in rotation sequences and bush fallow over the years

Figure Degraded grass strips used to check soil erosion by runoff

Figure Direct application of crop residues to the gardens

Figure Using cereal stalks as thatching and fuel wood materials

Table 2: Soil practices disseminated and influence of each dissemination method used on uptake by farmers

The method the respondent considered to have best enabled him/her to grasp the skills on soil fertility management	Level of adoption of soil the respondent (%)				
	Inorganic fertilisers	Animal manure	Green manure	Inorganic fertilisers + animal manure	None
Use of demonstration with field days and workshops (mother-baby approach).	7.4	72.4	3.2	6.4	10.6
Use of brochures	0	20	20	60	0
Use of posters	0	0	0	0	100

Table 3: Diffusion of disseminated soil practices through farmer to farmer transfer of skills

S/n	Number of visiting adopters per host farmer who adopted at least one of the soil practices disseminated	Frequency	Percent
1	1-5	69	69
2	6-10	18	18
3	11-15	4	4
4	16-20	2	2
5	None of the visiting farmers adopted a practice	7	7
	Total	100	100

Table 4: Influence of social relations on diffusion of soil practices by mother-baby approach

S/n	Relationship of the visiting adopters with host farmer	Frequency	Percent
1	Relatives in the village	64	64
2	Non relative in the village	22	22
3	Relatives outside the village	9	9
4	None relatives outside the village	5	5
	Total	100	100

Ranking

Figure 7: Variability in household income, food availability and workload as a constraint to adoption

Table 5: Most constraining factors to the use of animal manure

Constraint	Frequency	Percentage
Limited transportation and handling facilities	15	15
Scarcity	9	9
Limited transportation/ handling facilities and scarcity	50	50
scarcity and bad smell	12	12
high labor, limited transportation and handling means/facilities	14	14
Total	100	100

Table 6: Major constraints to inorganic fertiliser use experienced by respondents

Constraints	Frequency	Percent
high fertiliser cost	15	15
limited access	1	2
limited access and high cost	82	82
limited use of knowledge of use of fertiliser	1	1
Total	100	100

Discussion

Indigenous soil fertility management practices used in the area

While all the five traditional practices are important to different categories of farmers; the following section will discuss use of grass strips, crop rotation and household crop residues that are used by most (80%) of the respondents in the three sub-counties. Less than 20% used fallowing and kraal rotation.

Discussions with farmers indicate that traditional soil fertility management practices have played a big role in maintaining soil fertility. However, increasing land shortage has affected application of these practices (Table 1). Grass strips, though used by Most (85%) of farmers, have shrunk in size from between 2-3 m wide to less than 0.5 m wide (Figure 3). More than 80% of farmers believe that proper management of crop residues helps maintain soil fertility. This is in line with findings by (FAO, 2001; Horwath, 2005; Sangina and Woomer, 2009) that recognise the value of crop residue in improving soil organic matter (SOM) level. However, maintenance of this vital component of a fertile soil is being affected by the growing level of competitive usage of crop residues as fuel wood and hut thatching materials (Figure 5).This concurs with other studies (IARI, 2012) on constraints to the management of crop residues for soil improvement. Crop rotation is still practiced by 100% of the respondents. However, the recommended practice of alternating shallow rooted crops with deep-rooted crops (UCS, 2008) has been interrupted as cereals become more dominant in the system than any other crop (Figure 2) due to land shortage. The usefulness of indigenous soil management practice has been negatively affected.

Methods used and their impact on uptake of the promoted soil practices in the area

These practices were introduced in the area by NARO through two methods: the Mother - baby training approach through farmer groups and use of print materials (brochures and posters). The 'mother-baby' depicts a technology/practice-dissemination approach that uses various strategies to impart soil improvement skills and knowledge to farmers. It entails a two-stage demonstration of recommended soil fertility improvement practices, and holding field days and workshops for participants. Discussion and survey results show that more than 70% of farmers who adopted any of the practices attribute their adoption to mother-baby methodology as compared to print materials (Table 2). Farmers attribute this to the practical nature of the approach (mother-baby) that facilitates hearing, seeing and doing, which make feedback easy, hands-on learning and experience sharing easy. This agrees with Berend (2004) who asserts that it is not the content but the method of delivering the content that makes a successful training. On what combination of extension methods to accelerate dissemination and adoption of soil fertility technologies, most (96%) of respondents preferred combination of extension methods that facilitated hearing, seeing and doing (mother-baby in combination with radio programs and regular contacts with field based trainers). Combination of mother-baby with print material was rated least at 4%. However, of those farmers who attributed their adopting soil technologies, appetite for reading declined with age. While 7.1% of 16-25 year age group found it useful in giving knowledge, 5.2% of age groups 26-45, 3.8% of 46-60 and 0% of and 61+ year categories found brochures useful. Discussions with participants in groups and as individuals attribute this trend to visual impairment and increase in responsibility that come with age. Younger persons are perceived to have better visual strength and less responsibility, thereby having time to read. Adults are perceived to have many responsibilities. Therefore, any extension methods that lengthen learning processes are less preferred as one ages. The problem attributed to visual problem agrees with findings by Donia and LaurenScharff (2002) which indicate that human body systems decline in performance with age.

Practices adopted and major constraints

Animal manure was adopted by 72.3% of the farmers while inorganic manure was adopted by 7.4% (Table 2). Main constraints to their use include poor accessibility/scarcity, high labour and monitory costs, drought, poor handling and transportation facilities (for animal manure) and low farm-gate prices (Tables 5 and 6). This agrees with other findings (Kaizzi *et al*., 2007b; FAO, 2012; Muzari, 2012). Yearly variability in household food and income level (lowest at planting seasons) (Figure 7), poor saving culture and prioritisation for investment in soils also emerged as constraining factors to adoption of use of animal manure and inorganic fertilisers. Social relationship also influenced farmers' decisions to share learnt soil fertility enhancement skills and knowledge with other farmers. While 73% of respondents shared learnt skills with relatives, only 27% shared with non relatives. This kind of preferential treatment is embedded in a common belief here that at a time of need, none relatives cannot help as much as one's relative does. This affects farmer-to-farmer knowledge diffusion in a heterogeneous society if contact farmers are of the same ethnic background. More than 90% of animal manure is collected during dry season and applied directly on surface to the field before cultivation and after planning.

Conclusions

- Indigenous soil fertility management practices used by farmers in the project area have experienced severe constraints and are collapsing due to land shortage resulting from the growing human population
- Farmers' uptake response to a soil technology/practice (especially use of animal manure and inorganic fertilisers) is influenced by accessibility/availability, labour and financial costs associated with it, farm-gate prices on which such an input was used, drought, land availability and limited capital/poor saving culture
- Effective dissemination of recommended soil fertility enhancement practices, other factors being constant, requires methods that facilitate seeing, hearing and doing by the target beneficiaries as in the case of mother-baby methodology
- Farmers are willing to share out soil information acquired but mainly with those from whom they see prospect of reciprocation in time need. The social support network is strongly centered on blood relations than any other factor. This in effect dictates on the pattern of sharing resources among farmers. As a result, it is common to find that vital information is shared mainly with those related by birth or marriage

Recommendations

- As indigenous methods of maintaining soil fertility collapse, farmers should embrace an integrated approach to soil fertility management
- Favourable policies that make recommended technologies affordable and accessible by farmers should be put in place by the policy makers
- Farmers should adopt a cooperative approach to marketing and purchasing of farm produce and input to enable them enjoy economies of scale and escape exploitation by middlemen. This will provide them with incentives to invest in soil technologies cheaply
- Dissemination of soil fertility technologies by extension agencies should take on a more practical methodologies that foster learning through combined effects of seeing, hearing and doing as is with mother-baby approach used by NARO. But this should integrate strategies that promote farmer institutional development, attitude and behaviour change of farmers for corporate use of agricultural information for growth
- Research, extension and policy makers should devise mechanisms of providing incentives to farmers to freely share soil information. This will encourage wider coverage of the community through one-on-one transfer of knowledge and skills
- This study focused on NARO which played the role of extension in diffusing recommended soil fertility management practices. However, there is need for further research in other parts of the country to explore how other agricultural agencies are effectively communicating soil fertility management practices to farmers

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Making farmer recommendations from experimental data: A case study of Gucha area of Kisii County

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Abstract

Studies have shown low soil nutrient levels in the Lake Victoria Basin, attributing this to inappropriate soil and water resource management methods used. Organic and inorganic fertilizers are recommended but farmers need to get economically viable fertilizer options for increased benefits. A study was carried out in Gucha District, one of the severely degraded areas in the Lake Victoria Basin, to determine fertilizer options that are economically viable to small scale farmers. On-farm trials were conducted with different levels of organic and inorganic fertilizers. The use of organic fertilizers gave high yields. However by use of the marginal rate of return analysis, the results showed that the use of DAP, CAN and Mavuno gave economically viable results. The results also showed limited options for farmers in their prevailing circumstances.

