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PERSPECTIVE

Tropical grasslands: A pivotal place for a more multi-functional agriculture

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Abstract Tropical grasslands represent a pivotal arena for the sustainable intensification of agriculture in the coming decades. The abundant ecosystem services provided by the grasslands, coupled with the aversion to further forest destruction, makes sustainable intensification of tropical grasslands a high policy priority. In this article, we provide an inventory of agricultural initiatives that would contribute to the sustainable intensification of the tropical grassland agro-ecosystem, and we recommend a shift in the scientific priorities of animal scientists that would contribute to realization of a more agro-ecological and multi-functional agriculture in the world's tropical grasslands.

Keywords Agro-ecology · Ecological intensification · Ecosystem services · Grassland · Multi-functional · Tropics

INTRODUCTION: THE FOOD SECURITY–BIODIVERSITY–GLOBAL CHANGE CRISIS

During the past 15 years, observers of global changes have outlined the emergence of a trilemma in sustainable development efforts. Concerns with food security emerged when agricultural commodity prices rose sharply after 2005 at the same time as projections about the effects of climate change grew more alarming and biodiversity losses mounted from increased human exploitation of tropical biomes. Increasingly, policy makers faced unappealing trade-offs. They could, for example, promote increases in food production by deforesting additional lands in the humid tropics but this course of action would accelerate the greenhouse gas emissions that drive climate change and continue the surge in species extinctions that occur with deforestation (Gibbs et al. 2010).

These circumstances invite analysts to prioritize some sustainable development efforts and sites over others. To this end, scientists and foundation officers have articulated a vision of sustainable agricultural intensification (Tilman et al. 2011). By more precise manipulations of inputs like water and fertilizers, farmers engaged in sustainable intensification would increase the production of agricultural commodities without increasing the extent of croplands and triggering further declines in ecosystem services. Of course, a very large number of farmers already practice precision agriculture. The conclusions espoused by scholars (Tilman et al. 2011) pertain in particular to places where yield gaps are large, where actual yields are considerably lower than potential yields for crops. Places with large yield gaps are primarily found in the countries of the Global South, and these places would become the focus for most sustainable intensification efforts.

Environmental constraints narrow the set of potential sites still further. The ongoing climate and biodiversity crises eliminate the forested zones in the tropics as sites for sustainable intensification efforts. The accelerated greenhouse gas emissions and biodiversity losses from deforestation in these zones make them undesirable sites for sustainable intensification efforts.[1] Agriculturally degraded fallow lands, croplands and grasslands would become, by default, the primary sites for sustainable intensification

[1] Hertel et al. (2014) point out how agricultural productivity increases have quite different effects on the extent of cultivated land depending on their proximity to the site of the yield increases. Sites close to the sites of a yield increase would experience increased pressures to deforest because the yield increase would make agriculture more attractive. Farmers far from the sites of the yield increase might be inclined to abandon agriculture because of the increased competition from the farmers in the site of the yield increase.

efforts. This paper outlines what sustainable intensification might look like in one primary site for these efforts, the world's tropical grasslands. The paper begins by describing the tropical grasslands, their inhabitants and the crucial ecosystem services that the grasslands provide for humans, as outlined in global assessments (MEA 2005; FAO 2010; Herrero and Thornton 2013). We then describe recent research on innovations in grassland use and management as reported in reviews, experiments carried out in tropical environments and a meta-analysis of the literature on mixed grazing (Boval and Dixon 2012; Agastin et al. 2013, 2014; d'Alexis et al. 2013, 2014; Boval et al. 2015) that, if adopted widely, would enable the grasslands to perform the multiple functions necessary to counter the food security—biodiversity loss—global change crisis.

