Intensification of cattle ranching production systems: socioeconomic and environmental synergies and risks in Brazil

Agnieszka E. Latawiec[1,2,3], Bernardo B.N. Strassburg[1,4], Judson F. Valentim[5,6], Fabio Ramos[7], Helena N. Alves-Pinto[1]

[1] *International Institute for Sustainability, Estrada Dona Castorina 124, 22460-320, Rio de Janeiro, Brazil*

2 *Opole University of Technology, Department of Production Engineering and Logistics, Luboszycka 5, 45-036 Opole, Poland*

[3] *University of East Anglia, School of Environmental Science, Norwich, NR4 7TJ, United Kingdom*

[4] *Department of Geography and the Environment, Pontificia Universidade Catolica, 22453-900, Rio de Janeiro, Brazil*

[5] *Brazilian Corporation for Agricultural Research (Embrapa Acre), Caixa Postal 321, CEP 69900-970, Rio Branco, AC, Brazil*

[6] *Sustainability Science Program and Energy Technology Innovation Policy research group, Kennedy School of Government, Harvard University, 79 John F. Kennedy Street, Cambridge, MA 02138, USA*

[7] *Agrosuisse, Rua Visconde de Pirajá 414, Rio de Janeiro, 22410-002, Brazil*

Corresponding author: Bernardo Strassburg Email: b.strassburg@iis-rio.org

Short title: Pasture intensification: synergies and risks

Abstract

Intensification of Brazilian cattle ranching systems has attracted both national and international attention due to its direct relation with Amazon deforestation on one side and increasing demand of global population for meat on the other. Since Brazilian cattle ranching is predominantly pasture-based, here we focus particularly on pasture management. We synthesize most recurrent opportunities and risks associated with pasture intensification that are brought up within scientific and political dialogues, and discuss them within the Brazilian context. We discuss that sustainable intensification of pasturelands in Brazil is a viable way to reach both increased agricultural output while simultaneously sparing land for nature. As in Brazil environmental degradation is often associated with low-yield extensive systems, by adopting practices like rotational grazing, incorporation of legumes and integrated crop-livestock-forestry systems it is possible to obtain higher yields, higher economic outcomes while both reversing degradation and protecting the environment. Technical assistance is however essential, particularly for small- and medium-scale farmers. Sound complementary policies and good governance must accompany these measures so that a "rebound effect" does not lead to increased deforestation, and other adverse social and environmental impacts are avoided or minimized. It is also important that animal welfare is not compromised. Although the discussion is presented with respect to Brazil, in an increasingly interconnected world, decisions in one region will have wider economic and political ramifications. Further, some aspects of the discussion presented here may be relevant to other developed and developing countries.

Keywords Pasture intensification, Trade-offs, Brazil, Sustainability, Land-use change

Implications

The results presented here synthesize the most relevant environmental aspects of intensification of cattle ranching systems with focus on increasing productivity of the Brazilian pasturelands. Projected agriculture demand may lead to deforestation. Sustainable intensification of cattle production systems is a viable way to achieve increased yield and protection of natural resources, yet there are still many challenges associated with practical implementation at scale. Here we discuss the environmental synergies and risks associated with sustainable pasture intensification. The discussion might have relevant considerations for other developing countries.

Introduction

Agricultural intensification - increasing agricultural inputs to improve yields per unit of area has been highlighted as one of the means to reach global food security and as a potential strategy for reducing agricultural expansion into natural ecosystems (Tilman *et al*., 2002, Phalan *et al*., 2011, Mueller *et al*., 2012, Strassburg *et al*., 2010, Strassburg *et al*., 2012a, Strassburg *et al*., 2013). Over the last years, intensification has been brought into international scientific and political discourse as a response to steadily increasing demand for agricultural products (Barretto *et al*., 2013). Across the tropics, agricultural intensification is often spurred by governmental policies (Van Vliet *et al*., 2012) and has also become central to policy formulation of Reducing Emissions from Deforestation and Forest Degradation (REDD+), a climate mitigation strategy included in the United Nations Framework Convention on Climate Change (UNFCCC). For example, countries including the Democratic Republic of Congo, Nepal, Mozambique, Madagascar or Indonesia are adopting agriculture intensification policies to discourage “slash-and-burn” agriculture and seek to “increase productivity and sedentary lifestyle” of 50% of its subsistence farmers by 2030 to reduce pressures on forests (World Bank, 2012).

Pasturelands have become a focal point of both development and conservation experts worldwide both due to their extent and forecasted increasing meat consumption in the coming decades (Tilman *et al*., 2002, Bowman *et al*., 2012, Barretto *et al*., 2013, Strassburg *et al*., in press). Beef cattle production systems are developed in all the 27 Brazilian states and are highly diversified as a result of historic social, economic and environmental factors. Cattle breed is predominantly *Bos indicus* (mainly Nelore, Gir and Guzera breeds) in the Southeast, Centre-West, Northeast and North regions, with *Bos taurus* (mainly Hereford, Aberdeen Angus, Simmental and Charolais) predominating in the South region. These systems may develop the entire cycle (cow-calf, rearing and finishing phases), rearing and finishing or only finishing phase, making use of cultivated and natural pastures, associated or not with supplementary feeding and, in most cases partial, confinement (Cezar *et al*., 2005).

