Sustainable Intensification of Livestock Systems Using Forage Legumes

Dubeux, J.C.B., Jr.[1]; Sollenberger, L.E.[2]

[1]Associate Professor, University of Florida – North Florida Research and education Center, 3925 Highway 71, Marianna, FL, 32446.

[2]Distinguished Professor, University of Florida, Agronomy Department, Gainesville, FL, USA, 32611.

Key words: biological N_2 fixation; ecosystem services; sustainability

Abstract

Global human population is increasing and expected to reach 9.7 billion people by 2050. Sustainable intensification (SI) of agricultural systems is key to increase food production while minimizing impact on global natural resources. Forage legumes provide a myriad of ecosystem services (ES) and represent an important tool for promoting SI in livestock systems. Forage legumes associate with soil microorganisms to reduce atmospheric N_2. This N input represents a valuable contribution to increase net primary productivity with reduced C footprint. In addition, forage nutritive value generally increases, resulting in greater animal performance. When forage legumes are integrated into livestock systems, they complement the essential role of grasses by adding N to the system, improving forage quality, sharing resources with the companion grass, and enhancing soil organic matter. Soil C:N ratio is typically in a narrow range; therefore, input of N is essential to increase C sequestration and maintain the soil C:N ratio. Additional ES provided by forage legumes include enhanced efficiency of nutrient cycling, improved pollinator habitat, medicine/food for humans, timber, wildlife habitat, and shade for livestock (tree legumes). There are options of herbaceous and arboreal legumes, as well as annuals and perennials. In temperate regions, herbaceous legumes are used widely (e.g., *Medicago* sp, *Trifolium* sp.) while arboreal legumes are often found in tropical regions. There are a few options of herbaceous perennial warm-climate legumes, and some of them are still underexploited (e.g. *Arachis pintoi*, *Arachis glabrata*). Documented examples of forage legumes increasing livestock productivity are available in different regions of the world, and recent progress has been made in developing and managing forage legume germplasm adapted to biotic and abiotic stresses in tropical America, Africa, Southeast Asia, and Australia. Learning past lessons and applying the knowledge to shape the future is essential to achieve SI of livestock systems.

Introduction

Global human population is rapidly increasing, and the projection is to reach 9.5 billion people by 2050 (United Nations 2013). Therefore, it is essential to increase food production to supply the increasing food demand. In addition to the challenge to increase food production, there is evidence that recent economic advances have been made at the cost of global natural resources, with increasing threat to biodiversity and quality of life (Whitmee *et al.,* 2015). Agricultural land is a limited resource, and the challenge is to produce more food per unit of land and resource input, while diminishing the threat for global natural ecosystems. Animal-food sources play a key role in the nutrition of future generations. Meat and milk from livestock are important food sources during early-stage development of humans, having a crucial role in the cognitive skills of children (Hulett *et al.,* 2014). Developing sustainable livestock systems to supply nutrient-dense foods to sustain human development over the next decades is a critical step.

Sustainable intensification (SI) of livestock systems requires greater output of animal products per unit of resource input while reducing negative environmental impacts (Tedeschi *et al.,* 2015; Dubeux *et al.,* 2017a). Forage legumes are key to achieve SI in livestock systems because they can reduce N inputs from industrial fertilizer, increase animal performance, and enhance delivery of other ecosystem services (Sollenberger *et al.,* 2019). There are numerous ways to integrate forage legumes into livestock systems in both space and time. Forage legume options include annual or perennial, herbaceous or arboreal, and adaptation to either cool or warm seasons. Climate and soil attributes at a regional scale and at the planting site will dictate the optimal choices. Other factors affecting choice of forage legume include seed availability, management expertise, and socioeconomic aspects of local production systems.

In subtropical areas with defined warm and cool seasons, it is possible to overseed perennial warm-season pastures with cool-season forages, including forage legumes (e.g., *Trifolium* sp.). If a perennial warm-season legume is present (e.g., *Arachis glabrata* Benth.), the system would have N inputs both in the warm and cool seasons (Garcia-Jimenez 2019). In many tropical regions, there is one defined forage growing season and the major limitation in the reminder of the year is reduced rainfall. In this case, herbaceous annual legumes would contribute mostly during the rainfall season, although some potential benefits might carry over to the dry season (Boddey *et al.,* 2020). In the tropics, there are multiple options of arboreal legumes with potential for use in silvopasture systems (Apolinário *et al.,* 2016; Costa *et al.,* 2016; Santos *et al.,* 2020). Because of the perennial nature of these arboreal legumes, they might contribute both in the rainy and dry seasons.

