Environmental challenges of pastoral farming systems in tropical areas[1]

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ABSTRACT

The need to increase food production has become urgent. Pastoral farming systems based on grasslands in the tropics are essential players in this scenario, considering the surface area and stakeholders they represent. Improving productivity from existing grasslands can be a way forward to produce food, because most of them still produce less than the potential primary and secondary production they could achieve if constraints to pasture and animal growth were surpassed using existing technologies. This potential production could be reached without increasing the surface area used. However, the technologies available to support this intensification process are generally based on an input approach, and are associated with increased use of natural resources and pollution. This classical anthropogenic effect has already been experienced in the temperate grasslands of developed countries, and has raised environmental concerns there. Pastoral farming systems in the tropics seemed to be following the same trend, but are currently being called upon to increase production without such side effects. Dealing with these new environmental drivers and unraveling the production *vs.* conservation dilemma requires pastoral farming to take a new process-oriented approach. Grassland science is responding to this environmental constraint, and is being asked to build innovative systems devoted to sustainable intensification, at a time when urgency contrasts with a seeming lack of creativity and innovation. Here we explore these issues, focusing on Brazilian pastoral farming trends. This case study is of worldwide interest because of its major place in the global market, and its impact on food security and natural resource conservation in Brazil and elsewhere.

Keywords: ecosystem services, grasslands, grazing, sustainable intensification

INTRODUCTION

The challenge to increase food production has become more urgent than ever, with the emerging consensus that the world will have approximately 9 billion mouths to feed by about 2050 (UN, 2008). Predictions of future food demand differ, but even the most optimistic scenarios require increases in food production of at least 50% by 2050 (Lal et al., 2013; Gill et al., 2010). Food demands will both grow and shift in the coming decades, with a strong growth in consumption of animal products in countries of the South (120% between 1980 and 2005), compared with that in the North (+7.6% for the same period, FAO, 2012). These changes are occurring not merely because of population growth, but also because uneven economic growth increases consumer purchasing power, especially for meats (Horlings and Marsden, 2011). Growing urbanization encourages people to adopt new diets, and climate change variations and events are threatening both land and water resources (Pretty et al., 2010), in addition to 17 billion animals using substantial amounts of natural resources (Herrero et al., 2013).

Agricultural production has shown an impressive conventional growth since the start of the first ‘Green Revolution’ in the 1960s to ensure food security. Compared with 1961, per capita food consumption has increased by 25% in proportion, but with significant variations among the continents (FAO, 2009). Intensive production systems have induced serious adverse side effects on the environment, with a "boomerang effect" on future food production (Delgado, 2003; Fedoroff et al., 2010). The myth of the efficiency of this paradigm model has been largely discussed. Intensified production has led to high-energy consumption and heavy use of fertilizers, pesticides and water, and an increase in emissions of nitrates and pesticides in the environment, and depletion of groundwater (Moss, 2008; Bennett *et al.*, 2005). Russelle et al. (2007) present the growing concerns with intensive specialized agricultural systems, manifested in (i) water contamination with excessive nutrients, pesticides, and pathogens, (ii) decreasing groundwater levels due to high demand, and competition from a variety of stakeholders, including specialized crop production, (iii) rising greenhouse gas emissions from soils depleted in organic matter, and (iv) dysfunctional soils that have become degraded from excessive tillage, salt accumulation, and pesticide inputs. About 30% of global greenhouse gas (**GHG**) emissions are attributed to agricultural activities, including land use changes such as deforestation (FAO, 2009). The agro-industrial model also has many social effects; many farmers are unable to compete in this 'race to the bottom' (Horlings and Marsden, 2011).

There has already been an expansion of 9.6% in the world's agricultural area over the last 50 years, in both arable land, permanent crops and permanent meadows and pastures (O'Mara, 2012). However, since 1991, the total area has been stationary, and with discrepancies among various countries of the world. While in developed countries the agricultural land area decreased by more than 34% between 1995 and 2007 (including pastures and permanent cropland), developing countries saw increases of nearly 17.1% (Gibbs et al., 2010). According to the FAO projection, global agricultural areas are likely to expand substantially, by about 280 Mha by 2030. However, there is a consensus that increasing yields on existing agricultural land without further expansion is a key component of food security. (Wirsenius et al., 2010). There is therefore a need to improve sustainable production from the existing land and grasslands, and most tropical areas will be concerned, as well as intact forests cleared for grazing (Gibbs et al. 2010).

POTENTIAL OF GRASSLANDS TO ENSURE SUSTAINABLE FOOD SECURITY

Grasslands are the basis of pastoral faming systems, and represent 26% of the land on the planet; around 47% and 36% of total grasslands are respectively still semi-natural or marginal (Bouwman et al., 2005; van Asselen and Verburg, 2012), mainly in the tropics and developing countries. This suggests that intensification may be possible with no further expansion of agricultural land (FAO, 2012).

Grasslands are associated with different farming system types and products; they may be non-arable areas, or integrated with crops in arable lands, with a low dependence on external inputs (i.e., fossil energy). Hence different products can be obtained at lower cost, with the bonus of added value of quality (Agastin et al., 2013), and the perception of "natural" products, which many consumers are willing to pay for (Gracia et al., 2011). Grasslands are able to make use of solar radiation all year round, and support livestock, which can alleviate seasonal food shortage and contribute to food security. For example, in northwest India, where droughts are frequent, the contribution of livestock to household income is essential (Devendra and Leng, 2011).

Grasslands represent a very flexible agroecosystem, which can help forestall inequalities in access to food and other products. The world today produces sufficient food to feed its population, but there still remain more than one billion people suffering from food insecurity and malnutrition (Pretty et al., 2010). Given their importance in terms of area and their geographical diversity, grasslands can allow different approaches to intensification for different contexts. Whereas extensive pastoral systems occupy regions where agricultural production is generally marginal, integrated crop-livestock systems are associated with high population density regions (Herrero et al., 2009; Tarawali et al., 2011). All these systems, based on the utilization of grazing areas, can be improved differently depending on local environmental and economic resources, needs and constraints. Grasslands can be used with cattle, sheep and goats, or horses, raised alone or in combination (Dennis et al., 2012; d'Alexis et al., 2013), with ranging intensiveness, partly indoors, and with grazing periods of ranging duration.