Intensive pasture base cattle production systems in Brazil are characterized by the utilization of improved high yielding high quality grasses and legume cultivars, fertilization management of pastures under rational stocking to increase forage harvest efficiency, improved animal breeding techniques, and application best production practices in animal nutrition. In 2006, average pasture stocking rate in Brazil was 0.91 animal units (1 AU equivalent to 450 kg of animal live weight) per hectare. Pasture stocking rates, both in native and cultivated areas converted from the different biomes ranged from the lowest level (0.81 AU/ha) in the semi-arid Northeast region, to intermediate levels in the in the Middle-West (0.91 AU/ha), Southeast (0.94 AU/ha) and North (0.97 AU/ha) regions and to the highest level (1.18 AU/ha) in the South region of Brazil. However, within the Legal Amazon region, pastures productivity varied from as low as 0.51 AU/ha in Amazonas and Roraima states to as high as 1.77 AU/ha in Acre and 1.76 AU/ha in Rondonia states (Valentim and Andrade, 2009).

Brazilian pasturelands, due to their total area (approximately 159 million hectares in comparison with 60 million hectares for crops) and low productivity (Valentim and Andrade, 2009) given international standards have been suggested as a promising resource in reconciling agricultural expansion with the reduction of the environmental pressure of agriculture in Brazil (Bowman *et al*., 2012, Bustamante *et al*., 2012, Martha Jr. *et al*., 2012). Indeed, studies carried out at the regional scale suggest that cropland intensification and expansion during the 2000s displaced cattle ranching to the frontier region causing deforestation (Barona *et al*., 2010). Pasturelands occupy approximately 85% of cleared areas (IBGE, 2006) and herd growth between 2000 and 2005 has a 40% correlation with deforestation (Soares-Filho *et al*., 2010). Cattle ranching in the Amazon explains more than 50% of deforestation variation (Rivero *et al*., 2009).

In the last decade, there was however a decoupling of agriculture and cattle ranching from deforestation in the Legal Brazilian Amazon. Owning primarily to the increase in governance by the federal and state environmental agencies, there was a 77% reduction in the annual deforestation rate in the Brazilian Amazon from 27,772 km^2 in 2004 to 6,418 km2 in 2011 (INPE, 2013) while at the same period the cattle herd of the region grew 8.7%, from 71.6 to 77.8 million heads (IBGE, 2013). Between 2010 and 2019 milk and beef production are expected to grow 1.9% and 2.1% per year, respectively, fuelled by both increasing domestic and foreign markets mainly from emerging economies (MAPA/AGE, 2010). Land use estimates and Amazon deforestation models consider not only a global approach (based mainly on global driving factors such as economic growth and demand) but are also based on the dynamics of local and regional context, such as distance to roads and infrastructure (Dalla-Noraa *et al*., 2014). Future trends for land use will depend on the dynamics of agricultural frontiers as well as land speculation.

The rate of land-use intensification will determine the need for additional agricultural land to support this growth. Current productivity of main agriculture commodities (soybean, corn) and beef and dairy cattle in Brazil in some regions are below the potential productivity using available technologies (Mueller *et al*., 2012). Recent research suggests that Brazil already has enough land under agricultural production in order to meet unprecedented increase in future demand for agricultural products, without deforestation and sparing land for nature until at least 2040, if adequate policies are put in place (Strassburg *et al*., in press).

In this paper we present a scientific debate on environmental and socioeconomic synergies and risks associated with intensification of cattle ranching production systems in Brazil. This involves increasing productivity of the natural productive base (soil, water, temperature and sunlight) by increasing productivity of human, manufactured and knowledge capital, thus both increasing productivity per area and reducing land area needed to supply the future demand of livestock products. We conducted a content analysis (e.g. Bryman, 2008), which involved identifying and recording the most common factors related to opportunities for and constraints to intensification of cattle ranching production systems. These are summarized in Table 1. It was not our goal to promote or criticize specific systems or intensification *per se*, but rather to highlight opportunities and risks associated with intensification of pasturelands in Brazil given current evidence.