LIVESTOCK PRODUCTION, HUMAN SUSTENANCE AND ECOSYSTEM SERVICES IN TROPICAL GRASSLANDS: A BRIEF DESCRIPTION

Naturally occurring tropical grasslands cover an extensive area of the earth's surface. Large blocks of these grasslands can be found in the Llanos of Colombia, in the Cerrado of Brazil, in the Sahel of sub-Saharan Africa, and beneath the extensive, open Miombo woodlands of Zambia, Zimbabwe and adjacent countries. Their human populations, particularly in Africa, are among the world's poorest peoples. The grasslands support a wide range of agro-ecosystems. Extensive pastoral systems occupy regions where agricultural production is generally marginal, but some grassland regions contain integrated crop-livestock systems and high human population densities (Herrero et al. 2009; Tarawali et al. 2011). All of these systems utilize grazing areas to raise cattle, sheep and goats, or horses, grazed alone or in combination (Dennis et al. 2012; d'Alexis et al. 2013), with variations in stocking rates, indoor–outdoor rotations and other grazing routines.

The livestock–grassland agro-ecosystem supports people, hosts biodiverse communities of organisms and sequesters appreciable amounts of carbon. Tropical grasslands contribute directly to the livelihoods of over 800 million people via livestock production (Herrero and Thornton 2013), providing income and meeting the socio-cultural needs of many smallholders. Indices of agricultural production for these regions often underestimate the contribution of livestock to regional or national economic development, since they often disregard many non-food livestock outputs (McDermott et al. 2010). The latter are quite often more important and varied in developing economies than in developed ones and constitute an important component of the agricultural economy (Herrero et al. 2013). Livestock reared on grasslands also contribute to the well-being of the breeder and play a crucial role in social protection for the poor by constituting a 'bank' in which the poor can store wealth for use in coping with uncertainties and constraints, such as crop failures and other disasters (FAO 2014). Livestock also are used for ploughing and for transport. In addition, they provide a local supply of manure and are of cultural importance for many communities, where cattle are the foundation of many religious rituals (e.g. Godfray et al. 2010; Pretty et al. 2010). The variable uses of leather underscores the locally contingent cultural contributions of grassland agro-economies. In temperate regions, animal skins are mainly used for making coats, jackets or various other leather products. In the tropics, in the Caribbean for example, goat skins are primarily used in the manufacture of drums which play a prominent role in the musical culture of the region (Alexandre et al. 2014). These links between the grassland agro-ecosystem and local culture underscore the importance of assessing the contributions of grasslands and livestock in local contexts.

Naturally occurring grasslands are also important havens of biodiversity, especially in tropical regions. This biodiversity is seriously threatened by anthropogenic factors including land clearance, exotic species introductions or invasions, soil cultivation, fertilizer applications and altered fire management (Prober and Smith 2009). For this reason, tropical grasslands have frequently been designated as biodiversity 'hotspots', with large numbers of endangered species (Bond and Parr 2010). As the largest user of grasslands, livestock increase pressure on this ecosystem at the same time that they maintain biodiversity in open landscapes (Derner et al. 2008), contribute to aesthetic value and leisure amenity and encourage rapid structural regeneration of land (Metera et al. 2010; Maczkowiack et al. 2012). Therefore, to balance the positive and negative impacts of livestock, management tools that operate on an appropriate scale are required (Boval and Dixon 2012), as well as comprehensive research to support the development of agro-environmental schemes to protect grassland biocenoses.