Because many grasslands are still marginal or semi-natural, and perform many functions, making better use of them is delicate, yet crucial (Boval and Dixon, 2012). Global estimates are that grazing land accounts for about one fourth of potential carbon (C) sequestration in world 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 (Follet and Reed, 2010). Tropical grasslands represent a storage pool of carbon (**C**), almost twice that of temperate grasslands, mostly sequestered in the soil, and a more stable form of storage than the aerial components of forests (Soussana et al., 2010). According to Bagchi and Ritchie (2010), stocking rate and impacts of livestock on vegetation composition are equally important in influencing soil C sequestration in grazing ecosystems. The management of grassland, N fertilization, manure management and grazing pressure are therefore determining in ensuring this C storage (Batlle-Bayer et al., 2010; McSherry and Ritchie, 2013; West et al., 2010), and must be considered in intensifying grasslands for animal production. Currently, further information is still needed on tropical grasslands in order to meet appropriate management options.

Grasslands are also havens of biodiversity, especially in tropical regions, where they are the source of about 50% of all plant species, although they represent only 7% of the land surface (Bond and Parr, 2010). However, this biodiversity is seriously threatened by anthropogenic factors including land clearance, introduction of exotic species or invasion, soil cultivation, fertilizer application and altered fire management (Prober and Smith, 2009). Livestock particularly, as the largest user of grasslands, increases pressure on this ecosystem (FAO, 2009), while being a tool to maintain biodiversity of open landscape (Derner et al., 2009), contributing to aesthetic value and leisure amenity, and even allowing rapid structural regeneration of land (Metera et al., 2010; Maczkowiack et al., 2012). However, there is still a need for comprehensive research to support the development of agro-environmental schemes to protect grassland biocenoses; this will require management tools that operate on an appropriate scale (Boval and Dixon, 2012).

In addition, good use of grasslands must be fostered, as they contribute directly to the livelihoods of over 800 million people (Herrero et al., 2013), while providing income and meeting the socio-cultural needs of many modest smallholders, and being an essential way to retain population in some areas. It has been estimated that about 70% of the 1.3 billion people around the world in "extreme poverty" survive on livestock grazing (FAO, 2009). The statistics also 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). Apart from marketable livestock products, grasslands also provide a variety of social, economic and cultural goods, and ecosystemic services (Ma and Swinton, 2011). These latter are quite often more important, more varied and more multi-purpose 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 social status of the breeder, and play a crucial role in social protection for the poor to cope with uncertainties and constraints, such as crop failures and other disasters (FAO, 2009). Livestock also are used for ploughing and transport, provide a local supply of manure, and are of cultural importance for many poorer communities, where cattle are the foundation of many religious rituals (e.g., Godfray et al., 2010; Pretty et al., 2010).

PASTORAL FARMING SYSTEMS IN THE TROPICS, *THE BRAZILIAN CASE STUDY*

Extensive cattle ranching is the predominant grassland-based activity in Brazil, and has been responsible for over 90% of the stocking rate (Animal Unit Equivalent, **AU**) since 1995. Most of the cattle herd (83.5%) is related to beef production (IBGE, 2006). This being so, it seems reasonable to assume that the environmental challenges to pastoral farming systems in Brazil will mostly concern the beef sector.

The beef sector has gone through intense growth and dynamic technological changes over the last few decades, mostly due to (i) increased demand for Brazilian beef, (ii) expansion of ranching through land conversion, particularly in the Cerrado and Amazonia, and (iii) growth of beef exports. In the light of global concerns over the impacts of climate change and climate variability, market pressures for mitigation of GHG emissions and the Low Carbon Agriculture Plan of the Brazilian Federal Government have also recently been shaping agriculture and livestock development.

Despite this general modernization pathway, Brazilian farming systems are still very diverse, given the marked regional differences in biophysical and socioeconomic characteristics. One environmental challenge for pastoral farming in Brazil associated with this heterogeneous territory relies on a spatially different rate of adoption of more sustainable technologies. Such regional specialization of the livestock sector is important to consider when making decisions about public investment, and targeting mitigation and adaptation strategies.

Data from the last Brazilian Census on Agriculture and Livestock (IBGE, 2006) report that more than half of the rural properties possess at least one bovine, which is not surprising as the country's bovine population is roughly 176 million (over 200 million in more recent estimates, IBGE, 2013) for 2.7 million rural farming units. Yet the variability is not only about herd size. Fasiaben et al. (2012) identified regional patterns over many variables, and made up ten different categories of municipality in relation to cattle production systems. It is noteworthy that only 8.5% of the municipalities, which correspond to 0.9% of total pasture area, fell into the category of semi-intensive livestock production. Extensive cattle ranching and municipalities where beef cattle form the main livestock activity are commonplace in many regions of the Central-West region of Brazil.

The expansion of pastoral farming systems in Brazil has been based on the “Nellore-Cerrado-*Brachiaria* tripod” since the 1970s (Ferraz and Felício, 2009). Central-West, North and Northeast regions were responsible for 41.7%, 29.1% and 15.2% of the growth in the beef herd over the period 1970–2006, respectively (see Figures 1 and 3). The *Bos indicus* genotype is well-adapted to the tropical climate, and Nellore has been the main option for beef production in these regions. The Brazilian Zebu Breeders Association estimate that 80% of the Brazilian herd has some influence from the zebu genotype.

The growth of beef exports has also brought new challenges to pastoral farming systems, as the market became more selective for slaughter age, animal health, traceability and environmental impacts of livestock production. Recent actions and regulations of both meat-packing industries and government in response to the new marked demands are compelling drivers of technological changes in cattle farming.

Beef production has moved spatially in the Brazilian territory, mainly across the Central-West region of Brazil, over the Cerrado biome, and more recently over Amazonia. Grasslands have been contracting in the South and Southeast regions due to the expansion of other land uses, particularly annual crops (Figure 2).