Pasture intensification and the conservation of natural areas - "The big picture"

The overarching connection between cattle ranching intensification and environmental conservation in Brazil is the potential of the former to reduce pressure on natural environments, thus contributing to conserve the natural capital stocks and the local and global services they provide. Because agricultural intensification increases agricultural per-area yields rather than expands cultivation, it carries the potential for reducing agriculture encroachment into natural areas, an effect described as ´land sparing´ (Phalan *et al*., 2011). Martha Jr. *et al*. (2012) demonstrate that while beef production increased mainly though pasture expansion between 1950-1975, during 1950-2006 productivity gains explained 79% of the growth in beef production in Brazil. Without this land-sparing effect, an additional pasture area that is 25% higher than the entire Amazon biome in Brazil would be required to meet 2006 levels of beef production (Martha Jr. *et al*., 2012). The authors also show that regionally land-sparing effects vary from 8 to 73 million hectares in the 1996-2006 period, for Southern region and North region, respectively (Martha Jr. *et al*., 2012). Barretto *et al*. (2013) have demonstrated that pasture intensification has historically correlated with a reduction in pasture area. They show that in southern and southeastern Brazil (in agriculturally consolidated areas), land-use intensification (of both on cropland and pastures) coincided with either contraction of both cropland and pasture areas, or cropland expansion at the expense of pastures, both cases resulting in farmland stability or contraction.

Current productivity of Brazilian cultivated pasturelands is 32-34% of its potential. Increasing productivity of these areas to 49-52% of their potential would meet all demands until at least 2040, without further conversion of natural ecosystems (Strassburg *et al*., in press). Economic, environmental, legal and social factors will have different weights in determining where, to what extent, and at what speed intensification takes place in the different Brazilian regions. In the Brazilian Pantanal, for instance, the use of best production practices in cattle production systems, such as rotational grazing, increased forage production and grazing efficiency, and allowed increase in pasture carrying capacity by two to six fold (Eaton *et al*., 2011). Gains in animal weight and increases in pregnancy rates (15% and 22%, respectively) were also observed (Eaton *et al*., 2011). In the Acre state (Amazon biome), improved grass-legume pastures of Massaigrass-forage peanut managed under rotational stocking presented average carrying capacity of 3.6 AU/ha during the rainy season and 1.8 AU/ha during the dry season (Andrade *et al*., 2006). In the same environmental conditions, pastures of Marandugrass mixed with forage peanut and tropical kudzu under rotational stocking had an average annual carrying capacity of 2.5 AU/ha (3.1 AU/ha and 1.8 AU/ha being the averages for the rainy season and the dry season, respectively) (Andrade *et al*., 2012).

Intensification in frontier regions, however, may itself induce agriculture expansion by making agriculture more attractive, thus causing a ´rebound´ (Lambin and Meyfroidt, 2011), a classic economic effect where increased productivity leads to an increase in production and the demand for inputs, in this case land. Agricultural intensification is also often associated with in-migration, road construction, and increased economic activity that may cause deforestation (DeFries *et al.,* 2010). Indeed, in the past, land-use intensification coincided with expansion of agricultural lands in agricultural frontier areas in Brazil, such as in the Amazon region (Barretto *et al*., 2013). Moreover, although vast areas in the Amazon may be only marginally profitable if ranched extensively, they are still profitable, especially when we considering land speculation (Bowman *et al*., 2013). Producers will likely intensify only when the marginal return of deforestation and ranching extensively is lower than that of intensifying (e.g. Cattaneo, 2008). Kaimowitz and Angelsen (2008) highlight that if intensification proves profitable, it will possibly increase rather than decrease the demand for land for cattle production in Brazil. Barretto *et al* (2013) concluded therefore that technological improvements create incentives for expansion in agricultural frontier areas and farmers are likely to reduce their managed acreage only if land becomes a scarce resource or if environmental governance is effectively enforced penalizing those who practice illegal deforestation. Therefore to effectively address land-use change in frontier regions, policies targeting agricultural intensification, such as the promotion of low-cost credit programs and use of more advanced technologies, have to be combined with investment in policies and institutions aiming at curbing extensive ranching and deforestation (Strassburg *et al.*, 2012b).

A link between production growth in consolidated regions and expansion of the agricultural frontier in Brazil has been discussed extensively as an example of displacement or indirect land-use change (Lapola *et al*., 2010). This can reinforce the potential land-sparing effect form increased cattle ranching productivity, as it may mitigate a potential leakage from the expansion of agriculture in other areas (Strassburg *et al.*, 2012a).

An associated debate relates to a supposed dichotomy between land sparing and land sharing. In short, land sparing suggests saving biodiversity through the intensification of agricultural lands, which would lead to lower demand for new land clearance and consequently larger areas dedicated to nature conservation (Phalan *et al*., 2011). Land sharing, on the other, hand proposes a concept of coexistence of biodiversity and agriculture on the same area through wildlife-friendly farming (Perfecto and Vandermeer, 2010). It is not our intension to discuss these approaches here and we believe understanding which approach is more beneficial is highly context-specific and that both have a role to play in biodiversity conservation (Latawiec *et al*., 2014). A shortage of relevant quantitative data still hampers further progress on this debate (Garnett *et al., 2013*) and more research could be of particular relevance. In Brazil, although land sparing may not be the only strategy for every local context, there seems to be a broad consensus on its potential for reconciling agriculture expansion and natural conservation, and improved pasturelands are the central element to this debate.