This review paper will address how forage legumes are key components for SI of livestock systems. We will explore how forage legumes can assist by producing more output per unit of resource input (provisional ecosystem services) while maintaining the delivery of other ecosystem services (ES) that are beneficial to the environment.

Provisional ecosystem services

Livestock performance is one of the major reasons producers around the world integrate forage legumes into grazing systems. There are numerous reports indicating greater livestock performance when forage legumes are present in the cattle diet, especially during the warm season in tropical regions (Garay *et al.,* 2004; Gomes da Silva *et al.,* 2020 *in press*). Greater livestock performance occurs because often forage legumes have greater digestibility and crude protein concentration than C_4 grasses (Garcia-Jimenez, 2019), resulting in greater intake of digestible organic matter. Besides livestock performance, forage legumes might provide other marketable products, such as firewood, timber, fruits, and pods (Apolinário *et al.,* 2016; Dubeux *et al.,* 2017b). These products are obtained with lesser off-farm inputs and, in most of the cases, are economically viable, which are two important premises of SI.

Supporting ecosystem services

Forage legumes are also intertwined in multiple aspects of supporting ES. Nutrient cycling and biological N_2 fixation (BNF) are perhaps two of the most important supporting ES delivered by forage legumes. Grassland systems are typically N-depleted environments, and this depletion tends to increase with grazing livestock. Piñeiro *et al.,* (2010) observed greater soil organic matter C:N ratio at grazed sites compared with ungrazed sites for 67 paired comparisons. They concluded that C sequestration and grassland productivity can be simultaneously increased by increasing N retention at the landscape level. This highlights the fact that integrating forage legumes might enhance soil organic matter (SOM) formation and C sequestration. In fact, there are numerous examples of enhanced soil C sequestration and SOM formation when integrating forage legumes (Fisher *et al.,* 1994; Tarré *et al.,* 2001; Liu *et al.,* 2017). Another aspect that might contribute to greater SOM formation when integrating forage legumes is the increase in net primary productivity. Greater plant species richness often is linked to greater primary productivity, especially when it comes along with diversification of functional groups (Tilman *et al.,* 2006). This is precisely the case when integrating legumes into grass monocultures. Enhancing SOM formation and C sequestration, BNF, and net primary productivity are key ingredients for the SI of livestock systems and forage legumes are an important component of these processes.

Regulating ecosystem services

Regulating ES include climate and water regulation, soil erosion regulation, water purification, pollination, and regulation of pests and diseases (Millenium Ecosystem Assessment, 2005). Forage legumes can directly or indirectly affect these ES. For example, legume-soil microorganism nexus might reduce atmospheric N_2 and minimize the need for N fertilizer application. This is important not only to reduce C emissions from the fertilizer industry and transportation sectors, but also to minimize nitrate leaching to the environment (Sollenberger *et al.,* 2019). There are different ways legumes can reduce nitrate leaching. The first mechanism might be simply by helping to reduce application of readily available soluble N via fertilizer that might leach beyond the root zone and reach the groundwater. Although forage legumes reduce atmospheric N_2 and add N to the system, the N is recycled in slow-release forms such as litter deposition or root/nodules turnover (Dubeux *et al.,* 2007). Nitrogen from livestock excreta often is lost via ammonia volatilization and denitrification, reducing the N pool that goes to the root zone. Another mechanism might occur with arboreal legumes, where a deeper root system might recycle back to the soil surface nitrate that has passed beyond the surface horizon (0-20 cm) where most of the grass roots are (Chintu *et al.,* 2004). Forage legumes might also enhance pollinator habitat (Garcia *et al.,* 2019; Sollenberger *et al.,* 2019) by providing more floral resources both in space and time. Forage legumes could also reduce soil erosion when used as cover crops or even used as windbreaks to reduce wind erosion, in the case of arboreal legumes (Garcia-Estringana *et al.,* 2013; Wood *et al.,* 2013). These examples of how legumes can provide essential regulating ES while intensifying livestock production illustrate well the key role of forage legumes in the SI of livestock systems.