The regional dynamics of the Brazilian grasslands has prompted discussions on the relation between cattle production, particularly beef, and deforestation. This has been a subject of great interest for both the Cerrado and Amazonia (Margulis, 2004; Fearnside, 2005; Brannstrom et al., 2008; Pacheco, 2012). Satellite images indicate that deforested areas have often been converted to tropical grass monocultures (Cardille and Foley, 2003; Brannstrom et al., 2008; Bustamante et al., 2012; de Espindola et al., 2012). However, the underlying causes of deforestation in Brazil, and its relation to cattle production, remain quite controversial.

There are compelling arguments implicating predatory deforestation to increase profit and metabiosis, where beef production pioneers use land after logging or burning to ensure property rights before other agricultural activity takes its place (Vosti and Faminow, 1998; Hetch, 1993; Margulis, 2004; Cohn et al., 2011; Bownman et al., 2012).

Grassland expansion made a limited contribution to the production rise until the late 1980s, and now plays an even more limited role (Martha et al., 2012). Data from the last two censuses (1995/1996 *vs.* 2006) indicate trends toward stabilization and contraction of grassland area. Even when analyzing data for the Central-West and North regions, which encompass the Brazilian Amazon and most of the Cerrado, grassland area expanded by 42%, while cattle numbers increased by 392% over the period 1970–2006. More recently, 1995/1996 *vs.* 2006 census, grassland area decreased by 2%, while cattle population increased by 37% in those same regions. As animal performance also increased quite steadily from 1970 to 2006 (Figure 3), a national grassland area expansion of 3% (IBGE, 2013) followed a beef production increase of 489% (FAOSTAT, 2013). Projections of grassland area, with changes calculated as the net difference of deforestation and net expansion of other land uses (particularly annual crops, sugarcane and forestry), by the World Bank (Gouvello et al., 2010), show a quasi-stable (−0.9%, reference scenario) or contraction (−34.0%, low carbon scenario) from 2006 to 2030.

From the technological perspective, this increase in stocking rates seems to be closely related to the introduction of new cultivated species over natural ones (Figure 4).

The reliance of productivity gains on the substitution of pasture species seems to have diminished from the mid 1990s, when supplementation on pastures and feedlots became more common. This may be an important factor in explaining the sharp increase in animal performance from 1990 to 2010 (Figure 3), in addition to animal breeding gains. Stocking rate slopes in relation to pasture substitution, from 1995/6 to 2006, were much higher in the whole country (3.18 *vs.* 1.16) and in all regions except for the South (Figure 4). Besides the substitution of pasture, attenuation of the effects of seasonal pasture production due to feed supplementation is an important factor for the stocking rate changes.

Despite the overall increasing stocking rates experienced in Brazilian pastoral farming, there is a broad regional variability. There is over 40 million hectares of grasslands with stocking rates lower than 0.62 AU/ha (Figure 5). Around 15.7 million hectares of these grasslands is in the Caatinga and Pantanal biomes, where forage productivity comes from low-input natural pastures severely impaired by flooding or climate. The highest stocking rates reach 2.0 AU/ha. Assuming Brazilian pastoral farming systems are essentially grassland-based, and taking stocking rate as an expression of forage production, Figure 5 gives a picture of the actual grassland primary production scenario in Brazil.

Figure 6 shows a map with estimated missing potential indicated by the ratio of current and potential stocking rates in Brazilian grasslands, the latter calculated based on a pasture growth model.

It seems paradoxical that potential stocking rates are far from being reached throughout the country, and yet overgrazing is one of the main processes threatening pastoral farming in Brazil. The reasons for this paradox encompass inability to maximize biomass production and to cope with the temporal variability in forage growth, in addition to farmers' stocktaking perception (discussed further).

Technology is available to increase the productivity of Brazilian pastoral farming systems beyond what would be required in a scenario of strong contraction of grassland area coupled with increased beef demand (Gouvello et al., 2011; Foresight, 2011). Cattle ranching technologies that are already in commercial use have proved cost-effective at increasing agricultural output (Cohn et al., 2011; Strassburg et al., 2012). Enhancing pasture management, supplemental feeding and genetic and health improvements allow changes in the actual to potential production ratio at a fixed rate of land use change (Martha et al., 2012). Estimates of the World Bank (Gouvello et al., 2011), in addition to results from optimization farm systems models, confirm that optimal level of productivity is higher than the current observed levels. Therefore, considering there is room to intensification, the issue is how to conduct this process.

Beef production from Brazilian pastoral farming systems plays a fundamental role in the global market, mostly when the increase in the global demand of livestock products is considered. The country's contribution is not only for the production itself, but is also important to reduce macroeconomic pressures, and for its potential to influence commodity prices in agricultural markets (Pereira et al., 2012), which in turn will impact food security and create pressures for deforestation elsewhere. Tropical grasslands are at the center of a low-carbon development strategy acting as a connection between solutions to cope with environmental challenges. The Brazilian picture is a good example of such dynamics that could be scaled up to other tropical regions. Grasslands are the main production environment for beef cattle in Brazil, and promise major opportunities and potential for mitigation and adaptation.

ENVIRONMENTAL CHALLENGES OF PASTORAL FARMING SYSTEMS WITH PARTICULAR REFERENCE TO BRAZIL

There are many challenges for pastoral farming in Brazil in response to demographic, economic, socio-political and environmental pressures, which are lending pastoral farming operations a new commercial and legal dimension. We focus here on environmental processes, but an important current legal context stems from the Brazilian Forest Act, which is the foremost environmental legislation in Brazil responsible for regulating private land use (Ferreira et al., 2012). This Act is now under major controversial revision. One of the most important changes relates to the amount of set-aside area that is required on private land, which can retrospectively place a large number of properties outside the limits of legal compliance, causing uncertainty (Ferreira et al., 2012).

Regarding environmental challenges, the most important concern is probably the current intensification trends, and the predictable non-desirable results that could arise from them. It recalls threats already experienced by developed countries, and exemplifies the ancient anthropogenic incapacity to deal with natural resources management.