Factors related to sustainability of intensification

Interventions to increase productivity

The inclusion of ´Good Agricultural Practices´ in current agricultural areas seeks both to increase production and maximize the benefit of production with the preservation and conservation of natural resources.Intensification technologies and strategies include supplementary feeding and the use of improved animal grasses and grass-legume pasture–based cattle production systems. In that respect, pastures are sown with improved grass and legume cultivars adapted to the specific environmental conditions, becoming more resistant to pests and diseases,thus producing more feed of higher nutritional value, and increasing pasture carrying capacity (Martha Jr. *et al*., 2012).

The introduction of well managed intensive rotational grazing, in which the livestock is shifted systematically at appropriate intervals to different subunits of fenced subdivisions, enables control over the height of fodder, which improves pasture-use efficiency and persistence, prevents overgrazing and erosion from both loss of fertility and compaction (Supplementary Figure S1). These systems are a central strategy being promoted in Brazil to increase carrying capacity (Andrade *et al*.,2006, Andrade *et al*., 2012, Martha Jr. *et al*., 2012). In the Brazilian Amazon, the municipalities with above-average usage of rotational grazing are characterized with approximately13% higher agricultural outcomes than the municipalities with below-average usage (CPI, 2013). Eaton *et al*. (2011) showed in their 17-month study that mean cattle weights and pregnancy rates were 15% and 22% higher, respectively, for the herd using the rotational system in the Brazilian Pantanal. The potential stocking rates of the rotational systems were two to six times higher than rates typical for continuously grazed areas(Eaton *et al*., 2011). Appropriate herd size and grazed area of rotating pastures (the number of days of paddock use varies depending on the forage, the biome, the season and the soil condition), and control of machine movements on the farmland enables adequate forage regrowth (Embrapa, 2011a).

Integrated crop-livestock and crop-livestock-forestry production systems, the adoption of best soil conserving production practices, such as soil covering to diminish erosion, are other strategies to increase cattle ranching productivity (Supplementary Figure S2; Cezar *et al*., 2005; Euclides *et al*., 2008; Pacheco *et al*., 2013). Complementary to increase the productivity of pasturelands are the efforts to improve herd productivity, such as using improved animal breeds (improved zebu breeds, *Bos indicus*) and its crossbreeding with European breeds using artificial insemination, which increases animal performance and beef and dairy productivity (Ferraz and Felicio, 2010). Indeed, studies conducted in Africa showed that artificial insemination and genetic improvement of cattle breeds led to gains of 60 to 300% in milk productivity (McDermott *et al*., 2010).

Soil compaction

Although a number of studies from tropical countries demonstrated advantages of adopting more intensive pasture management, if it is not performed correctly it may lead to increased soil compaction from trampling (Martinez and Zinck, 2004) and ultimately loss in productivity. Compaction of the topsoil resulting from the pressure exerted by the hooves of increased number of livestock per unit area has been shown to negatively impact soil physical conditions: increasing bulk density and penetration resistance, decreasing soil porosity and infiltration rates. This, in turn, decreases soil fertility through reduced nutrient recycling and mineralization, decreasing storage and supply of water, reducing activities of micro-organisms, impeding root growth and promoting erosion, impacts being most prominent in areas where animals congregate, for instance around field gateways and along fence lines (McDowell, 2008).

For example, studies of Donkor *et al*. (2002) demonstrated effects of different grazing intensities on surface runoff leading to greater losses of nutrients and sediment, soil loss and infiltration. Fine textured soils (clay rich) are more susceptible to trampling effects than coarse-textured soils. Increased soil bulk density and consequent impedance to root penetration and a reduction in aeration may negatively affect legumes productivity and growth, and thus nitrogen fixation in pasture (see section below). Because soil moisture is critical factor determining soil compaction, compression of a saturated soil by squeezing out water may lead to adverse consequences of soil consolidation (Drewry, 2006), thus grazing on wet soils should be prevented. In case of Brazil this is especially valid for widespread clay-rich acrisols (argissolos). Another strategy to combat possible compaction is general reestablishment of the pasture every 10 years with deep sub-surface tillage (in areas with no restriction for mechanization). Moreover, in well-managed mixed-systems, soil compaction can be prevented since forages may act as a buffer, dissipating part of the energy from cattle intensification. Further, the soil covered with vegetation (as opposed to bare soil) is more structured, and more resistant to the impact (Junior *et al*., 2009). Healthy and well-managed pastures are more productive and contain more organic matter than degraded pastures. Higher contents of soil organic matter in well-managed pastures contribute to soil aggregation and its physical protection (Fonte *et al*., 2013).