Key words: soil fertility, fertilizer options, marginal rate of return.

Introduction

Inappropriate soil and water resource management (SWM) practices in the Lake Victoria basin have led to soil degradation as well as low crop and livestock productivity (Swallow *et al.*, 2001). This phenomenon has also been reported by Makokha and Kamoni (2011) who showed that between 1998 and 2008 maize yields reduced from 25 to 4-5 90 kg bags/acre. Most farmers in Kisii get less than 2.0t of maize grain ha^{-1} compared with on-station researcher yield of 9.0t ha^{-1} (Okoko *et al.*, 2000; Nzabi *et al.*, 2000). Farmers attributed the low yields to declining soil fertility caused by continuous cropping, crop residue burning, soil erosion and inadequate use of organic and inorganic fertilizers. Population pressure has resulted in sub-division of the parcels to very small sizes (mean land acreage was 2.5) with the consequence that past practices, which used to improve soil fertility are no longer practiced.

About 87% of households depended on on-farm employment. The study by Makokha and Kamoni (2011) shows that about 74% of the households had a monthly income of up to KES 10,000. With an average household size of 5 persons, each household member had KES 2,000 per month. This was lower than the International Poverty Line of USD 1.25/person/day (World Bank, 2008). Soil fertility analysis of 30 samples from the study site showed that 90% of the samples had low N, 13.3% had low P, 3.3% had low K, 36.7% had low Ca, 3.3% had low copper, 3.3% had low iron and 10% had low Zinc.

Tongi and Mochoge (2000) have shown that seasonal soil losses for a bare soil with a 9% slope were 54 to 76t ha^{-1}, 1.6 to 2.54 t ha^{-1} for maize and 0.64 to 0.91 t ha^{-1} for intercropped maize. The same results show that in addition to other SWM interventions, efforts need to be made to increase fertility of depleted soils in the study area. Therefore the aim of this study was to determine the appropriate soil fertility options for improved smallholder farm productivity.

After diagnosis of the soil fertility problems , a survey was done to understand the conditions of farmers and the soil fertility status. One of the recommendations made after the survey was to set up on-farm experiments to determine the most appropriate soil fertility options. However, agronomic recommendations need to be economically viable in order for farmers to adopt, because costs and benefits have to be considered before adopting a new practice. Although research has been carried out in the Kisii region on various combinations of fertilizer and manure treatments in maize (Nzabi *et al.*, 2000; Obaga *et al.*, 2000; Onyango *et al.*, 2000), a few economic analyses studies have been carried out to give insights on

the economic viability of the various tested treatments. An experiment may show insignificance among thel treatments but an economic analysis may reveal hidden differences on net benefits, which may cause changes in the final recommendations.

Materials and methods

The study sites were in Ogembo and Sameta Divisions, Gucha District. The actual sites were located at Kiragia and Eburi in Ogembo Division and Etora and Itumbi in Sameta Division. Two thirds of the study area is classified as uplands with slopes of 5 to 16% and they are referred to as undulating to rolling, while one third of the area is rolling to hilly (slopes 8-16%) or mountainous (slopes > 30%) (Wielemaker and Boxem, 1982). The area has a mean annual rainfall of 1700-1800mm. The soils are mainly Nitosols, which are well drained, and very deep (>120cm). Gucha River with its tributaries cuts through the middle of the area and drains into Lake Victoria. Due to population pressure and scarcity of land, all the land was under cultivation with very tiny portions under pasture.

Six treatments and a control were tested in a Completely Randomised Block Design (CRBD) in four on-farm experiments in Ogembo and Sameta Divisions. The treatments were:

- 60 kg P_2O_5 ha^{-1} (P supplied by DAP at planting, topdressed with CAN at 60 kg N ha^{-1} at knee high)
- 30 kg P_2O_5 ha^{-1} + 5t FYM ha^{-1} (DAP and FYM at planting, topdressed with CAN at 30 kg N ha^{-1} at knee high)
- 60 kg P_2O_5 ha^{-1} (P supplied by Mavuno at planting, top dressed with CAN 60 kg N ha^{-1} at knee high)
- 30 kg P_2O_5 ha^{-1} + 30 kg Nha^{-1} + 5t FYM ha^{-1} (Mavuno and FYM at planting, topdressed with CAN at 30 kg N ha^{-1} at knee high)
- 5t ha^{-1} FYM at planting, topdressed with CAN at 30 kg N ha^{-1} at knee high
- 10 t ha^{-1} FYM at planting
- Control (no inputs).

The plots were in an area of 4.5 x 6 m (27 m^2). The chemical composition for Mavuno was 10% N, 26% P_2O_5, 10% K_2O, 4 % S% Ca, 4% Mg plus trace elements.

Data was collected for three seasons; short rains 2010, short rains 2011 and long rains 2011. Yields from the short rains of 2011 were very low because the maize was attacked by a virus, therefore not included in the analysis. Each plot was in triplicate except the one at the Itumbe site, which was in duplicate

The following data was collected for economic analysis:

Average Cariable Costs for each of the seven treatments across the sites.

Variable costs are all inputs affected by moving from one treatment to another. In the experiment the variable costs involved were DAP, Mavuno, CAN, manure, planting, 1st and 2nd weeding, topdressing and maize harvesting. However, the variable costs that changed from one treatment to the other were DAP, Mavuno, CAN, manure and topdressing.

Average Yield (in kg/ha) for each of the seven treatments across the sites

Price of dry maize at the study site during harvesting. The price of maize at the time of harvest was KES 3000 per 90 kg bag, translating to KES 33 per kg

The demonstration sites were managed by farmers from planting to harvesting, so the yields recorded are assumed to be the yields a farmer would get on their farm for the particular treatment. From the data the net benefits and the Mean Rate of Return (MRR) were derived. The net benefits are obtained by subtracting the total costs that vary from the gross value of maize yield while the MRR is the change in net benefits divided by the change in costs. It indicates what farmers expect to gain, on average, in return for their investment when they change from one practice (or technology) to another.

To calculate recommendations that would be economically viable to the farmers, the calculated variable costs are arranged from the lowest to the highest, and tabled with their corresponding net benefits. From the Table the net benefit that is lower than the previous one is eliminated from the analysis. This is because no farmer can adopt recommendations that have higher costs and lower benefits. The MRR from one treatment to another is calculated until it goes below the minimum MRR. The minimum MRR for most agronomic treatments is taken as 50% (CIMMYT, 1988).

Results

In all the seasons the treatments yields were significantly different from the controls (F (6, 47) = 6.189, p, 0.001 SR2010); (F (6, 33) = 5.609, p, 0.001 LR2011). However, without the controls the the other treatments yielded equally on seasonal basis**.**

Short rains 2010

Table 1 shows mean maize yield, variable costs, benefits and MRR for data obtained during the short rains 2010.

Table 1: Mean maize yield, variable costs, benefits and MRR for Short Rains 2010 for Kiragia, Eburi, Etora and Itumbe sites

Variable (ha^{-1})	T7	T1	T3	T5	T2	T4	T6
Mean yield							
Total benefit (KES)	85,305	141,240	159,588	146,751	160,578	140,547	160908
Variable cost (KES)	0	33,985	38,499	44,319	51,090	53,347	58,333
Net benefits (KES)	85,305	107,255	121,089	102,432	109,488	87,200	102,575
MRR		64%	306%	N/A	N/A	N/A	

MRR=Marginal Rate of Return; N/A= Not applicable; T7-Control, T1-60 kg P_2O_5 ha^{-1} (P supplied by DAP at planting, top dressed with 60 kg N ha^{-1} CAN at knee high; T3-60 kg P_2O_5 ha^{-1} (P supplied by Mavuno at planting, top dressed with 60 kg N ha^{-1} CAN at knee high; T5-5 t ha^{-1} FYM at planting, top dressed with 30 kg N ha^{-1} CAN at knee high; T2-30 kg P_2O_5 ha^{-1} + 5t FYM ha^{-1} (DAP and FYM at planting, top dressed with 30 kg N ha^{-1} CAN at knee high; T4-30 kg $P_2O_5ha^{-1}$ + 30kg Nha^{-1} + 5t FYM ha^{-1} (Mavuno and FYM at planting, top dressed with CAN at knee high; T6-10 t ha^{-1} FYM at planting

From Table 1 the highest yield was 10t ha^{-1} FYM at planting, and as expected, the lowest was the control. The highest net output was in T3, where Mavuno was used. To calculate the MRR the net benefit that is lower than the previous one is removed. In this case treatments T5, T2, T4 and T6 have lower benefits and higher costs than T3. From the MRR, T3 is the best recommended for farmers. An MRR of 306% means that for every KES1 invested, a farmer gets KES1 back and KES3.06 more. T1 is still good because it is higher than the conventional MRR of 50%. The choice of whether T3 or T1 will depend on the availability of Mavuno, although T3 still has an advantage over T1 in that it does not acidify the soil after long use.