Habitat conversion and loss of biodiversity

Agricultural expansion has increased recently, and now extends to about one-third of Brazilian territory. Four (Cerrado, Pampa, Caatinga and Atlantic Forest) out of six Brazilian terrestrial biomes have lost at least 50% of their natural habitats (Ferreira et al., 2012). Sown grasslands replacing natural pastures have been massively adopted in the last 50 years, justified by the assumed low carrying capacity and productivity of natural pastures. Legumes in mixtures have low adoption and probably represent less than 3% of sown pasture area (Carvalho et al., 2006). Negligible efforts to promote more diverse pastures, and the known low persistence of legumes in mixtures with tropical grasses accounts for this. According to Euclides et al. (2010), only 8 grass and 7 legume genera were officially registered in domestic trade in 2010. From approximately 100 million ha of sown pastures, the most important genus is *Brachiaria*, whose area is greater than all pastoral areas in Europe (Carvalho et al., 2012).

Pastoral farming in Brazil has thus developed based on huge areas of sown tropical grass monocultures, and the obvious consequences of this low diversity are now being experienced. The statistics are not conclusive, but Macedo (2009) reports 60 million ha of degraded pastures in Brazil. The pasture degradation process is complex (Dias-Filho, 2011), but it is well accepted that diversity is a fundamental issue (Altieri, 1999). Hence large areas of grass monocultures are unable to face natural climatic variations and anthropogenic mismanagement, which seems a contradiction in a mega-diverse country.

Multispecies pastures are now becoming widespread in developed countries, where the scientific community has largely proposed multifunctionality of pastures (Kemp and Michalk, 2007). Huyghe et al. (2012) suggest that diverse pastures are more productive (biomass production) and their sustainable long-term production is based on ecological processes such as complementarity (use of the same resource at different times or sites, and use of different resources for a similar physiological process) and facilitation (presence of one species increases the probability of presence of a second one). According to Gaujour et al. (2012), diverse pastures provide benefits for ecosystem functioning and agricultural production, such as increased forage production, greater ecosystem stability in response to biotic and abiotic disturbances, decreased invasion by exotic weed species and indigenous species from surrounding habitats, and enhanced nutrient cycling. Not only is botanical diversity important, but also functional diversity matters (groups of species promoting similar effects on the ecosystem functioning by common responses to biotic and abiotic factors), as it is essential to aspire to broader ecosystem services. In this sense, justification for pastoral farming systems based on more diverse pastures is convincing, yet this is not the current trend in Brazil. In addition, managing grazing intensity is crucial to maintaining and/or promoting floristic and functional diversity in multispecies pastures, only moderate grazing promoting both (Cruz et al., 2010).

Overgrazing

Overgrazing is a global trend. According to Hanselka and Landers (1993), the reasons are complex, and reflect biological, social and economic factors. Costa and Rehman (2005) studied the overgrazing behavior of Brazilian beef cattle operations, reviewed ranchers' objectives, and concluded that cattle ownership sense (cattle asset value) and its benefits in terms of security and liquidity were the main reasons for overgrazing.

Carvalho and Batello (2009) report that Brazilian legislation requirements regarding access to land cause an unexpected stimulation to overgrazing, since they set a minimum stocking rate to maintain the ownership of land. Compulsory set stocking rates usually exceed current pasture production, with no distinction for sown or natural grasslands, so the latter are particularly threatened. Farmers have dealt with legislation by intensifying pasture production (mainly by replacing natural grasslands by sown “more productive” commercial species as described earlier) and/or simply increasing stocking rates in the existing grasslands. Therefore, meeting legislation requirements is almost the only management factor in place, with low production indices, pasture degradation and decreasing ecosystem services. Costa and Rehman (2005) suggest that farmers are conscious of overgrazing costs, but choose the option of holding more cattle, believing this can outweigh the increased pasture recovery and maintenance costs.

Grazing modifies the structure and function of ecosystems (Piñeiro et al., 2010), so grazing management constitutes a challenge for pastoral farming in Brazil. Conte et al. (2011) studied long-term impacts of overgrazing, and reported that C stocks, diameter of soil aggregates, and root mass were inversely related to herbage allowance. Poor soil structure caused by overgrazing determines low infiltration rates (Bertol et al., 1998), with negative hydrologic effects. Also, Chaves et al. (2011) demonstrated that grazing intensity affected soil microbial biomass and diversity, and Cruz et al. (2010) reported that functional diversity in natural pastures depended on grazing intensity. In general, overgrazing threatens many environmental key indicators, and moderate grazing promotes most of them (Carvalho et al., 2011).

Overgrazing is the foremost process associated with pasture degradation in Brazil. These pastures contribute to GHG, since lower C inputs from pasture lead to lower sequestration rates. In addition, this low herbage allowance of low forage quality increases GHG emitted per unit of animal production, so grazing intensity is intimately linked to livestock emissions, moderate grazing again decreasing emissions per unit animal production (Cezimbra et al., 2013).

Intensification process

Biological invasion is related to intensification, and is estimated to be the second most important cause of biodiversity loss worldwide. Brazil has introduced 11,605 plant species, representing one-fifth of the native flora (Ferreira et al., 2010). Concerning pastoral farming in Brazil, probably the most documented process is invasion by *Eragrostis plana* in the Pampa biome. The substitution of natural pastures by sown ones, aiming to increase beef production, accidentally introduced this South African perennial tufted grass. According to Medeiros and Focht (2007), it has invaded more than one million hectares of natural and managed grasslands. This process has been strongly exacerbated by overgrazing, because higher grazing intensities decrease diversity and pasture cover, and increase grazing pressure on preferred plants, favoring the spread of *E. plana* (Carvalho and Batello, 2009).

Other phenomena related to the intensification process are being studied, and deserve reference because of their potential impacts on ecosystem services. Multifunctional pastures producing ecosystem services are celebrated, but currently they are not drivers of technologies and innovation (Carvalho et al., 2012). Intensive pasture production dominates as the main goal. Consequently, “input technologies” predominate over “process technologies”, with no particular trend toward sustainable intensification. High levels of grassland fertilization are frequently proposed to accomplish high herbage production levels allowed by C4 responding tropical forages. This is of obvious concern. However, the use of fertilizers is still restricted to a few intensive areas. According to the Brazilian National Association for Fertilizer Diffusion, a total of 405 thousand tonnes of fertilizers (including all types of chemical fertilizers) were annually applied to pastures in Brazil (ca. 2.5 kg per ha).