Nutrients cycling

The use of forage legumes able to establish symbiotic relations with soil bacteria of the genus *Rhizobium* and fix nitrogen from the air to supply it to the plants was popularized in the first half of the 20th century as a way to benefit livestock production in the tropics (Shelton *et al*., 2005). In general, cultivated tropical pasture ecosystems present low plant biodiversity and consist mainly of one grass species (Dias Filho and Ferreira, 2008). In Brazil up to 40 million hectares of pastures are planted with *Brachiaria brizanhta* cultivar Marandu (FAO, 2013), followed by over 11 million hectares with *Panicum Maximum,* introduced from Africa (Jank *et al*., 2005). Tropical grasses, having lower nutritional value than the temperate species, particularly benefit from the introduction of legumes that increase low nitrogen availability predominant in tropical soils and increase protein content of the ruminants diet (Shelton *et al*., 2005). The use of legumes may diminish or entirely replace the need for use of synthetic nitrogen fertilizer and thus not only increase productivity but also reduce production costs and environmental contamination, as it avoids the peaks of high concentrations of nitrogen in soil and leaching, which normally follows applications of fertilizers (Supplementary Figure S1). For example, in the Brazilian Amazon, in the last 25 years farmers established grass-legume pastures with tropical kudzu (*Pueraria phaseoloides*) which was present in more than 30% of the pasture area (420 thousand hectares) in more than 5,400 properties of Acre in 2005, indicating prolonged fertilization effect (Valentim and Andrade, 2005). Forage peanut (*Arachis pintoi*) cultivar Belmonte was also established in 138 thousand hectares (Valentim and Andrade, 2005) resulting in economic benefits of US$ 38.5 million to Acre farmers in 2012. In addition, pastures at the national level were enriched with S*tylosanthes* cultivar Campo Grande. The key factors for the successful adoption of legumes in Acre were: a) availability of technology appropriated to the farmer's needs, b) the strategic partnership between researchers, extension agents, farmers and public policy makers in promoting the economic and environmental benefits of the use of grass-legumes pastures among beef and dairy cattle farmers , c) the critical economic situation of farmers facing the syndrome of death of *Brachiaria brizanhta* cultivar Marandu and the growing environmental pressures from governmental agencies to restrict deforestation, d) access of farmers to the market and the substantial economic benefits from the adoption of legumes (Valentim and Andrade2005). In addition, a cow produces in average 70Kg of manure per day, which may substitute 128 kg of synthetic nitrogen. Nutrients in such system can support crop cycles over long terms, and in Africa farms with mixed systems presented positive nutrient balances (Eisler *et al*., 2014)

Intensification, however, may contribute to excess nutrient runoff, especially when applied without appropriate training (McDowell, 2008Herrero *et al*., 2010). Apart from leached nitrogen, uncontrolled application of phosphorus, commonly used to improve pasture fertility, can risk diffuse pollution of surface waters. Because concentrations of phosphorus in unpolluted waters are generally low, relatively small discharge can cause eutrophication, especially if heavy rain falls soon after the application of fertilizer. Drainage should therefore be adopted to prevent manure lagoons and possible release to surface and ground waters of high levels of hydrogen sulphide and other toxic gases, , nutrients, toxins and pathogens. Reducing the length of the grazing season is another option to mitigate nitrogen losses while careful application of relevant gradual-release source can prevent adverse effects of phosphate application.

Pest control

More intensive systems may use higher quantities of herbicides, fungicides insecticides (to control ecto- and endo-parasites in animals) due to the increase in animal numbers. It will ultimately depend on the level of training and familiarity with the best practices of the farmer that will impact possible pollution from pesticide use. Some of the best practices include the use chemicals with low environmental impact (not soluble and with risk of water contamination). Taxing fertilizers and pesticides, and removing subsidies for these inputs could also further discourage excessive use (Tilman *et al.*, 2002).

More intensive systems that use pesticides in excess may also reduce the presence of pollinators. On the other hand, intensive mixed systems that include forage legumes and trees (for shade or as a cash crop) in integrated crop-livestock-forestry systems diversify the pasture ecosystem and attract pollinators, increasing their numbers.

Well managed and more diversified cultivated pastures improve ecosystem's resilience in general (Andrade *et al*., 2011), leading to low weed occurrence due to high competition with well-established forage species (usually multiple species, which further contributes to minimize occurrence of weeds). Also, higher stock densities contribute to increased browsing of broadleaf weeds, while weeds that are not used as livestock feed (for example thistles) are exposed to more physical damage by trampling. Therefore in many improved (well-managed) intensive systems there is lower usage of herbicides and when extensive weed cover occurs, the system is managed with mechanical means or the pasture is re-established with new seeds. Good practice also includes a routine yearly pasture-maintenance which includes trimming of possible weeds while every ten years it is assumed the pasture is tilled for both weed and compaction control.