Long rains 2011

Table 2 shows the mean yield, variable costs, benefits and MRR for data obtained during the long rains.

A comparison of mean yields in Tables 1 and 2 shows that the short rains gave higher yields than the long rains, although they were not statistically significantly different. Late weeding contributed to the decreased yields in LR2011 compared with SR 2010.

Table 2: Mean maize yield, variable costs, benefits and MRR for Long Rains in 2011 for Kiragia, Eburi, Etora and Itumbe sites

KES/ha	T7	T1	T3	T5	T2	T4	T6
Average (kg/ha)	1,513	4,282	3,883	4,104	4,681	4,344	3,583
Total benefit (KES/ha)	49,929	141,306	128,139	135,432	154,473	143,352	118,239
Variable costs (KES/ha)	0	42,836	48,598	51,966	60, 608	63,489	68,519
Net benefit (KES/ha)	49,929	98,470	79,541	83,466	93,865	79,863	49,720
MRR		113%	N/A	N/A	N/A	N/A	N/A

MRR=Marginal Rate of Return; N/A= Not applicable; T7-Control, T1-60 kg P_2O_5 ha^{-1} (P supplied by DAP at planting, top dressed with 60 kg N ha^{-1} CAN at knee high; T3-60 kg P_2O_5 ha^{-1} (P supplied by Mavuno at planting, top dressed with 60 kg N ha^{-1} CAN at knee high; T5-5 t ha^{-1} FYM at planting, top dressed with 30 kg N ha^{-1} CAN at knee high; T2-30 kg P_2O_5 ha^{-1} + 5t FYM ha^{-1} (DAP and FYM at planting, top dressed with 30 kg N ha^{-1} CAN at knee high; T4-30 kg P_2O_5ha^{-1} + 30kg Nha^{-1} + 5t FYM ha^{-1} (Mavuno and FYM at planting, top dressed with CAN at knee high; T6-10 t ha^{-1} FYM at planting

Treatment T2, a combination of half rate fertilizer (30 kg N ha^{-1} N supplied by CAN and 30 kg P_2O_5, P supplied by DAP at planting) and half rate manure (5 t ha^{-1}) gave higher yields in the two seasons compared with the other treatments. Generally, treatments with farm yard manure gave high yields but the costs made the treatment uneconomically viable. From Table 2, movement from the control to T1 gives an MRR of 113%. This treatment involves the use of research recommended full rate fertilizer (60 kg P_2O_5 ha^{-1}, P supplied by DAP at planting and 60kg N ha^{-1}, N supplied by CAN at topdressing).

Discussion

The results indicate that without fertilizers, yields are quite low depicting the known fact that the soils in the study area are highly depleted and interventions are needed to increase fertility. Half rate farm yard manure in combination with half rate fertilizer (DAP) gave highest output in both seasons but did not give the highest net output because manure was not easily available, making it expensive. In addition the quality of manure, especially for cattle is critical for crop yields (Lekasi *et al.,* 2000)

The highest net output was in T3, in SR2010 where the recommended full rate fertilizer (60kg N ha^{-1} and 60 kg P_2O_5 kg ha^{-1}) with P supplied by Mavuno at planting was used. However this trend was not consistent in the next season (LR2011) raising the question whether Mavuno composition is consistent in every season.

Conclusions

These results indicate that under the prevailing circumstances of unavailability and high cost of manure, farmers' options are limited. This means that some of the current fertilizer treatments that farmers are using may be giving low returns. Farmers would have more options if several treatments had an MRR of more than 50%.

Recommendations

- Extension officers should promote generation snd use of manure by farmers in the region in order to increase its availability and hence reduce its costs
- Treatment T2 (30 kg P_2O_5ha^{-1} + 5t FYM ha^{-1} (DAP and FYM at planting, top dressed with 30kg Nha^{-1} CAN at knee high) consistently had more than 50% MRR in both seasons and therefore is the best that can be recommended. The combination of fertilizer and manure also promotes good soil health and is a sustainable land management practice. The combination is also expected to take care of the long term acidifying effects of DAP
- More research using Mavuno should be carried out together with its analysis to determine its consistency in benefits and in its composition. A final decision on its suitability is therefore not possible for now

- More similar on-farm experiments with other crops should be done. This is because different crops have different fertility requirements
- All on-farm experiments should undergo such economic analysis to optimally allocate scarce resources

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Effect of types of fertilizers on soil chemical properties and yield of tomato in Alfisol, southwestern Nigeria

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Abstract

Field experiments were conducted between 2010 and 2012 to determine the effect of organic, organomineral and NPK fertilizers on soil chemical properties and yield of tomato in Ondo south western Nigeria. Organic (OG) and Organomineral Fertilizers (OMF) were each applied at the same rate of 2.5, 5 and 10 t ha^{-1} while NPK 15:15:15 fertilizer was applied at 300 kg ha^{-1}. The treatments were arranged on a Randomized Complete Block Design with three replicates. Relative to control, OG and OMF significantly increased ($p<0.05$) soil pH, OM, N, P, K, Ca, Mg, Fe, Cu, Zn and Mn. Compared with control, OM applied at 5 t ha^{-1} most increased soil total N (143%), 10 t ha^{-1} OG had the highest percentage increase in Ca (98%), K (114%) and ECEC (221%), Organic fertilizer applied at 2.5 t ha^{-1} recorded the highest available P(695%), Zn (887%) and Cu (110%). Organomineral fertilizer applied at 10 t ha^{-1} had the highest increase in Fe (232%). Compared to the control, OG, OMF and NPKF significantly increased ($p>0.05$) tomato fruit yield. Organomineral fertilizer applied at 5 t ha^{-1} had the highest increase in fruit weight of tomato.

Introduction

Research attention in tropical countries especially in Nigeria has shifted to the utilization of agro based industrial wastes and farm waste products which if not converted to other economic uses such as fertilizers might pose environmental hazards. The use of agrowastes as sources of plant nutrients serve as environmental sanitation as well as reduction in craving for mineral fertilizers by farmers. Federal and state governments of Nigeria import fertilizers especially NPK fertilizers of different grades as well as nitrogenous fertilizers. In Nigeria, poor resource farmers could not justify the economic use of mineral fertilizers in as much as the output could not justify the input high cost of fertilizers. Nmadu, (2002) noted that the price of 50 kg of fertilizer rose from less than 10 Naira (Nigeria currency) in the 1970s and early 1980s to 2000 Naira in the year 2000. Poor resource famers are unable to apply the recommended dosage of mineral fertilizers due to their high costs

Commented [M92]:

Low activity clay in most of Nigeria soils hinders the application of large doses of mineral fertilizers except in split applications. The cost, scarcity and acidifying effect of mineral fertilizers on soils have led to the use of plant and animal wastes. Although some organic wastes have beneficial effect on soil properties and yield of crops, they also have negative effects on optimum crop production. They are slow in nutrient release, bulky and low in nutrient quality.

John *et al*. (2004) and Ayeni, (2011) advocated for use of low levels of mineral fertilizers combined with organic manures to supply adequate/balanced plant nutrients for sustainable crop production and minimized environmental impact from nutrient use. Management of mineral fertilizers has become increasingly critical in crop production from both economic and environmental standpoint. Moses, (2009) supported the view that soils fertilized with mineral fertilizers do not supply adequate organic matter needed for optimum crop performance.

Many farmers prefer combined application of mineral fertilizers with organic manures. Organomineral fertilizers combined the attributes of both organic and inorganic fertilizers (Ayeni *et al*., 2008).

In Nigeria, organic fertilizers are being developed from both farm and city wastes, and organomineral fertilizers (organic wastes) fortified with N and/or NP fertilizers. Industrially manufactured

organic/organomineral fertilizers are currently being produced by the Ondo State Government in southwestern Nigeria called sunshine organic and organominreal fertilizers.

Tomato is one of Nigeria's highly prized vegetables and ranked among the top vegetables of economic importance. Most African farmers especially in the northern part of Nigeria and Cameroun take tomato production as a means of livelihood since its marketability is high and nearly every household consumes it. Tomato fruit yield in Nigeria is low compared to the developed countries of the world where mechanized farming is practiced practised.