The prevailing management philosophy focuses on productivity per unit area of land, and associates the main indicator of this purpose with stocking rate. Accordingly, the main current technologies are almost all devoted to increasing the number of animal units per hectare as a profit goal. New highly productive varieties, high pasture fertilization, and irrigation are considered to be the main innovation-driven pastoral farming systems in Brazil (e.g., Balsalobre et al., 2002), in addition to increasing levels of feed supplementation. Developed countries previously experienced this approach, and the negative consequences for the environment are well-known (Lemaire et al., 2005).

We need to consider that the intensification of existing pastoral areas can be a strategy to avoid further loss of native vegetation. According to Martha et al. (2012), the land-saving effect of recent (after 1975) productivity gains from the Brazilian beef sector saved about 525 million hectares, which would be needed to meet 2006 levels of beef production in Brazil. However, expanding areas is no longer the production pattern currently in place, as described earlier. Furthermore, there are many threats associated with this option, and confusing political mediation of conservation and production interests by public policies are not helping to solve this dilemma (Carvalho and Batello, 2009).

TECHNOLOGIES FOR PASTORAL FARMING SYSTEMS

In developing countries such as Brazil, livestock is an important provider of income and employment, and so its socio-economic roles are increasing in importance as the sector grows (Herrero et al., 2013), demanding new pastoral farming systems to cope with the *sustainable intensification* challenge (Doré et al., 2011). Developing countries in particular must unravel the "productions *vs.* conservation" dilemma, because they need more animal production from grasslands than developed countries (Thornton and Herrero, 2010), and because at the same time about 70% of the global technical mitigation potential from agriculture lies in developing non-OECD countries (Hristov et al., 2013).

Grazing livestock is the basis for meat and milk production in tropical pastoral farming systems, and until a few years ago it was considered ecologically sound. Today there are environmental concerns regarding ruminants reared on grasslands, even though there is a substantive body of evidence that suggests that well-managed productive pastoral systems more than offset emissions from livestock (FAO, 2010; Herrero et al., 2011), and are energy-saving (Peyraud, 2011).

This context thus constitutes a scenario where pastoral farming systems in the near future will be increasingly driven by competition for natural resources, particularly land (Thornton, 2010) and water (Doreau et al., 2012). Kemp and Michalk (2011) state that critical functions that deserve attention by new pastoral farming systems are: minimizing soil erosion from wind or water, delivering clean water into river systems, and maintaining a diversity of plant and associated species such that productivity is optimized and opportunities for weed invasion are limited. Consequently, there is an urgent need to replace the intensive production-oriented approach (intensification by external inputs) by more environmentally friendly pastoral farming systems, which will require innovative systems supported by science and technology, and oriented to intensification in the use of natural functionalities (processes–oriented intensification).

Integrated crop-livestock systems

Mimicking nature in agricultural farming systems could be a way forward to sustainable intensification (Carvalho and Moraes, 2011), through better use of biological regulation mechanisms by means of strategic crop management, crop system design and landscape layout and management (Doré et al., 2011). Models of new farming systems based on the *farmscaping* concept are emerging, which aim to create a more biodiverse set of habitats, enhancing ecosystem services (Smukler et al., 2010).

Owing to this current scenario, integrated crop-livestock systems are now taking on new importance. In Brazil and worldwide, they are being considered as an example of sustainable intensification, where pastures are planned in synergism with crops, with or without trees, and interacting in on-farm or area-wide arrangements (Carvalho et al., 2010). While maximizing interactions among soil-plant-animal compartments, integrated crop-livestock systems mimic natural components and nutrient cycling fluxes (Anghinoni et al., 2013), thus approaching the highest level of integration among agricultural systems (Ryschawy et al., 2012). These systems increase environmental resilience through increased biological diversity, permit efficient nutrient cycling/recycling, improve soil health, provide ecosystem services, enhance forest preservation, and contribute to adaptation and mitigation of climate change (FAO, 2010). This is not a new farming system (Keulen and Schiere, 2004), but rather the use of new knowledge and functionalities (Carvalho and Moraes, 2011). Cerri et al. (2009) consider pasture restoration by integration with crops an important GHG mitigation strategy, both restoring C stocks by productive pastures and decreasing methane emissions as a result of higher forage quality.

Because of these features, integrated crop-livestock systems comprise a recent large-scale Brazilian government initiative known as the ABC Plan (Low Carbon Emission Agriculture Programme), aiming to decrease GHG and meet a pledge made at the 2009 Copenhagen Climate Conference. The Brazilian agricultural sector aims to reduce 22.5% of its emission by restoring 15 million degraded pastures, increasing 4 million hectares with integrated crop-livestock systems, and 8 million hectares in no-till conservation agriculture, among other initiatives. Hence Brazilian pasture farming systems will be in the vanguard of renovation if grass monocultures make room for more diverse (botanical and functional diversity as mentioned earlier) and sustainable grasslands (e.g., pastures in rotation with crops recycling nutrients within no-till systems, and sown/natural multispecies pastures being privileged) committed to animal production and ecosystem services.

Grazing management

One outcome of recent multifunctional demands on pastoral farming systems is the increasing complexity of grassland management and experimentation. As stated earlier, grazing is an essential component of pastoral farming, and affects ecosystem properties and functions. To deal with such a complex system, a reductionist approach is needed to understand the underlying processes mediating low time-spatial scale interactions (e.g., bites and plants), and at the same time a holistic and systemic approach is necessary to scale up practical management for pastoral system management level. The need for innovative and creative approaches is therefore more pressing than ever, given the urgency of the food security agenda.

Van den Pol-van Dasselaar (2012) reported recent innovations to support grazing in Europe. Surprisingly, the popularity of pastoral farming systems based on grazing is declining. Important factors accounting for this are labor and too few easy tools available to support farmers in grazing management. Average herd size is increasing, and large herds are difficult to manage. Continuous stocking is attracting new interest in Europe, and is mentioned among other innovations to support grazing, along with mobile automated milking systems and precision grazing initiatives such as automatic fence gates and automated grass yield measurements (van den Pol-van Dasselaar, 2012). Surveys among members of the European Grassland Federation Working Group concluded that no major developments in grazing systems management were recently occurring (van den Pol-van Dasselaar, 2012).