Water resources

Agriculture is the largest consumer of freshwater accounting for 70% of freshwater withdrawals from rivers, lakes and aquifers – up to more than 90% in some developing countries (FAOstat). Animal production p accounts for 29% of the total water footprint of the agricultural sector in the world and one-third of the global water footprint of the animal production is related to beef cattle (Mekonnen and Hoekstra, 2012). In Brazil, the average water consumed is 16,691 liters per kg of beef. The use of green water (rainwater) in the predominantly pasture-based grazing systems in Brazil is approximately 2.4 times higher than in industrial systems due to lower conversion efficiency of feed. However, the use of grey water (required to assimilate pollution) is approximately three times lower than in industrial system (Mekonnen and Hoekstra, 2011), since cattle are more dispersed in the Brazilian pasture-based grazing systems. Intensification of cattle production systems with the use of improved grass and grass-legume pastures, integrated-crop-livestock-forestry systems and adoption of good production practices have the potential to increase productivity of animal products per area while reducing water footprint per unit of animal product. On the other hand, there are cases reported where deintensification was necessary due to overuse of water resources (Herrero *et al*., 2010).

Although agricultural intensification may lead to increase in absolute volume of water withdrawals per farm, the efficiency of water use may improve. For example, by maintaining pasture in good condition with high levels of organic matter and preventing compaction, the water holding capacity increases, which prevents wilting and excess runoff of nutrients and pesticides. In addition, well managed pasturelands promote protection of riparian areas. In Brazil riparian areas are protected by ´Permanent Protection Areas´ (APPs), a strip of land (size dependent on river width and farm size) should remain with native vegetation. In reality, however, not all farms meet APPs requirements.

Good pasture management also prevents water pollution from infiltrating N, P, pathogens and urine leaching. The consequences of animal grazing on riparian areas may otherwise involve: trampling and overgrazing of stream banks, loss of stream bank stability, reducing resistance by removing protective vegetation and loosening soil and soil runoff, soil erosion, declining water quality due to siltation and pollution, affecting aquatic and riparian wildlife (Belsky, 1999) with detrimental effects increasing with increasing inclination. The effects of agrochemicals such as pesticides if used in excess on groundwater and streamwater are largely unknown but potentially significant (Brando *et al*., 2013). In semi-arid regions of Brazil (North-East), intensification may impact on water supply, less frequent problem in the Central and West regions, so far. Good management and the enforcement of existing legislation should protect this key natural resource.

Agroforestry

Mixed agricultural systems, including agrosilvopastoral systems (crops, forestry and cattle) can increase agricultural sustainability and productivity (Supplementary Figure S2). It has been demonstrated that silvopastoral systems, where trees are included into pastures, can increase meat and milk quality and quantity, and provide shadow for cows, improving animal welfare (Porfírio-da-Silva, 2004, Embrapa, 2011b, Paciullo *et al.,* 2014). For instance, Paciullo and partners (2014) showed that milk yield was higher in agrosilvipastoral systems when compared to open pastures in about 1 Kg/cow per day. Transition of extensive pastoralism to agroforestry may also result in a range of socioeconomic benefits (Tilman *et al*., 2002), such as risk reduction due to supply of alternative market products and higher incomes. Agroforestry has been shown to enhance rural livelihoods by providing firewood and preventing and reversing soil degradation, increasing biodiversity and provision of environmental services by increasing carbon storage (Tilman *et al*., 2002, German *et al.*, 2006). Trees and shrubs planted in strips surrounding pasturelands also decrease soil erosion and act as buffer zones decreasing nutrients and silt loading (sedimentation) of waters (Tilman *et al*., 2002). Buffer strips may also be managed to reduce inputs of weeds and other agricultural pests.

On the other hand, transition to agroforestry, if not properly planned and executed, may result in lower yields and income. Although large-scale farmers may be able to forego short-term returns, this is more problematic for small and medium ranchers. Although shade from trees provides benefits for the cattle reducing the risk of heat stress, animals congregate heavily in the shade which may lead to nutrient loading and runoff, uneven grazing, soil compaction and soil erosion. In addition, water-demanding trees may negatively impact the farms, which rely heavily on springs and rivers for drinking and irrigation (German *et al*., 2006).

Socioeconomic impacts

Because transformation into more intensive systems may result in higher animal and land productivity it may increase profitability of the production chain. According Embrapa´s annual economic, environmental and social assessment of 2012, the adoption of forage grass cultivars in 39.8 million hectares and forage legumes (*Stylosanthes* Campo Grande and *Arachis pintoi* cv. Belmonte) in 1.84 million hectares of improved grass and grass-legumes pastures resulted in net annual benefit of US$ 3.45 billion (US$ 1.00 = R$ 2,349) to farmers in Brazil in 2012 (Embrapa, 2013). Similarly, converting pasturelands of low productivity into silvopasture can increase and diversify the output per unit of area (German *et al*., 2006). Experiments in selected farms in Mato Grosso stateshowed that intensification (in 740 ha) resulted in an increase in 62% of the farm revenue and a 20% weight gain, as well as reduced time before slaughter (CEPEA/Esalq, 2012). . Further, if premiums are added for farmers committed to complying with environmental and social guidelines of sustainable production and meeting quality standards, their products may also benefit from value added. Payment for Environmental Services (PES) schemes, including REDD+ (Strassburg *et al*., 2009), would benefit farmers that provide ecosystem services such as avoided emissions, carbon sequestration or other, more local ecosystem services.