The effect of organomineral fertilizers on crop performance and soil fertility management cannot be over emphasized. [Makinde *et al*. (2011) confirmed that organomineral fertilizers enhanced the performance of *Amaranthus cruentus* in Lagos Nigeria. Ayeni, (2012) agreed that integrated plant nutrition management enhanced crop performance compared to sole application of either mineral fertilizer or organic manure as shown by better performace of *Amaranthus cruentus* when cocoa pod ash was combined with NPK20:10:10 fertilizer than the sole application of NPK fertilizers. There is scarce information on the use of industrially manufactured organic and organomineral fertilizers on soil chemical properties, growth and yield of tomato in Ondo Southwestern Nigeria. Hence the objective of this study was to determine the effect of industrially manufactured organic, organomineral and NPK15:15:15 fertilizers on soil chemical properties and yield of tomato.

Materials and methods

The research was carried out at Ondo (070^0 05^1N, 040^0 55^1E at 381.3 m), southwestern Nigeria between 2010 and 2012. The experiment was carried out in three years at different sites. It is in the tropical rain forest zone. The soils belong to the order Alfisol (USDA, year) or Luvisol (FAO, year)

Soil analysis

Top soil soil samples 0-20cm were collected randomly from each site prior to start of the field experiments. Another set of soil samples were taken at the end of the experiment using a soil auger. Chemical properties of the soils were determined at the beginning and end of the experiments. Percentage organic carbon was determined by the (Walkley and Black year, not in references) wet oxidation method with H_2s0_4 and $K_2Cr_20_7$ followed by titration with Iron (II) Ammonium sulphate (Ibitoye, 2008 not in references). Total N was determined by the Kjeldahl digestion procedure [(Udo and Ogunwale 2009) omplete in references]. Available P was determined by Bray 2 method. Exchangeable K Na, Ca and Mg were extracted by ammonium acetate buffered to pH 7. Potassium and Na were determined with a flame photometer while calcium and magnesium were determined by AAS. Soil pH in water and 0.IN KCl was determined using a glass electrode pH meter.

Field experiment

The field experiment was conducted in 2010, 2011 and 2012 in Agricultural Research Farm of Adeyemi College of Education, Ondo southwestern Nigeria. The land was cleared, stumped, pegged and marked into plots of 3 x 3m. The experiments were laid out in a Randomized complete Block Design (RCBD) replicated three times.

Organomineral fertilizer and organic manure were each applied at the rates of 0, 2.5, 5 and 10 t ha^{-1} while NPK 15:15:15 fertilizer was applied at 300kg ha^{-1}.

Planting of tomato and application of treatments

The same cultural practices were carried out in all the experiments. Tomato seedlings were raised in the nursery and then transferred to the main site. Planting was done at spacing of 60cm x 60cm at the rate of 1 stand per hole. Weeding was done manually at 3 weeks interval with the use of hand-hoe.

Determination of growth and yield components of tomato

Five plants were selected and tagged per plot for the measurement of growth and yield parameters. Data were collected on number of branches per plant, leaf area and plant height at 50% flowering,fruit weight, fruit percentage, plant height Plant height was measured with measuring tape while leaf area was determined by graphical method

Fruit weight and percentage fruit weight were determined by harvesting the fruit at least three times per week and weighed with the electronic weighing balance, the weight are recorded in kilogramme and extrapolated (t ha^{-1}). The number of fruit per plant was also recorded.

Data analysis

Data collected was subjected to analysis of variance (ANOVA) using SPSS package and the means separated by using Duncan's Multiple Range test (DMRT) at 0.05 level of significance.

Result and discussion

The soil was deficient in OM, N, P, K and Mg (Table 1). Calcium and Zn were fairly adequate (Adebusuyi, 1985; Sobulo and Osiname, 1987; Agboola and Corey, 1977) indicating that the soils required fertilizer application. The nutrients compositions of NPK 15:15:15, Organic and organomineral fertilizers are presented in Table 3. N P K fertilizer had higher N, P and K than organic and organomineral fertilizers. Organomineral fertilizer had higher P and K than organic fertilizer. The soils from the three locations belong to sandy loam. The pH of the sites used for the experiment in 2010 and 201 were slightly acidic while the soil used in 2012 was acidic.

Table 1: Initial soil properties at the three sites 2010,2011 and 2012

Soil properties	2010	2011	2012
pH (H_2O)	6.2	6.5	5.8
pH($CaCl_2$)	6	5.9	5
organic matter	1.98	1.2	1.59
N (%)	0.12	0.08	0.1
C/N	9.4	8.62	9.14
P (mg kg^{-1})	3.49	5.62	4.89
Exchangeable bases c mol kg^{-1}			
K	0.1	0.13	0.1
Ca	2	0.97	2
Mg	0.89	1.04	0.69
Na	0.12	0.08	0.08
Micronutrient (mg kg^{-1})			
Fe	4	4.7	5.23
Zn	32	40	29
Cu	0.14	0.17	0.19
Mn	1.3	2.3	4.8

Table 2: Nutrient composition of mineral, Organic and Organomineral fertilizers (%)

Nutrient	N P K 15:15:15	Organic manure	Organomineral fertilizer
N	15	3.5	3.5
P	15	1.0	2.5
K	15	1.2	4.0

The data presented in Table 3 shows that application of N P K 15:15:15, Organic and organomineral fertilizers had effect on the yield and growth of tomato. Compared to to the control, all the treatments significantly increased ($P<0.05$) tomato plant height, number of branches, leaf area and fruit weight. Organomineral fertilizer applied at 10 t ha^{-1} gave the highest plant height and number of branches followed by 5 t ha^{-1}. Organic fertilizer applied at 2.5 t ha^{-1} gave the lowest plant height. Organomineral fertilizer applied at 5 t ha^{-1} gave the the highest leaf area but was not significantly different ($P>0.05$) from 10 t ha^{-1}.. Orgnomineral fertilizer applied at 2.5 t ha^{-1} had the highest root dry matter [this parameter is not captured in Table 3] followed by its corresponding 5ha^{-1}. Organomineral fertilizer applied at 5 t ha^{-1}.Had the highest fruit weight rephrase this statement according Table 3

Table 3: Mean effect of organic, organomineral and NPK15:15:15 fertilizers growth and yield of tomato (2010 - 2012)

Treatment	Plant ht (cm)	No of branches	Leaf area (cm^2)	Fruit w (t ha^{-1})
Control	20.61d	2.34e	7.22c	8.42f
OMF 2.5	41.32b	5.01b	13.22b	9.63c
OMF 5	52.01a	11.31a	16.42a	21.61a
OMF 10	58.90a	12.31a	15.27a	12.49b
OG 2.5	34.85c	4.32b	12.52b	9.87d
OG 5t	37.30c	5.02b	11.12b	9.19g
OG 10	41.81b	6.03b	13.67b	10.28e
NPK300kg ha^{-1}	35.98c	6.03b	11.05b	9.03d

Table 4 shows the effect of organic , organomineral and NPK15:15:15 fertilizers on soil chemical properties. Compared to the control, all the treatments except NPK, increased soil pH N, OM, available P, Na, Ca, K and ECEC but there were no significant effects (except 2.5t ha^{-1} OMF). Exchange acidity was significantly increased by the application of OMF at 2.5 and 5 t ha^{-1}.

Relative to control, all the treatments significantly increased soil Mn, Cu, Zn and Fe. The rate at which the fertilizers increase the soil micronutrient were different .Organomineral fertilizer applied at 5t ha^{-1} had the highest increase in Mn while OG 2.5t ha^{-1} had the highest increase in Cu and Zn. Application of 10 t ha-1 OMF had highest increase in Fe.