Grassland ecosystems play a key role in the dynamics of interactions between the atmosphere, hydrosphere and lands that drive global change and environmental risks (Lemaire et al. 2011). Grasslands provide consequently various services, namely the protection of soil quality and its conservation, the quality of the ground water and surface water and also the regulation of climate, mainly through carbon sequestration in the soil. According to Follett and Reed (2010), grazing land accounts for about one-fourth of potential carbon sequestration in the world's soils and removes the equivalent of 20% of the carbon dioxide released annually into the earth's atmosphere from global deforestation and land-use changes. According to Soussana et al. (2010), tropical grasslands represent a storage pool of carbon, almost twice that of temperate grasslands, mostly sequestered in the soil, constituting a more stable form of storage than the aerial components of forests which can be damaged by fire. The services provided by grasslands are related to various processes (i.e. photosynthesis, respiration and decomposition of soil organic matter), which are all parts of the global cycles of C and N (Soussana and Lemaire 2014). While photosynthesis and rhizosphere activity at the vegetation level contribute to strong C–N coupling, the grazing animals uncouple N from C (Soussana and Lemaire 2014). While these coupling–decoupling processes are in equilibrium in extensive rangelands, they become gradually decoupled when the animal stocking rate exceeds a certain threshold. Beyond these threshold stocking rates, tropical grasslands lose their carbon sequestering capacity. In addition to the stocking rate, other management tools like the nitrogen added for fertilization and manure management affect the volume of carbon storage in grassland soils (Batlle-Bayer et al. 2010; West et al. 2010; McSherry and Ritchie 2013) and must be considered in intensifying grasslands for animal production. The management of the grassland and of the number of animals per ha should aim to increase the capacity of grasslands to couple the C and N cycles and minimize their decoupling with animals (Soussana and Lemaire 2014), especially because beyond a certain threshold, increasing the stocking rate, is no longer produces increments in profits per ha (Burns and Sollenberger 2002; Boval et al. 2015).

Tropical grasslands host multiple processes whose management can prevent grassland degradation in ways that enhance food security, stem biodiversity losses and retard climatic change (Parr et al. 2014). More generally, agriculture should prioritize a multi-functional form, i.e. (1) produce food and other commodities for the larger economy; (2) support and renew the communities of people who live from agriculture (Perraud 2003; Caron et al. 2008); and (3) provide ecosystem services for the environment (Costanza et al. 1997). Efforts at sustainable intensification would presumably have to bolster all three of these processes if they were to contribute to a multi-functional agriculture that addresses the intertwined issues of food security, biodiversity losses and global changes.

MULTI-FUNCTIONALITY THROUGH SUSTAINABLE INTENSIFICATION: A CONCEPTUAL TOOLKIT

Multi-functional agriculture (MFA) and ecosystem services are two important concepts for sustainable agricultural research and policy-making that emerged from initial efforts by international actors to craft strategies for sustainability (Huang et al. 2015). The concept of multi-functional agriculture, in which agriculture's contributions go beyond food and fibre production, gained in importance after being discussed in the Agenda 21 documents of the Rio Earth Summit (UNCED 1992). Negotiators for the European Union identified multi-functional agriculture as an important reason for agricultural supports in the rules of the World Trade Organization (WTO). Researchers for the Organization for Economic Cooperation and Development (OECD) developed an analytical framework for assessing the multi-functionality of agriculture (OECD 2001). This vision of MFA, combined with political demands for scientific output, has stimulated many research programs (Laurent et al. 2003).

The concept of ecosystem services was introduced in 1981 (Ehrlich and Ehrlich 1981), as a joint initiative of economists and ecologists. They emphasized that valuing nature's services in decision systems would correct misperceptions regarding the relationship between humans and nature. Costanza's later work (1997) and the United Nation's Millennium Ecosystem Assessment (MEA) program (MEA 2005) has stimulated research focused on ecosystem services. The MEA placed this concept on the policy agenda (Gomez-Baggethun et al. 2010).

Effective programs of sustainable intensification strengthen the multi-functionality of agriculture. Sustainable intensification in the literature means 'increased production' and 'minimized environmental impacts' through the 'best management of inputs, outputs, environmental services and natural resources/capital' (Wezel et al. 2015). The principles of sustainable intensification remain often quite broad and diverse and are mostly less concrete than those of ecological intensification. Ecological intensification implies additional keywords like "resource use efficiency", "ecological processes and ecosystem services" (Dore et al. 2011; Rey et al. 2015). The practices proposed in the literature, to operationalize a sustainable or ecological intensification, are quite similar (Wezel et al. 2015).