On the other hand, initial studies discussed that intensification may not be the best strategy to reduce deforestation: the cost-benefits of intensifying are lower than the one of deforesting due to tenure gains. Historically, land occupation in Brazil has been strongly correlated to land tenure, which may compensate the positive benefits from intensification (Fearnside, 2002). Further, there are concerns that if cattle ranching intensification proves profitable, it will increase rather than decrease the land demand for cattle production in Brazil ("rebound effect", see section above). This could severely impact socioeconomic wellbeing by reducing the provision of local and global ecosystem services. Some policy option to mitigate this risk include: taxes and removal of subsidies for unsustainable practices, implementation of new regulations or enforcement of existing (such as territorial planning through Brazil’s economic and ecological zoning), incorporating landowners in any process of technological improvement, monitoring, payments to farmers (either as incentives or as PES) or consumer incentives such as pricing and labeling each type of livestock product to reflect the true total costs of its production (Tilman *et al*., 2002). For instance, the Brazilian National Law No. 12.651 from May 25th, 2012 (referred hereafter as the 'Forest Code') is a national environmental legislation for the protection of forests. Landowners have to maintain a minimum percentage of forested areas inside their properties: 80% of their total land area in the Amazon region and 35% in the *Cerrado* region and the natural vegetation surrounding water bodies and other special areas such as mountaintops

Phleps *et al*. (2013) showed that as productivity increases future agricultural land rents will also increase, which may escalate future conservation costs. Therefore, if conservation incentives fail to match future agricultural rents, particularly in a landscape characterized by intensive agriculture, conservation could face local resistance and conflict, potentially leading to deforestation (Phleps *et al*., 2013). In addition, if conservation reduces land available for farming, agricultural rents may further increase, compounded with increasing commodity prices and economic globalization (Lambin and Meyfroidt, 2011). In order to mitigate future deforestation, conservation incentives need therefore to remain competitive against rising agricultural land rents (Phleps *et al*., 2013).

Transition to improved, more intensive cattle farming requires not only initial financial investment (for fencing, soil enhancers, machinery and additional labour) but also training, market support, access to roads and relevant policy. Different mechanisms have been developed in order to support the development of these practices (Alves-Pinto *et al*., 2013) and various credit lines, aim to support agricultural activities towards better-managed systems.

Small farmers usually do not have the necessary funds for developing more intensive agricultural practices (McDermott et al., 2010). Yet, in a recent study based on a series of Focus Groups and anonymous questionnaire, the cattle ranching producers from the Amazon region (municipality of Alta Floresta in Mato Grosso state), indeed both small and large scale farmers, pointed that the most important difficulties associated with intensification of cattle ranching are their financial problems (insufficient funds) and difficulties to get the credit, such as bureaucracy (Latawiec *et al*., unpublished data). Competition for skilled worker and technical assistance were also listed as the most difficult bottle necks. Critical is also the capacity of farmers to detect, learn, and adapt to change within complex intensified systems. In particular, a significant challenge is the training of the personnel from different sectors of the beef supply chain, including those who deal directly with cattle, data collection and health management and also those responsible for the property administration, slaughterhouse companies, distribution and handling and preparation of intermediate and final products (McDermott *et al*., 2010). Transition to more intensive systems may also result in loss of traditional agriculture and way of farming (such as slush and burn) and some knowledge can also be lost, although the sustainability of some types of this ´traditional agriculture´ can be called into question. Intensification of pasturelands might lead to job gains or losses depending on the labour-intensity of the new techniques. Due to refinement and increase complexity of pasture management is it possible that the system will require more workers, and thus create new jobs. It is possible, however, that aggregate jobs per unit of output (e.g. tons of beef) might decrease due to higher efficiency. Mechanization might lead to a reduction in jobs in the rural sector but increased jobs in urban areas in sectors directly and indirectly related to the production of machinery. Mixed cropping activities may diversify their production guaranteeing better resilience to market variation and demand factors. Further, studies showed that women increased their participation along the supply chain with intensification (White *et a*l., 2013). On the other hand, increased production may raise the importance of formal markets and strengthen the vertical chains, making it more difficult for small producers to participate in the supply chain (McDermott *et al*., 2010). In this context, understanding winners and losers and the social aspects of adoption of more intensive systems is critical (Briske *et al*., 2011).