Table 5.:Mean effect of organic, organomineral and NPK15:15:15 Fertilizers on soil macronutrients (2010 - 2012)

Treatment	pH	OM	N	P	K	Ca	Mg	Al3+ +H	ECEC	Base Sat %
		%		mgkg^{-1}	c mol kg^{-1}					
control	5.84c	2.21e	0.12b	2.22d	0.13b	4.19e	1.74c	0.17b	6.23d	97.27a
OMF 2.5	6.64a	2.88d	0.23a	4.18c	0.25a	4.57d	1.93b	0.15a	6.90d	97.83a
OMF 5	6.71a	4.97b	0.30a	4.78c	0.27a	7.49a	2.64a	0.12a	7.76b	98.45a
OMF 10	6.88a	4.59b	0.30a	3.48c	0.31a	7.84a	2.57a	0.10b	10.54a	99.00a
OG 2.5	6.55a	4.04c	0.26a	17.59a	0.23a	7.73a	2.48a	0.09b	10.44a	99.13a
OG 5	6.22ab	6.94a	0.33a	14.36b	0.25a	7.24a	2.36ab	0.09ab	9.94b	99.09a
OG 10	5.06c	4.43b	0.28a	17.41a	0.33a	8.28a	2.22b	0.07b	10.90a	99.34a
NPK 300 kg ha^{-1}	5.03c	4.32b	0.28a	14.43b	0.25a	6.50c	2.69a	0.18b	9.62ab	98.13a

OMF organomineral fertilizer (t ha^{-1}); OG organic fertilizer (t ha^{-1}); Means with the same letter are not significantly different according to Duncam Multiple Range Test

Table 3. Mean effect of organic, organomineral and NPK15:15:15 Fertilizers on soil micronutrients (2010 - 2012)

Treatment	Mn	Cu	Fe	Zn
Control	1.27d	0.22c	2.14e	0.68d
OMF 2.5	3.47a	0.30a	6.33b	1.96bc
OMF 5	3.83a	0.33a	5.59c	2.05b
OMF 10	3.67a	0.29b	7.08a	1.97c
OG 2.5	1.97c	0.44a	5.29c	6.93a
OG 5	3.07b	0.29b	4.82d	1.74c
OG 10	1.61c	0.35a	4.24d	2.22b
NPK 300 kg ha^{-1}	1.97c	0.35a	4.49d	1.59c

Means with the same letter are not significantly different according to Duncam Multiple Range test; OMF organomineral fertilizer (t ha^{-1}); OG organic fertilizer (t ha^{-1})

The control experiment was it a control experiment or treatment recorded the lowest growth and yield of tomato because it was deficient in nutrients required by the the crop. The performance of the tomato fertilized with 5 ha^{-1} of organomineral fertilizer may have resulted due to the presence of mineral fertilizer used to fortify the organic matter leading to quick mineralization of of N, P, K, and Ca required by the tomato crop. The mineral fertilizer in the organic matter may have lowered the C/N ratio of the organic matter. It was also found that both organic and organomineral fertilizers increased tomato production, in agreement with Libert *et al*,(2009) and Libert *et al*, (2013) who reported that organic and organomineral fertilizers increased yield of tomato under tropical Andosol soil conditions and organic/inorganic-cation balanced fertilizers on yield and temporal nutrient allocation of tomato fruits in Sub-Saharan Africa..

Although the analysis of the three fertilizers used showed that NPK15:15:15 had higher N, P and K than both organic and organomineral fertilizer, organomineral and organic fertilizers increased soil N, OM, P, Ca, K and CEC, Mn, Fe and Zn more than NPK 15:15:15. The N, P, and K in the mineral fertilizer may have leached out faster than from the organic fertilizers. Also, organic and the organomineral fertilizers might contained Ca, K and the micronutrients which were not in the mineral fertilizers used for the three experiments. This observation was in agreement with Ayeni and Adetunji, (2010) that organic manures contain other essential nutrients other than N, P and K. It was also observed that 300 kg ha^{-1} NPK compared

favourably with organic and in organic fertilizers in the release of Mn, Cu, Fe and Zn. This might be as a result of the native micronutrients present in the soil before the conduct of the experiments as the initial soil analysis indicated that the micronutrients in the soil was adequate. It was noted that the fertilizers release the nutrients at different rates. Application of 5t ha^{-1} organic fertilizer and organomineral fertilizer had the highest OM ,N and Mn contents, 2.5t ha^{-1} OG recorded the highest available P, Ca, K, Cu and Zn and ECEC while 5 t ha^{-1} organomineral fertilizer had the highest Mg. This shows that one could not point out which of, or rate of the fertilizers best add all the nutrients to the soil. The discrepancies might have arose from the different textural classes of the soils used for the experiment or it might be as a result of inconsistence of organic manures in the release of soil nutrients.

Fertilization of the soil with NPK 15:15:15 fertilizer did not increase soil organic matter in this experiment. This is in line with the assertion of MOSE(2009) that soils fertilized with mineral fertilizers do not add organic matter to the soil compared with agrowastes.

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African traditional vegetables as agents of integrated soil fertility manangement-crotolaria and amaranth farming

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Abstract

The knowledge and understanding of African leafy vegetables had become minimised over time but in the recent past there is more interest in their research for their nutritive and medicinal values. Of value are those that have the potential to ameliorate soil nutrient levels. This is with the background that despite inorganic fertilizers having had a dramatic impact of agriculture in the world, the economic situation in sub-Saharan African calls for alternative methods of reducing soil fertility degradation. The use of leguminous vegetables may be a solution. The study looks at the potential contribution of a leguminous traditional vegetable, *Crotalaria brevidens* to soil nitrogen and its response to various nutrient additions. The crop was chosen for its vigorous growth and adaptability to many regions of Kenya. During the study which was conducted over two seasons, *C. brevidens* was grown under two treatments of inorganic fertilizer (IF) and organic fertilizer (OF) with a control in which there was no fertilizer applied (NF). A non-leguminous vegetable, Amaranthus dubious (Amaranth) was grown under the same treatments for comparison purposes. Soil analysis was done before planting on a composite sample collected from six sites in the experimental plot and soil nutrients were again measured after harvest in the NF subplots. Growth parameters were measured every fortnight and these included leaf number, shoot length, dry weight and nodule number for Crotolaria. Results indicated that while the leguminous vegetable was not affected by external inputs with no significant differences between treatments and control. The non-leguminous vegetables responded well to both IF and OF treatments in all the measured parameters. This underlines the potential for improvements in soil nitrogen levels using leguminous vegetables especially as intercrops with the non-leguminous types.

Introduction

Human nutrition and food security in Africa has been a key issue facing the ever rising population. Cases of malnutrition have been on the rise in the recent days. This is attributed to our lifestyle and diet. Of late, people tend to embrace foods that seem to be easy to cook and modern in nature. This trend has led to neglect of the traditional foods and vegetable which have high nutritional values. Examples of these vegetables include crotalaria spp and amaranth spp.

Like many other plants on the continent of Africa, the role and understanding of African leafy vegetables became minimized as people became more and more urbanized in their livelihoods. Such vegetable were then associated with poverty or a lack of sophistication. In the past, they were collected from the wild and apart from being a dietary item; they also had a useful medicinal role. In the recent past however, there has been a realization of their potential to contribute to better health and this has invariable led to more studies being made on various aspects such as agronomy for cultivation purposes. Indigenous vegetables tend to have short production cycles, require intensive labour but few purchased inputs, and produce high yields with strong nutritional value. They can therefore support rural, peri-urban and urban populations both in terms of subsistence and income-generation, without requiring large capital investments. In some areas they are also becoming popular with commercial growers (Sonja *et al*, 2007).

This study went a stage further and aimed at assessing the contribution of a leguminous vegetable, Crotalaria spp to soil nitrogen levels. A non-leguminous vegetable, amaranth was selected for comparison purposes

Integrated soil fertility management and Human nutrition

Soil fertility degradation is widely acknowledged as a major factor limiting productivity of the sub-Saharan Africa smallholder farming systems. The use of inorganic fertilizers and to some extent, manures is a solution for restoring this soil fertility.. However inorganic fertilizers have been linked to numerous environmental hazards including marine eutrophication, global warming, groundwater contamination, and stratospheric ozone destruction (Crewsa and Peoples, 2004). This has meant that in many industrialized countries, research interests in low-external-input agriculture are driven largely by overproduction and concerns of the environmental effects of intensive agrochemical use. In the less industrialised countries interest in low-external-input agriculture is often a necessity, fuelled by the lack of access to high input approaches due either to local or national economics (Giller and Cadisch, 1995). These include unreliable returns limited access to capital by smallholders and unreliable markets for agricultural produce. The use of manure is limited because the quantities available on-farm are often insufficient to maintain soil fertility.