Both variants of agro-ecological intensification emphasize social practices based on local and cultural contexts and on farmers' knowledge (Altieri et al. 2012). The importance of intensifying knowledge is emphasized, not only for scientists and decision makers but also for smallholders (Karamura et al. 2013; Angeon and Chave 2014). For this reason, the feasibility of agro-ecological intensification in tropical grasslands depends on the accumulation of bodies of knowledge about concrete agricultural practices which we review below.

SUSTAINABLE INTENSIFICATION IN TROPICAL GRASSLANDS: A MENU OF INITIATIVES

In terms of livestock production, farmers, extension agents and agricultural scientists have assessed and sometimes reassessed a wide range of management strategies intended to intensify agriculture in tropical grasslands (Minson 1990; Humphreys 1991; Poppi et al. 1997; Lemaire et al. 2011). It has sometimes proven difficult to quantify the overall effectiveness of particular strategies because they involve a plurality of elementary strategies, implemented in a wide range of conditions and assessed in addition according to a wide range of criteria. In addition, most studied strategies have been examined and promoted only for their value in enhancing production, so they get an 'incomplete' on the multi-functional test because we know little or nothing about their abilities to enhance the agro-ecology of a place (Altieri 1989). The research reviewed below, in addition to pointing out the environmental utility of some elementary strategies, underlines the usefulness of some more complex practices that integrate a plurality of elementary strategies.

Some elementary strategies implemented alone may offer simple ways to improve animal performance in tropical grasslands. Strategies like modifying duration and frequency of grazing, using supplements or legumes, or modifying the stage of regrowth of pasture would improve animal performance (Boval and Dixon 2012). By altering when they reintroduce animals into a pasture, farmers change the regrowth stage of the pasture, and, if well adapted to the local forage species, (Gulsen et al. 2004; Boval et al. 2007) this change can really change the diet of grazing animals and contribute to the subsequent regrowth of the forage. Grazing at an appropriate stage of regrowth may help sustain a pasture and its supply function for livestock, thereby maintaining a balance between short-term pasturing needs and the long-term viability of pastures (Laca 2009).

The long established practice of composting is another simple way of improving animal performances. Used for centuries in densely settled agricultural districts, composting maintains soil fertility and plant health. The mechanisms by which diseases are controlled by composts are just now being elucidated (Hoitink and Changa 2004). Composting, involving the action of earthworms to obtain a vermicompost, appears to contribute to both more productive and biodiverse grasslands. The increased presence of earthworms enhances the recycling and recovery of various manures (Sierra et al. 2013); it improves the quality of organic soil, the nutrient bioavailability and grassland biomass while having a nematophagous action, beneficial to a lesser gastro-intestinal parasitism of small ruminants in pastures (d'Alexis et al. 2009). As composts or vermicomposts help improve the organic matter of the soils, as well as interfere with crop nematodes (Arancon et al. 2002; Foley et al. 2014) and with the gastro-intestinal nematodes of animals grazing on grasslands (d'Alexis et al. 2009), they add value to the supply of manure.