Da Silva and Carvalho (2005) reported a contrasting situation in Brazil, where new understanding of processes interfering with animal production in pastoral systems, and plant and animal responses to grazing management, has resulted in considerable incremental increases in animal performance and productivity in recent years (Carvalho et al., 2012). Da Silva and Nascimento Jr (2007) reviewed trends and research philosophies in Brazilian grassland science towards the planning of sound and efficient management practices, and concluded that recent sward targets developed for tropical pastures based on sward structure, and integrating both plant and animal goals, are changing paradigms related to tropical pasture management. Forage quality has been mostly cited as the main constraint to animal production in tropical pastures, but Da Silva and Carvalho (2005) argued that sward structure was more important in constraining forage intake than previously supposed. Sward targets oriented to maximize instantaneous intake rate for grazing dairy cows are being proposed to support new rotational stocking strategies aiming to maximize the intake of herbage per unit grazing time (Fonseca et al., 2012). In addition, sward targets based on canopy light interception and dynamics of forage accumulation are supporting new management strategies for both continuous and rotational stocking methods (e.g., Da Silva et al., 2012; Montagner et al., 2012). These proposed targets probably converge to increase C sequestration from grasslands and decrease GHG emissions, promoting pasture growth and higher forage intake.

Concerning multispecies natural grasslands, conservative grazing appears to favor both animal production and ecosystem services (Carvalho et al., 2011), and has been proposed to promote grazing in natural grasslands. However, the primary management action that would generally be taken in overgrazed natural grasslands is to decrease stocking rate, and farmers are responsive to this approach as previously stated. Besides, natural grasslands would compete with cash crop expansion pressures, so the sustainable intensification approach for natural grasslands is even more crucial because intensification is fundamental. The lack of innovative grazing management strategies able to change this picture is thus a threat to natural grassland areas (Carvalho and Batello, 2009).

CONCLUDING REMARKS

Environmental challenges for grasslands in tropical areas are demanding new pastoral farming systems devoted to sustainable intensification. Potential new developments useful for building future farming systems would include advances in process-oriented approaches to support creative and innovative pastoral farming. The current input-oriented approach is not sustainable, as already experienced by developed countries. Taking Brazil as an interesting case study for the tropics, there are environmental concerns, but these are not drivers in the current intensification processes. There is scope for increasing productivity in grassland-based systems, and Brazil can play an important role in global food security, but current trends are promoting grass monocultures and overgrazing. The prevailing focus is intensification *per se*, so there is a challenge to change current concepts towards multifunctionality. This course can be very intricate. Farmers do not perceive ecosystem services as a goal, as they do not bring profits in the short term. Confusing legislation does not help, and even deepens the production *versus* conservation dilemma, causing uncertainty. To deal with such complexity, there is a need for a more holistic but at the same time uncomplicated approach applied to building and managing pastoral farming systems that can be widely adopted. Recent initiatives hold promise, such as the low carbon agriculture program and the promotion of more diverse sustainable agricultural systems at unprecedented levels. Exclusive pastoral systems, integrated or not with crops, and the new grazing management targets oriented to efficient capture of solar radiation and animal intake, have potential to change current trends and lastingly transform pastoral farming systems in the tropics. However, the urgency for food production is outrunning the time needed to make profound conceptual changes, and so this debate must be hastened.

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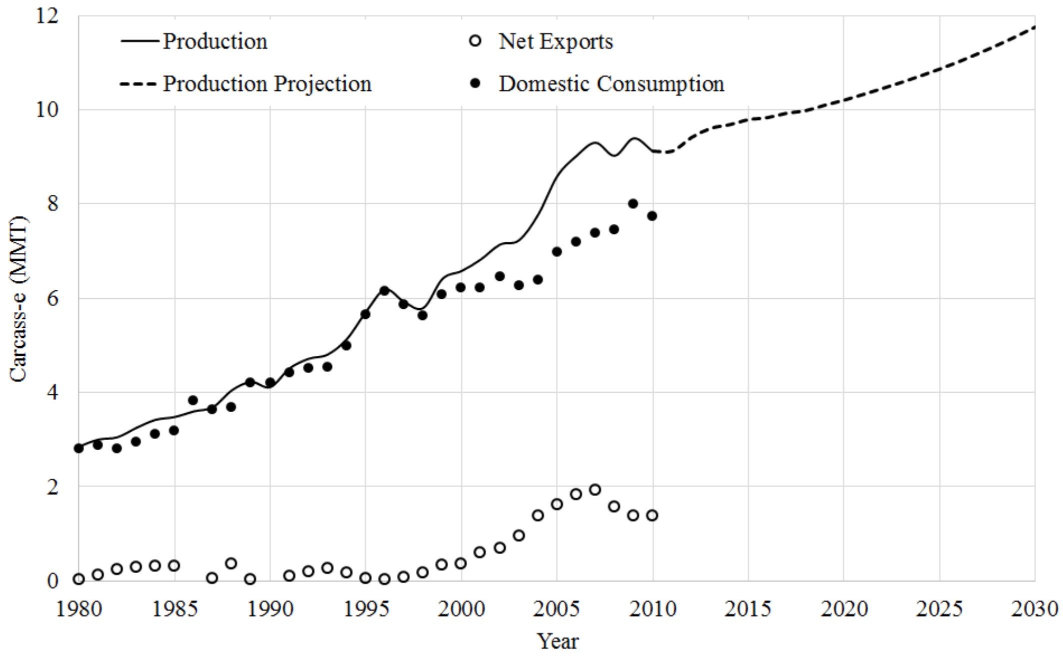

Figure 1. Time course of beef production for domestic consumption and exports (source: FAOSTAT; Gouvello et al., 2011)