Adoption of forage legumes

All these benefits highlighted for forage legumes will have a significant positive impact only if there is a greater adoption of these forages in livestock systems. Temperate legumes have been widely used in livestock systems, with *Trifolium* and *Medicago* sp. being perhaps the most adopted genera. In tropical and subtropical regions, however, adoption still needs to increase. Successful examples of adoption have occurred in different parts of the world, with greater adoption in Southeast Asia, Africa, and Australia (Shelton *et al.,* 2005), with emerging options in Latin America (Boddey *et al.,* 2020). Reasons for adoption include availability of seed supply at an affordable price, pioneer farmers, and most importantly, understanding from land managers about the advantages associated with adopting forage legumes.

Concluding remarks

Global population is rapidly increasing, and food supply must increase to follow demand. Animal food sources are key to ensure quality early-childhood development and sustain human progress. Intensive use of agricultural inputs and economic growth have been threatening global natural resources and ecosystems. In this scenario, forage legumes are key to develop sustainable livestock systems, increasing livestock production with reduced use of resources. Besides increasing livestock production with limited off-farm inputs, forage legumes deliver other ecosystem services that are beneficial for the entire society. These include enhanced pollinator habitat, biological N2 fixation and nutrient cycling, soil organic matter formation, and increase in net primary productivity. The future of forage legumes in the process of sustainable intensification depends on larger adoption worldwide. Demonstrated on-farm success and supportive governmental policies must be put in place to increase the adoption of forage legumes in livestock systems.

References

Apolinário, V.X.O., Dubeux, J.C.B., Jr., Lira, M.A., Ferreira, R.L.C., Mello, A.C.L., Santos, M.V.F., Sampaio, E.V.S.B., and Muir, J.P. 2016. Tree legumes provide marketable wood and add nitrogen in warm-climate silvopasture systems. *Agronomy Journal*, 107:1915-1921.

Boddey, R.M., Casagrande, D.R., Homem, B.G.C., Alves, B.J.R.. 2020. Forage legumes in grass pastures in tropical Brazil and likely impacts on greenhouse gas emissions: A review. *Grass and Forage Science*, 00:1-15.

Chintu, R., Mafongoya, P.L., Chirwa, T.S., Mwale, M., and Matibini, J. 2004. Subsoil nitrogen dynamics as affected by planted coppicing tree legume fallows in Eastern Zambia. *Expl. Agric.*, 40:327-340.

Costa, S.B.M., Mello, A.C.L., Dubeux, J.C.B., Jr., Santos, M.V.F., Lira, M.A., Oliveira, J.T.C., and Apolinário, V.X.O. 2016. Livestock performance in warm-climate silvopastures using tree legumes. *Agronomy Journal*, 108: 2026-2035.

Dubeux, J.C.B., Jr., Sollenberger, L.E., Mathews, B.W., Scholberg, J.M., and Santos, H.Q. 2007. Nutrient cycling in warm-climate grasslands. *Crop Sci.*, 47: 915–928. doi:10.2135/cropsci2006.09.0581

Dubeux, J.C.B., Jr., Sollenberger, L.E., Muir, J.P., Tedeschi, L.O., Santos, M.V.F., Cunha, M.V., Mello, A.C.L., and DiLorenzo, N. 2017a. Sustainable intensification of livestock production on pastures. *Archivos Latinoamericanos de Producción Animal*, 24(3-4): 2017.

Dubeux, J.C.B., Jr., Muir, J.P., Apolinário, V.X.O., Nair, P.K.R., Lira, M.A., and Sollenberger, L.E. 2017b. Tree legumes: an underexploited resource in warm-climate silvopastures. *R. Bras. Zootec*., 46(8):689-703.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.

Fisher, M.J., Rao, I.M., Ayarza, M.A., Lascano, C.E., Sanz, J.I., Thomas, R.J., and Vera, R.R. 1994. Carbon storage by introduced deep-rooted grasses in South American savannas. *Nature*, 371: 236–238. doi:10.1038/371236a0

Garay, A.H., Sollenberger, L.E., Staples, C.R., and Pedreira, C.G.S. 2004. 'Florigraze' and 'Arbrook' rhizoma peanut as pasture for growing Holstein heifers. *Crop Sci.,* 44:1355-1360.