Nitrogen input, through growing of legumes is a feasible option. The legumes are important as a component of an integrated soil fertility management (ISFM) strategy, since nutrients such as phosphorus (P) has to be acquired from elsewhere (Ojiem *et al*, 2007). Eventually the growing of these vegetables shall help improve the current status of human nutrition

Materials and methods

The experimental design was a randomized block design consisting of three treatments and one replicate for each of the two vegetables selected. A plot of land measuring about 10m x 6m was subdivided into six subplots measuring 2m x 2m each. The three treatments were inorganic fertilizer application (IF), organic fertilizer application (OF) and no fertilizer application (NF). The treatment plots measured. Sowing for season one was done on the 15th of May 2012 and followed by season two following recommendations for such vegetables as made by the ministry of |Agriculture Handbook (2001) and all the subplots received water to a soil saturation point an alternate days of the week. Prior to this, three soil samples were collected from each subplot to a depth of 20 cm, mixed in a composite sample and taken for analysis to the soil testing labs of the Kenya Agricultural Research Institute, Westlands. The organic fertilizer used was a made earlier using alternate layers of cow manure and cut plant leaves, flowers and grass while the inorganic fertilizer was a commercial fertilizer (DAP). All of them were subjected to common conditions and closely monitored for any changes that could arise. Plant growth was monitored through harvesting of three plants from every treatment every fortnight and measurements made on stem length and number of nodules for the leguminous varieties. Final harvest was done 60 DAS and soil samples were again collected for soil analysis for each season.

Results

Analysis of soil and organic manure

Soil Nitrogen in experimental plot before application of treatments

Nutrient levels in the soil collected from the experiment plot showed adequate levels of macro and micro nutrients as indicated in Table. 1. below.

Table 1. Nutrient levels in a composite sample of soil from the experiment plot

Soil nutrient	Quantity in soil	Assessment	Quantity in manure
Total Nitrogen%	0.21	Adequate	1.4
Org. Carbon %	2.14	Adequate	-
Phosphorus ppm	25	Adequate	0.49
Potassium me%	1.33	Adequate	2.65
Calcium me%	7.5	Adequate	2.2
Magnesium me%	3.68	Adequate	0.42
Manganese me%	0.43	Adequate	166
Copper ppm	2.60	Adequate	370
Iron ppm	48.6	Adequate	3110
Zinc ppm	15.9	Adequate	138
Sodium me%	0.66	Adequate	-

Table 2: Total soil nitrogen in control (NF) subplots after harvest

Sub-plot crop	Total Nitrogen (%)	Assessment
Crotalaria	0.23	Adequate
Amaranthus	0.23	Adequate

Amaranthus

Number of leaves

The IF treatment recorded the highest mean leaf number in both seasons. Leaf number in OF treatment showed marked increases from week ten in both seasons while that of the control was lowest (upto 50%) in all weeks in both seasons. The differences between the treatments and the control were highly significant (P<0.001) while that between the two treatments was not significant in both seasons.

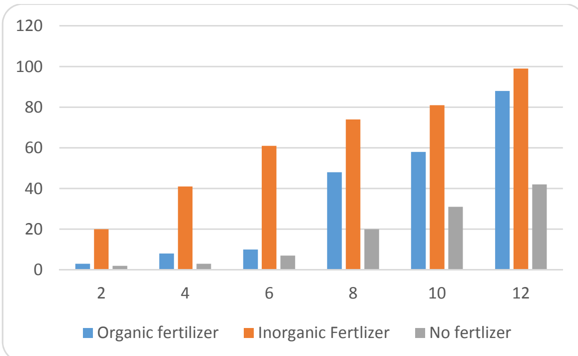

Figure 1: Mean leaf number per plant in the treatments and control over 12 weeks in season one

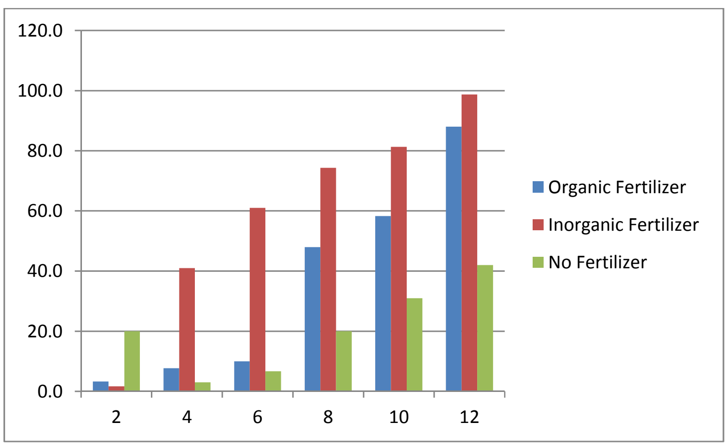

Figure 2. Mean leaf number per plant in the treatments and control over 12 weeks in season two

Table 3: Mean leaf number per plant in the treatments and control over 12 weeks Season one

Week	Organic Fertilizer	Inorganic fertilizer	No fertilizer
2	3	20	2
4	8	41	3
6	10	61	7
8	48	74	20
10	58	81	31
12	88	99	42

Table 4: Mean leaf number per plant in the treatments and control over 12 weeks Season two

Week	Organic fertilizer	Inorganic Fertilizer	No Fertilizer
2	3	23	20
4	8	41	3
6	10	61	7
8	48	74	20
10	58	81	31
12	88	99	42

Shoot length

The IF treatment recorded the highest mean shoot length in both seasons. Mean shoot length in the control was about 50% less than that in the two treatments. The difference was highly significant at $p<0.001$ in both seasons.

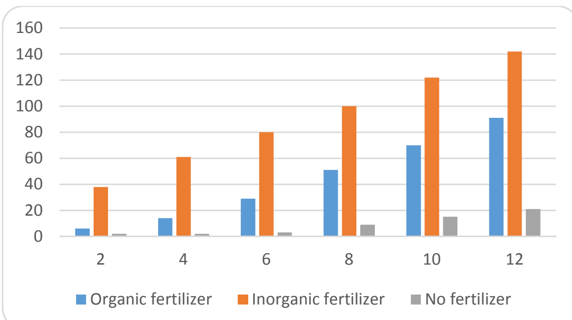

Figure 3: Mean shoot length (cm) in the treatments and control over 12 weeks in Season one

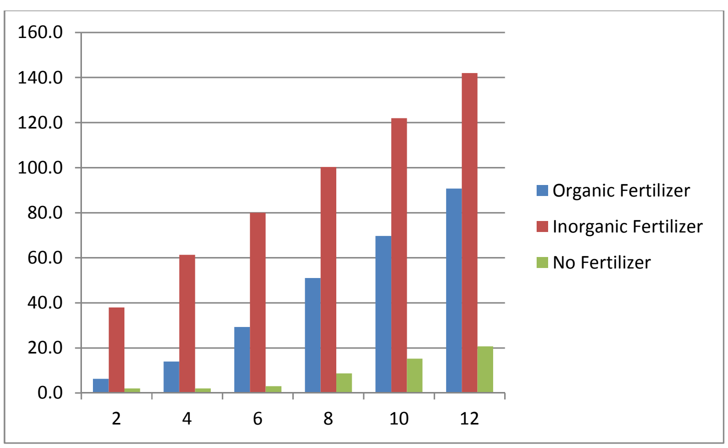

Figure 4: Mean shoot length (cm) in the treatments and control over 12 weeks in Season **two**

Table 5: Mean shoot length (cm) in the treatments and control over 12 weeks in season one

Week	Organic Fertilizer	Inorganic fertilizer	No fertilizer
2	6	37	4
4	14	59	5
6	29	78	2
8	51	102	9
10	70	126	17
12	91	139	25

Table 6 : Mean shoot length (cm) in the treatments and control over 12 weeks in season two

Week	Organic fertilizer	Inorganic fertilizer	No fertilizer
2	4	38	2
4	13	61	2
6	29	80	3
8	50	100	9
10	76	122	15
12	98	142	21

Dry weight

High dry weight values were recorded in both seasons for the IF treatmentThe NF treatment in season one had values that were almost 50% less than the other treatments. The no fertilizer treatment had a significant difference in season two with a $p<0.05$

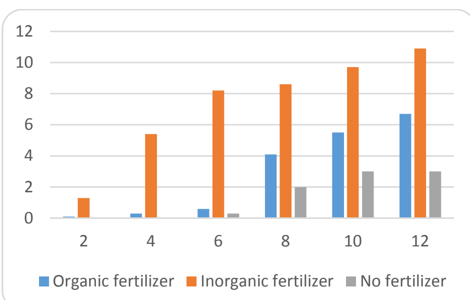

Figure 5: Mean dry weight in the treatments and control over 12 in season one

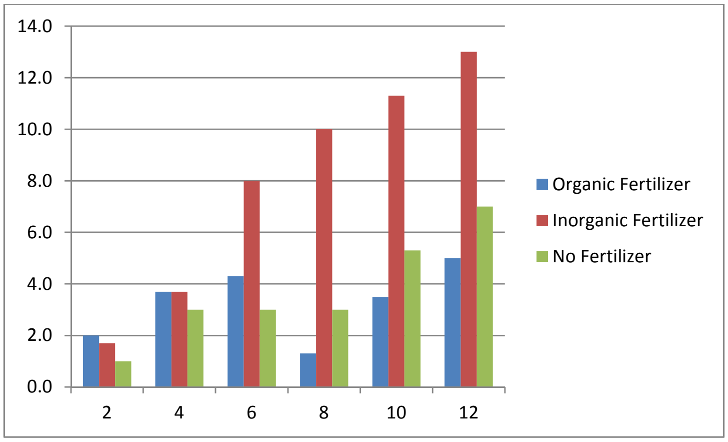

Figure 6 : Mean dry weight in the treatments and control over 12 in season two

Table 7: Mean dry weight (g) in the treatments and control over 12 weeks in season one