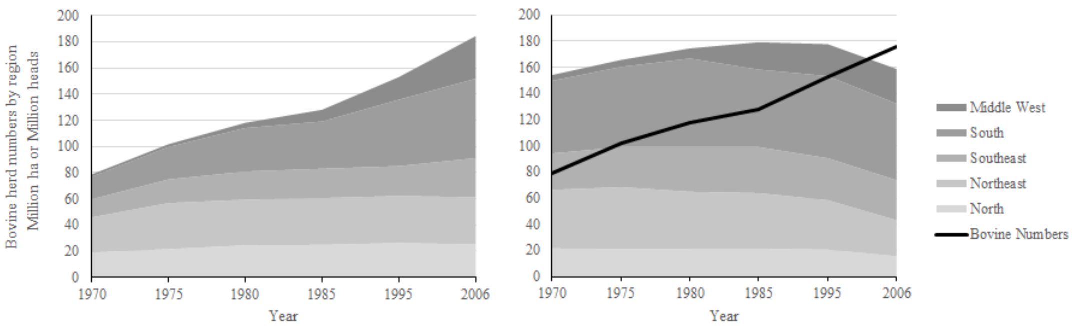

Figure 2. Grassland area and cattle population dynamics in different regions of Brazil (source: based on 1970 – 2006 Agricultural Censuses; IBGE, 2013)

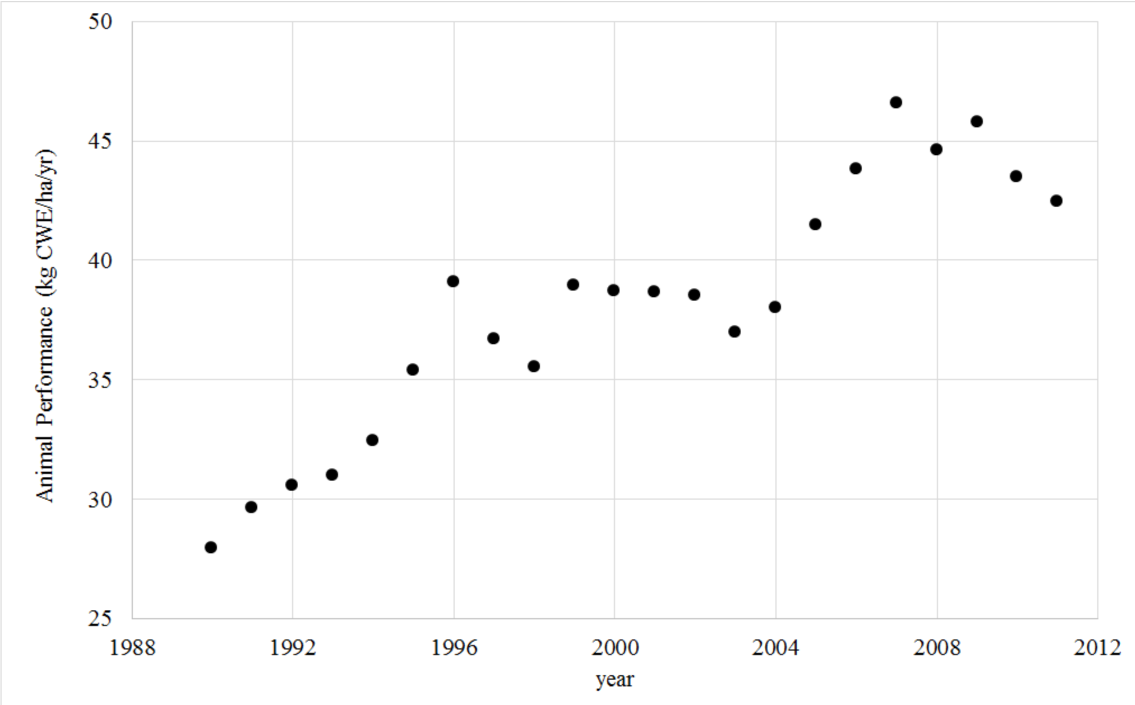

Figure 3. Average animal productivity (kg of carcass weight equivalent/head/year) calculated by dividing total country beef production by cattle population (derived from FAOSTAT data).

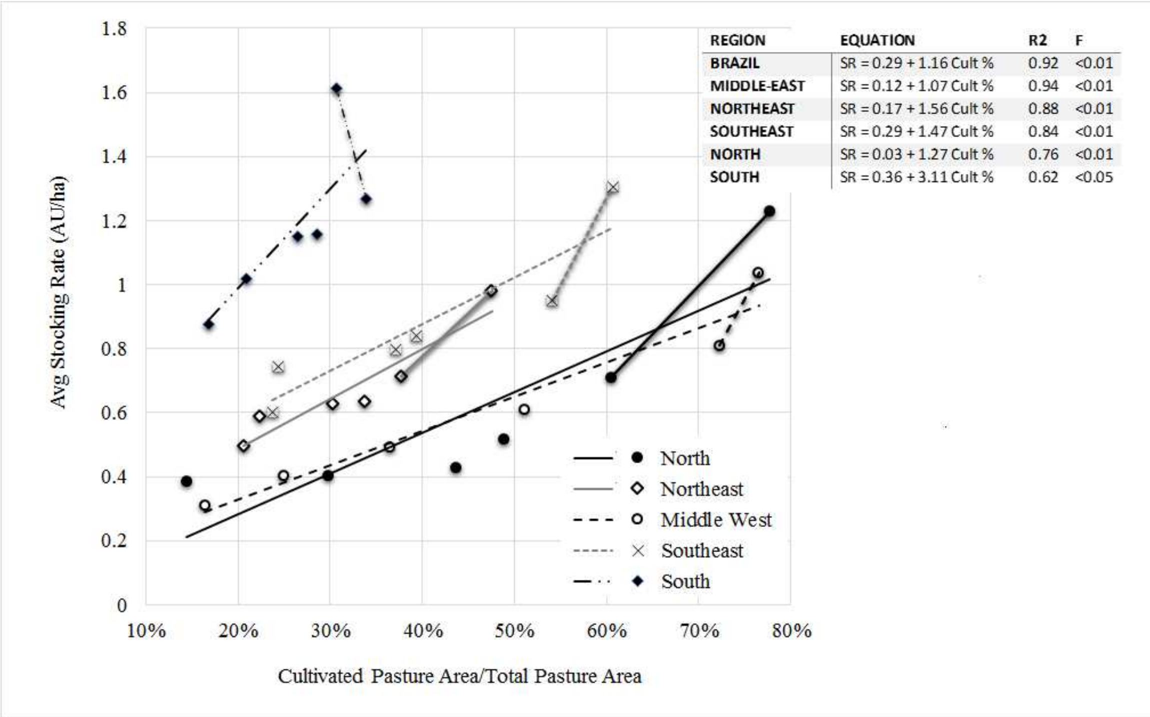

Figure 4. Relationship between average regional stocking rates and percentage of cultivated pasture species in Agricultural Census time-series (IBGE, 2013). Linked point lines represent the changes between the 1995/96 and the 2006 census.