Garcia-Estringana, P., Alonso-Blázquez, N., Marques, M.J., Bienes, R., González-Andrés, F., and Alegre, J. 2013. Use of Mediterranean legume shrubs to control soil erosion and runoff in Central Spain. A large-plot assessment under natural rainfall conducted during the stages of shrub establishment and subsequent colonization. *Catena*, 102: 3-12.

Garcia-Jimenez, L.M. 2019. *Ecosystem services provided by contrasting grazing systems in North Florida*. PhD Dissertation (Agronomy, University of Florida), Gainesville, FL, 2019. 206 p. Full text available online at https://ufdc.ufl.edu/UFE0055613/00001

Gomes da Silva, I.A., Dubeux, J.C.B., Jr., Mello, A.C.L., Cunha, M.V., Santos, M.V.F., Apolinário, V.X.O., Freitas, E.V. 2020. Tree legume enhance livestock performance in silvopasture system. *Agronomy Journal* (*in press*) https://doi.org/10.1002/agj2.20491

Hulett, J.L., Weiss, R.E., Bwibo, N.O., Galal, O.M., Drorbaugh, N, and Neumann, C.G. 2014. Animal source foods have a positive impact on the primary school test scores of Kenyan schoolchildren in a cluster-randomised, controlled feeding intervention trial. *British J. of Nutrition.,* 111: 875-886.

Liu, Y., Tian, F.P., Jia, P.Y., Zhang, J.G., Hou, F.J., and Wu., G.L. 2017. Leguminous species sequester more carbon than gramineous species in cultivated grasslands of a semi-arid area. *Solid Earth*, 8:83–91. doi:10.5194/se-8-83-2017.

Piñeiro, G., Paruelo, J.M., Oesterheld, M., and Jobbágy, E.G. 2010. Pathways of grazing effects on soil organic carbon and nitrogen. *Rangeland Ecology and Management*, 63:109-119.

Santos, A.M.G. dos, Dubeux, J.C.B., Jr., Santos, M.V.F., Lira, M.A., Apolinário, V.X.O, Costa, S.B.M., Coêlho, D.L., Peixôto, T.V.F.R., Santos, E.R.S. 2020. Animal performance in grass monoculture or silvopastures using tree legumes. *Agroforestry Systems*, 94:615-626.

Shelton, H. M.; Franzel, S. and Peters, M. 2005. Adoption of tropical legume technology around the world: analysis of success. *Tropical Grasslands,* 39:198-209.

Sollenberger, L.E., Kohmann, M.M., Dubeux, J.C.B., Jr., Silveira, M.L. 2019. Grassland management affects delivery of regulating and supporting ecosystem services. *Crop Sci.,* 59: 441-459.

Tarré, R., Macedo, R., Cantarutti, R.B., de Rezende, P.C., Pereira, J.M., Ferreira, E., Alves, B.J.R., Urquiaga, S., and Boddey, R.M. 2001. The effect of the presence of a forage legume on nitrogen and carbon levels in soils under *Brachiaria* pastures in the Atlantic forest region of the South of Bahia, Brazil. *Plant Soil,* 234:15–26. doi:10.1023/A:1010533721740

Tedeschi, L.O., Muir, J.P., Riley, D.G., and Fox, D.G. 2015. The role of ruminant animals in sustainable livestock intensification programs. Intern. J. Sustainable Dev. *World Ecol.,* 22:452-465.

Tilman, D., Hill, J., and Lehman, C. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science,* 314: 1598–1600. doi:10.1126/science.1133306

United Nations, Department of Economic and Social Affairs, Population Division. 2013. *World population prospects; the 2012 revision* [Internet]. New York (NY): United Nations; [cited 2015 Feb 1]. Available from: http://esa.un.org/unpd/wpp/index.htm

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A.G., Dias, B.F.S., Ezeh, A., Frumkin, H., Gong, P., Head, P., Horton, R., Mace, G.M., Marten, R., Myers, S.S., Nishtar, S., Osofsky, S.A., Pattanayak, S.K., Pongsiri, M.J., Romanelli, C., Soucat, A., Vega, J., Yach, D.. 2015. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. *The Lancet*, 386(10007):1973-2028. https://doi.org/10.1016/S0140-6736(15)60901-1

Wood, T.J., Smith, B.M., Hughes, B., Gill, J.A., and Holland, J.M. 2013. Do legume-rich habitats provide improved farmland biodiversity resources and services in arable farmland? *Aspects Appl. Biol.,* 118:239-246.