More complex management strategies also show promise in tropical grasslands. Mixed grazing has agro-ecological benefits. It improves individual animal growth, and it raises per hectare yields from livestock. It exploits complementarities in feeding behaviours among animal species and reduces the impact of gastro-intestinal parasites on small ruminants. Until recently, breeders, each with a small number of different species of animals, fed them regularly together. But with the increase in the size of farms and the productive specialization that has increasingly marked operating systems during the last half century, breeders began to graze the different livestock species separately. When landowners segregated grazing animals by species, they made more use of deworming medicines and non-herbal foods which in turn induced additional grassland degradation. Parasites resistant to many chemical anti-helmintics emerged among the studied animals (Kaplan 2004). Researchers then began to reassess mixed grazing systems (Nolan and Connolly 1977). Recent studies indicate that mixed grazing accelerates the growth of animals and reduces the incidence of parasites in animals (Jackson et al. 2009; Hoste et al. 2010). For sheep, a meta-analysis of the literature highlighted individual weight gain of 15 g/animal/day, which varies depending on the physiological stages (lactating, pre- or post-weaning) and a 29 % gain in animal weight produced per hectare in mixed grazing compared to grazing of sheep alone (d'Alexis et al. 2013). For goats, an experiment over 2 years in tropical pastures revealed an individual gain of 14 g body weight/animal/day. The rate of gain doubled in the mixed pastures, and the grazing by several different animals made for more complete use of the biomass. For cattle pastured with other species, the benefit is less clear. It fluctuates between studies but individual growth is at least equivalent to that recorded for cattle grazing alone (d'Alexis et al. 2014). In addition to increasing animal production, mixed grazing promotes more diverse pasture soil ecologies; the turnover of biomass reduces production costs, and the use of conventional anthelmintic strategies produces healthy animals without the chemical residues of anti-helmintic medicines.

The traditional practice of tethering offers a range of yet to be quantified social and agro-ecological benefits in some tropical areas (Boval et al. 2014). Tethering is largely practiced in low latitude places like Ghana, Ethiopia, Uganda or the Sahel (Ayantunde et al. 2008; Duku et al. 2010; Senbeto et al. 2013) in India (Das and Hema 2008) as well as in North America (Heredia-Nava et al. 2007; Patra et al. 2008). It provides income to a wide range of low income breeders (including pensioners, women and youth) via an efficient conversion of biomass into animal protein at low cost on any non-arable land. The animals, when well attended, regularly visited and watered in this way, contribute in addition, to shape the landscape and maintain the ecological condition of local savannas. By tending to the animals individually, stocking rate adjustments by the owner may prevent overgrazing (Boval et al. 2014). Tethering also makes local food chains more robust which in turn reconfirms the meaning of farm work, reinforces social links and reduces energy consumption (Mundler and Rumpus 2012). These services remain difficult to quantify, but they clearly enhance the multiple functions of agriculture and contribute in a non-negligible way to countering the food security—biodiversity—global change crisis.

Both elementary strategies like composting and more complex strategies like mixed grazing seem desirable because they confer benefits across a wide range of activities. They bolster agricultural productivity at the same time that they deliver important ecological services to humans. In addition to providing people with animal protein, grasslands can strengthen the link between herbivores and floral diversity (Gliessman 2009). Well-managed, grasslands also provide ecological and regulating services, notably to maintain and restore biodiversity in open landscapes (Ma and Swinton 2011; Metera et al. 2010), preserve pollination and retard erosion and leaching.

In addition to provisioning people with meat, tropical grasslands can offset a significant proportion of global greenhouse gases emissions. Animals are essential actor in the regrowth of grass. The extent of C storage may be increased by managing stocking rates and grazing pressure of livestock (Allard et al. 2007; Ammann et al. 2007). Animals contribute to improving the quality of the grassland in some circumstances by retarding soil erosion and enhancing processes of infiltration and water retention (Gliessman 2009). For Koocheki and Gliessman (2005), pastoral nomadism is a complex set of practices and knowledge which ensures the long-term maintenance of a sophisticated "triangle of sustainability" that links plants, animals and people and varies in substantively important ways across tropical agro-ecosystems. To be sure, these sustainable regimens only exist within a range of stocking rates (Soussana and Lemaire 2014).

The links between agricultural and societal routines among pastoralists may provide opportunities for the adoption of recommended practices. Most traditional agro-ecological practices have their foundation in customary institutions for agro-ecological management as well as in normative arrangements for resource access and benefit sharing (Gliessman 2009; Altieri and Manuel Toledo 2011). Under these circumstances the promotion of these practices would simultaneously address the challenges of the food security, biodiversity and the global changes crisis. Continued research into these practices would contribute to the creation of the knowledge based societies envisaged in the United Nations Sustainable Development Agenda for 2030.