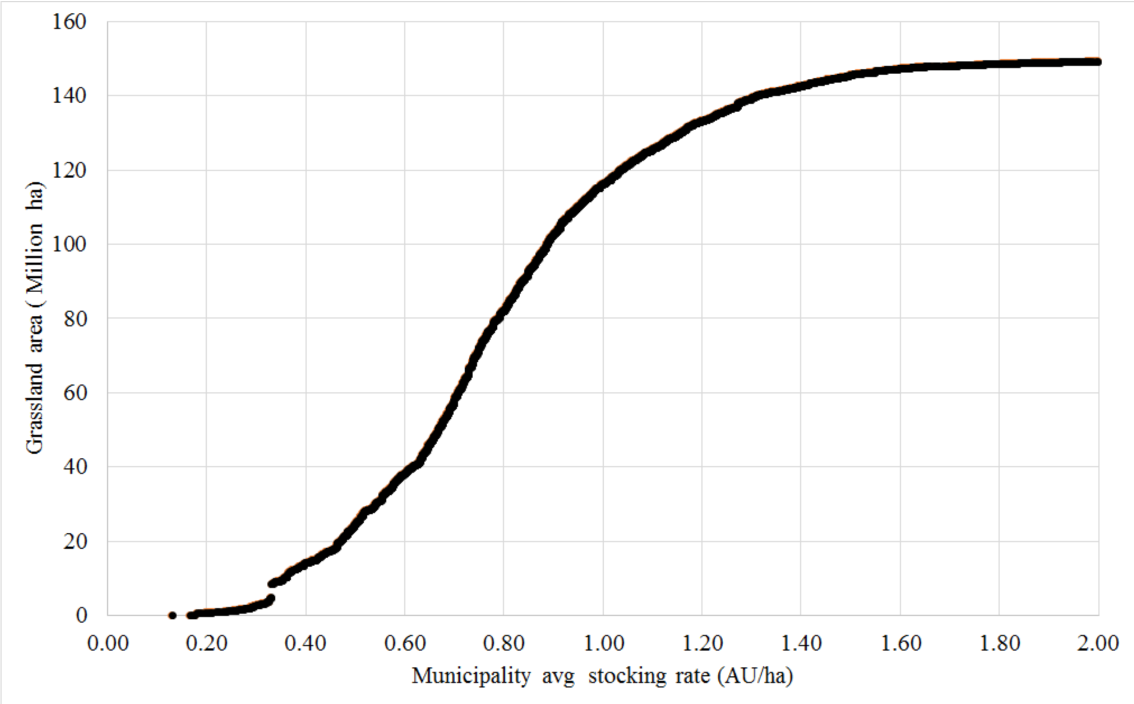

Figure 5. Accumulated grassland area in municipalities with cattle production ordered by average stocking rates (source: IBGE, 2013).

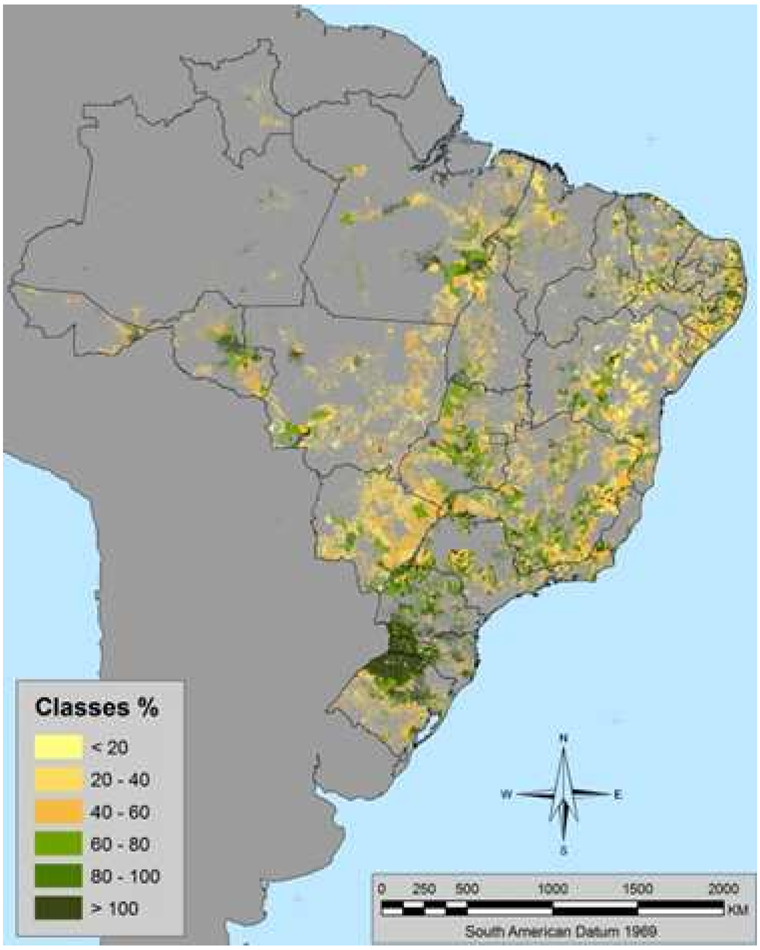

Figure 6. Ratio of actual/potential pasture stocking rates in Brazil. Potential stocking rates were calculated with municipality climate data for non-supplemented animals.