Week	Organic Fertilizer	Inorganic fertilizer	No fertilizer
2	0.1	1.3	0
4	0.3	5.4	0
6	0.6	8.2	0.3
8	4.1	8.6	2.0
10	5.5	9.7	3.0
12	6.7	10.9	3 .0

Table 8: Mean dry weight (g) in the treatments and control over 12 weeks in season two

Week	Organic fertilizer	Inorganic Fertilizer	No fertilizer
2	2.0	1.7	1.0
4	3.7	3.7	3.0
6	4.3	8.0	3.0
8	1.3	10.0	3.0
10	3.5	11.3	5.3
12	5.0	13.0	7.0

Crotolaria

Leaf number

There were no significant differences between the two treatments through out both seasons although the NF treatment plants had the greater leaf number towards the end of the growing season. The differences in mean leaf number between the two treatments and the control were however not significant.

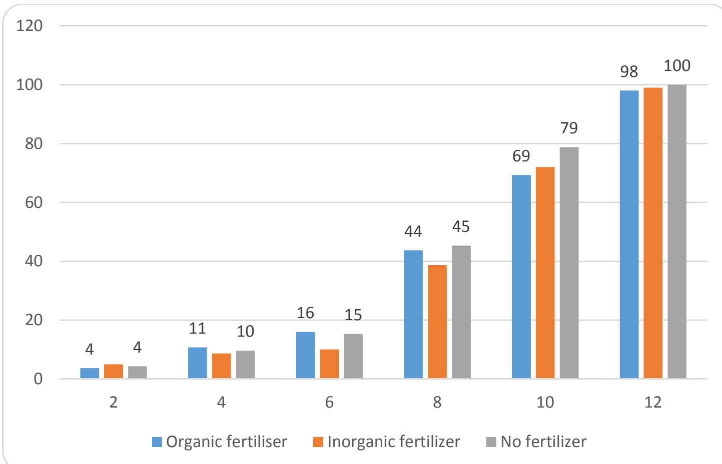

Figure 7: Mean leaf number per plant in the treatments and control over 12 weeks in Season one

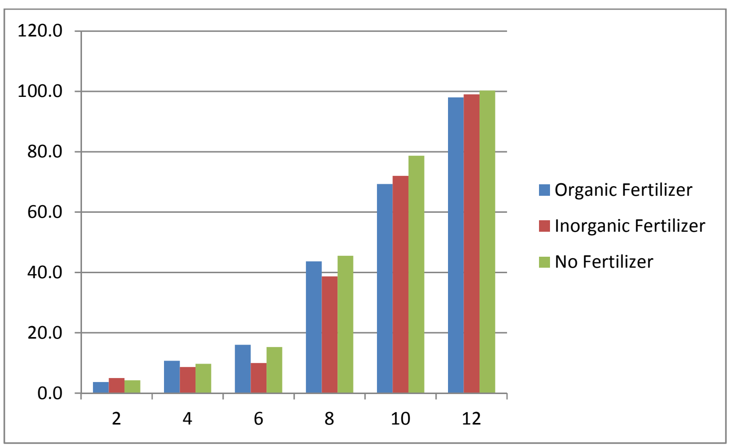

Figure 8: Mean leaf number per plant in the treatments and control over 12 weeks in Season two

Table 9: Mean leaf number per plant in the treatments and control over 12 weeks in season one

Week	Organic Fertilizer	Inorganic fertilizer	No fertilizer
2	4	5	4
4	11	9	10
6	16	10	15
8	44	39	45
10	69	72	79
12	98	99	100

Table 10: Mean leaf number per plant in the treatments and control over 12 weeks in season two

Week	Organic fertilizer	Inorganic fertilizer	No fertilizer
2	6	7	7
4	12	9	13
6	18	11	16
8	47	38	46
10	65	70	79
12	94	97	101

Shoot length

The NF treatment was highest almost throughout the treatment for the two seasons. There was no significant different between the treatments and control in both seasons. However, it was noted that OF treatment in both seasons recorded highest values between week four to week ten.

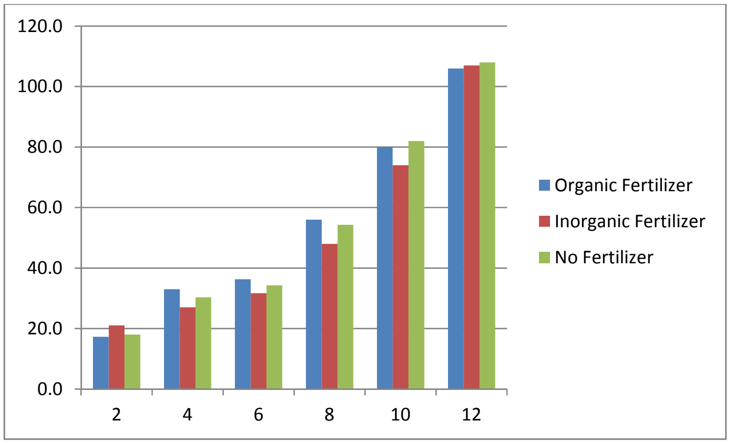

Figure 9: Mean shoot length (cm) in the treatments and control over 12 weeks in season one

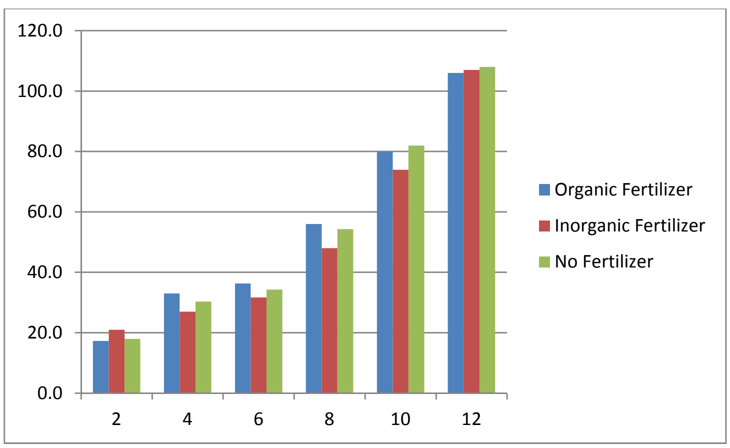

Figure 10: Mean shoot length (cm) in the treatments and control over 12 weeks in season two

Table 11: Mean shoot length (cm) in the treatments and control over 12 weeks in season one

Week	Organic Fertilizer	Inorganic fertilizer	No fertilizer
2	17	21	18
4	33	27	30
6	36	32	34
8	56	48	54
10	80	74	82
12	106	107	108

Table 12: Mean shoot length (cm) in the treatments and control over 12 weeks in season two

Week	Organic Fertilizer	Inorganic Fertilizer	No Fertilizer
2	19	19	14
4	30	27	28
6	38	30	36
8	53	49	52
10	79	71	79
12	104	109	110

Dry weight

The NF treatment was highest in both seasons even though the values obtained in season two were almost the same for all the treatments. There was no significant difference between the control and the other two treatments in both seasons.