REORIENTING THE AGRICULTURAL SCIENCES OF TROPICAL GRASSLANDS

Research focused on the agro-ecology of tropical grasslands would seem to require a holistic emphasis that differs substantially from common practices among animal scientists. They have typically carried out studies which prioritize increases in outputs of animal products by having as a reference animal production in intensive conditions (i.e. stall-fed settings) with a key objective of examining the impacts of the highest possible intakes of metabolizable energy (ME). But the financial costs (costs of buildings and concentrates, costs of labour for mowing and harvesting cultivated forages) and environmental costs (due to fertilization or soil compaction) have often been neglected in these studies. Also the qualities and diversity of products have been rarely considered. Yet some forms of animal production (leather, manure and fine wool) do not, for example, require necessarily high intakes of ME. In other words, because grassland exploitation contributes to other services besides the provisioning of animal products, researchers need to recognize its multi-functionality and design research that recognizes, examines and assesses its multi-functionality.

Much grassland-related research has proceeded as if agriculture in this setting has only one function, the production of foodstuffs. A recent quantitative analysis of the literature (Agastin et al. 2014) showed that equivalent animal performances may be obtained whatever the feeding environments (in stalls or at pasture) provided that the amounts and quality of the supplementary feed are the same. Indeed, the main factor that explains the differences in input efficiency often reported in the literature is the variable use of feed concentrates in stalls. Pastured animals rarely receive feed concentrates, so these findings have little application in grassland settings. Grass fed animals do provide higher quality products. A recent review (Venkata Reddy et al. 2015) shows, for example, better ratios of polyunsaturated fatty acids when animals are finished in pastures.

This mismatch between the presumptions of the researcher about useful findings and the role of animals in a multi-functional tropical agriculture suggest that researchers need to reconceptualize the agricultural ideal that they seek to further through their research. This reorientation means considering goals other than the performance of individual animals and the level of inputs of ME to those animals. It means being aware of various temporal and spatial scales (the short-term vs long-term and sustainable performance) and various dimensions (integrating financial, labour and environmental costs), in considering the value of an innovation for breeders. It is also essential that researchers include in their assessment criteria factors that reflect the local context within which they work (Boval and Dixon 2012). In this respect, NIRS (Near-Infrared Spectroscopy) progress with portable devices that allow evaluation of in situ situations is important (Liu et al. 2014; Decruyenaere et al. 2015).

CONCLUSION

The tropical grasslands represent a pivotal place for the emergence of a multi-functional agriculture that responds to the food security–biodiversity–global changes crisis. It covers a very large area of the world's most biologically productive biome and its human resources remain underutilized. As outlined above, new agro-ecological regimens can further the emergence of a multi-functional agriculture in this setting. These processes necessitate in addition to specific interventions, strategies and coordination among different actors (breeders, policy makers, researchers, etc.) that intervene in various ways, at different levels and at appropriate scales of action to implement consistent management of grasslands.

Researchers can expedite this agro-ecological transition by abandoning the heretofore dominant productivist model of agriculture and adopting an agro-ecological model of agriculture that stresses the multiple direct and indirect contributions of agriculture to societal well-being. This intellectual conversion would incorporate researchers into a societal pact that federates all the stakeholders around an agro-ecological project (Angeon 2015). It calls for the development of convenient tools and methods to develop radical innovations and more widely to collectively think and organize a transition to a more agro-ecological, multi-functional agriculture. This program is of first importance in vulnerable areas like the Tropics. It should increase their contributions of people in these places to worldwide efforts to cope with the food security—biodiversity—global changes crisis. This agro-ecological transition would also integrate the goals of production and consumption through a continuous dialogue between producers and consumers, which relies on an environmental commitment and ethic. This then necessitates as required by the FAO (2015) "Developing Sound Tools for Sustainable Food and Agriculture".

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