Animal welfare

In Brazil, the vast majority of cattle production takes place in pasturelands and considerations of intensification means transformation to semi-intensive or semi-extensive rather than to truly intensive confinement-based system (Bowman *et al*., 2012). Improper, low-productive pasture management provides insufficient feed, while implementing more intensive better managed systems ensures animals nutritional balance, provides clean water and supply of mineral salt, concomitantly improving the immune system. This not only improves animal health but also results in better productivity, improving fertility and body mass. Moreover, although high-density animal production can increase livestock disease incidence, including the emergence of new, often antibiotic resistant diseases (Tilman *et al.,* 2002), extensive and badly managed systems may also lead to diseases. If intensification leads to better management it can improve animal health though vaccination and control of endo- and ecto-parasites through rational application of antibiotics, when necessary. Appropriately stocked and managed grassland–ruminant ecosystems that employ a wider ethical framework can be sustainable way for both producing high-quality protein and providing improved standards of animal welfare with minimized environmental impacts.

Climate change mitigation

Cattle ranching is directly or indirectly responsible for approximately half of Brazilian emissions in the last decade (Bustamante *et al.*, 2012). The largest fraction of emissions related to cattle is associated with deforestation, with enteric emissions contributing about 25% of the total emissions and pasture burning being a minor fraction (Bustamante *et al.*, 2012). On the one hand, high level of emissions from cattle-ranching make it the sector with the highest mitigation potential of the Brazilian economy.

Cattle ranching intensification can lead to GHG mitigation through two major routes. The first one is via the land-sparing effect, when intensification of current lands translates into reduced deforestation. Also the conservation of natural environments could lead to more stable and resilient food systems, important characteristics in the face of climate change. The other route is related to local mitigation per unit of production. Although intensification might increase emissions at farm level, Barioni *et al.* (2007) demonstrated that total emissions per animal or per production unit (e.g. kg of beef) decrease in a more intensive scenario. Reduced enteric emissions (due primarily to shorter lifespan and total herd size) and increased soil carbon content are important mitigation sources. Strassburg *et al.* (in press) estimated that a land-sparing scenario due to intensification would mitigate 14.3 GtCO2 until 2040, being 12.5 from reduced deforestation and 1.8 GtCO2Eq from reduced enteric emissions due to smaller herd size and earlier slaughtering (when compared with a business-as-usual scenario). Well managed grasses sequester more carbon when compared to other uses, such as degraded systems.

On the other hand, intensification might also lead to increased emissions. If no complementary conservation measures are put in place, instead of land sparing, intensification might lead to a rebound effect, where more deforestation, and related GHG emissions, takes place. Another potential source of increased GHG emissions is related to over-fertilization of degraded pastures, which increases N_2O emissions.

Sustainable intensification of pasturelands in Brazil – Great Expectations

The conversion of natural ecosystems is perhaps the most evident human alteration of the Earth. Agricultural practices determine both the level of food production and the state of the global environment. The answer to the problem of how to achieve increased production and reduced environmental pressure is arguably simple: produce more and impact less. In reality however, achieving such a way forward represents great scientific, technical and social challenges due to context-specific trade-offs among competing (real or perceived) socioeconomic and environmental goals.

Owing to both governmental programs and non-governmentally led extension initiatives it is likely that in Brazil the increase of meat production will arise principally through a combination of intensification of productivity on existing pastures and reclamation of degraded land. It was not the goal of this paper to promote pasture intensification nor we insist this is the only way to achieve both food security and environmental benefits. We do argue, however, that in certain circumstances it is a viable option to spare nature, diminish environmental degradation and improve cattle ranching efficiency and productivity in Brazil. Although intensification has potential to spare land and diminish negative environmental pressures it is however not a universal panacea for addressing all impacts associated with the land conversion in Brazil. Its positive and negative consequences will largely be dependent on the context (soil fertility, access to infrastructure, humidity, transaction costs, among others). In order to increase meat production and decrease new clearing of forest for ranching, a combination of policies that discourage the clearing and utilization of land to establish land tenure and policies that promote environmentally and economically sustainable production will need to be in place. It is critical to take into consideration aspects discussed here, such as socioeconomic and biodiversity benefits, animal welfare, human nutrition and sustainable development in rural economies. Moreover, intensification is not an all-encompassing solution but is a part of multipronged strategy to achieving sustainable food production. Importantly, the challenge is context- and location-specific, especially where it relates to promoting sustainable development and improving rural livelihoods (Garnett *et al*., 2013).

Because of its implications for food security and global environmental issues, agricultural intensification has been widely discussed in the international arena. Large extensions of areas are occupied by extensive pasturelands in Brazil and worldwide, and intensification poses one of the greatest opportunities to mitigate adverse effects of expanding agriculture. Establishing a mechanism of economic incentives to farmers as a buffer against a rebound of deforestation in a likely scenario of extreme economic events, such as economic crises can drive towards more intensive and sustainable livestock production systems globally (Strassburg *et al.*, 2013). Combined with a landscape approach (DeFries *et al*., 2010), sustainable pastureland intensification can facilitate achieving social, economic and environmental objectives. If farmers can better perceive and be properly rewarded by the environmental benefits derived from sustainable pasture intensification, this might create a strong economic incentive for a transition from the extensive, low productivity and environmentally expensive traditional systems that still predominate in the tropics.

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