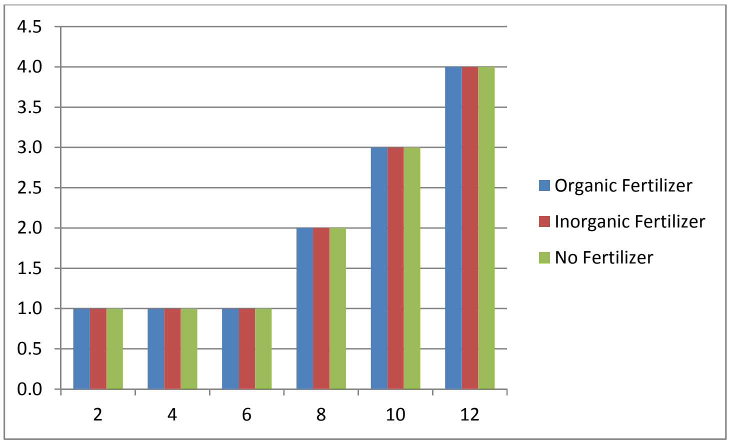

Figure 11: Mean dry weight in the treatments and control over 12 weeks in season one

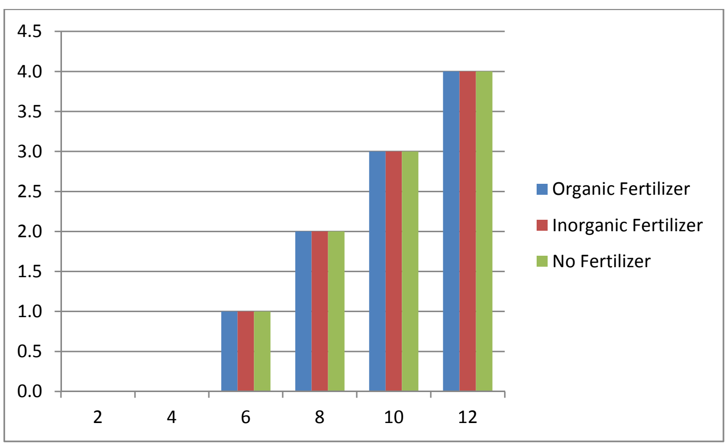

Figure 12: Mean dry weight in the treatments and control over 12 weeks in season two

Table 13: Mean dry weight (g) in the treatments and control over 12 weeks in season one

Week	Organic Fertilizer	Inorganic fertilizer	No fertilizer
2	1	3	5
4	1	1	2
6	3	3	4
8	3	3	5
10	4	4	5
12	4	4	5

Table 14: Mean dry weight (g) in the treatments and control over 12 weeks in season two

Week	Organic Fertilizer	Inorganic Fertilizer	No fertilizer
2			
4			
6	1	1	1
8	2	2	2
10	3	3	3
12	4	4	4

Nodule number

The NF treatment recorded the highest number of nodules in both seasons. The OF and IF treatments had almost the same number of nodules in both seasons. The mean number of nodules per plant increased as the plants grew.The values for the two treatments were almost the same for in both seasons but any differences between their value and that of the control were not significant.

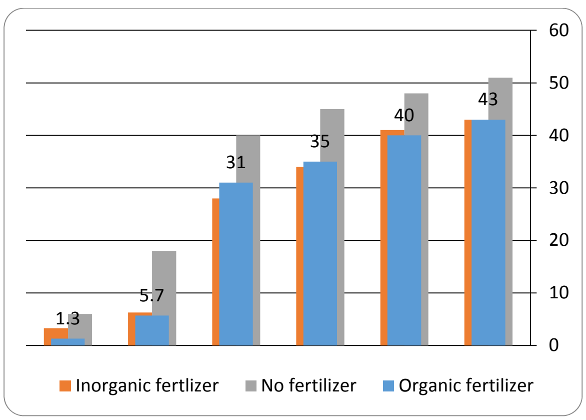

Figure13 : Mean nodule numbers per plant in the treatments and control over 12 weeks in season one

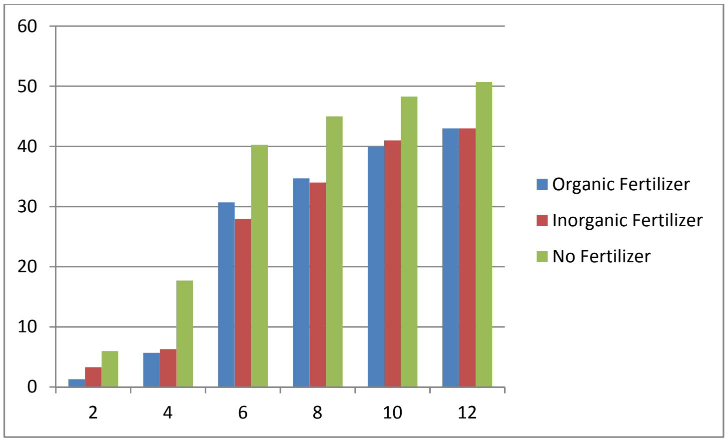

Figure14 : Mean nodule numbers per plant in the treatments and control over 12 weeks in season two

Table 15: Mean nodule number in the treatments and control over 12 weeks in season one

Week	Organic Fertilizer	Inorganic fertilizer	No fertilizer
2	1	3	6
4	5	6	18
6	31	28	40
8	35	34	45
10	40	41	48
12	43	43	51

Table 16: Mean nodule number in the treatments and control over 12 weeks in season two

Week	Organic Fertilizer	Inorganic Fertilizer	No Fertilizer
2	1	3	6
4	6	6	18
6	31	28	40
8	35	34	45
10	40	41	48
12	43	43	51

Discussion

From the measurements of shoot length, leaf number, dry weight and nodule number, it was observed that Crotolaria responded well in the NF treatments in the two seasons. This was due to the fact that it fixes

nitrogen through the nodules. It has been shown that when mineral N is depleted in the root zone of the legume, nitrogen fixation of legumes may be promoted.

Amba and Agbo, (2011) found that the presence of adequate quantities of phosphorous element in the soil was key to nitrogen fixation and as its value in Table 1 (pre-planting soil tests) indicate the soils at the experiment sitehad adequate amounts of phosphorous. This meant that plants in the NF treatment were able to carry out nitrogen fixiation well and thus the high values in the measured plant parameters. There was no significant boost of total soil nitrogen levels in the NF subplot for the legume Crotalaria but this may become more evident with the trial over a longer term.

Amaranthus showed highly significant responses with additions of inorganic fertilizer as shown in its high values of leaf number, shoot length and dry matter accumulations. A notable observation with organic fertilizer treatments in this crop was the surge in the measured parameters from around week ten. This could be a synchrony factor where nutrient release was at its optimum making a case for perhaps an earlier application before sowing (Kuepper, 2003). This aspect certainly merits further investigation.

Another factor to observe is that Crotalaria plants in the control plots (NF) did well throughout the two seasons surpassing the plants in the IF and OF treatments. This can probably be explained by the fact that Crotalaria species do reduce plant-parasitic nematode populations which tend to limit the intake of soil nitrates. More often than not, crop species such as Crotolaria are non-host or poor host to several plant-parasitic nematodes. They also produce allelochemicals that are toxic, inhibitory or sticky to nematodes. Such compounds include pyrrolizidine, alkaloids and monocrotaline (Wang *et al.,* 2002). This explains why crotalaria should be embraced by farmers in sustainable management of plant-parasitic nematodes (Omami, 2012).

Given the economic challenges to smallholder farmers in Kenya (and Africa in general) in applying sufficient inorganic fertilizers, it would be recommended that the vegetable trial extend to an intercrop between leguminous and non-leguminous types and between cereals and leguminous vegetables in the small holder farms. Chandel *et al*, 1989, found that cereal legume intercrops increased competition for soil Nitrogen hence resulting in the stimulation of nitrogen fixation. An alternative would be to grow the vegeTable legumes immediately after the harvest of a cereal crop (when levels of soil nitrogen are low) rather than after a fallow period as this would stimulate the legumes to fix greater amounts of nitrogen (Peoples *et al.,* 1995). Overall, the results obtained are indicative of the potential of leguminous vegeTables being an important source of soil nitrogen in addition to their nutritive value.

Conclusions

At community and household level, knowledge associated with these vegetables is essentially passed on from one generation to the next and in certain parts there is the risk that this knowledge can be lost. Considering their potential nutritional value, indigenous and indigenized leafy vegeTables could contribute in a major way to the food security and balanced diets of rural households. The African traditional vegeTables have played and continue to play in the food systems of African people. (Sonja *et al*.,. 2007).

Additional nitrogen applications had no significant effect on growth, leaf and seed yield of crotalaria vegeTable plant nitrogen rates had no significant effect on germination percentage of stored crotalaria seeds. Crotalaria seeds can be stored for a period of two years without significantly affecting its germination percentage. (Abukutsa-Onyango, 2007).

In as much as use of organic manure is highly recommended, proper proportions should be applied as under application or over application of it can result in their building to detri-mental levels which puts excessive phosphate in the soil and polluted surface waters. Nutrient excesses also "tie up" other minerals. Excessive phosphate interferes with plant uptake of both copper and zinc; excessive potash can restrict boron, manganese, and even magnesium. (Kuepper 2003).

Recommendations

Integrated soil fertility management has become a tool for improving crop production in modern day agriculture. Therefore, traditional vegetables having the capability of adding nutrients and also regulating the soils conditions for suitable growing should be embraced by smallholder farmers as a tool of integrated soil fertility management. Pre-season or intercropping these vegetables with other crops that are not leguminous should be taken up by most of the smallholder farmers.

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