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

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Intensification of Brazilian cattle ranching systems has attracted both national and international attention due to its direct relation with Amazon deforestation on the one hand and increasing demand of the global population for meat on the other. Since Brazilian cattle ranching is predominantly pasture-based, we particularly focus on pasture management. We summarize the 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 argue that sustainable intensification of pasturelands in Brazil is a viable way to increase agricultural output while simultaneously sparing land for nature. Since environmental degradation is often associated with low-yield extensive systems in Brazil, it is possible to obtain higher yields, while reversing degradation, by adopting practices like rotational grazing, incorporation of legumes and integrated crop-livestock-forestry systems. 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. It is also important that animal welfare is not compromised. Although the discussion is presented with respect to Brazil, some aspects are relevant to other developing countries.

Keywords: pasture intensification, trade-offs, Brazil, sustainability, land-use change

Implications

This review synthesizes the most relevant environmental aspects of intensification of cattle ranching systems in Brazil. Sustainable intensification of cattle production systems is a viable way to achieve increased yield and protection of natural resources according to the land sparing paradigm. Yet there are still many challenges associated with its practical implementation. Here we discuss the environmental synergies and risks associated with this intensification; these are also relevant 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; Strassburg *et al.*, 2010; Phalan *et al.*, 2011; Mueller *et al.*, 2012; Strassburg *et al.*, 2012a and 2013). Over the last years, intensification has been brought into international scientific and political debate as a response to the steadily increasing demand for agricultural products (Barretto *et al.*, 2013). Across the tropics, agricultural intensification is often spurred on by governmental policies (Van Vliet *et al.*, 2012) and has also become central to policy formulation on Reducing Emissions from Deforestation and Forest Degradation (REDD+), a climate mitigation strategy included in the United Nations Framework Convention on Climate Change. 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 lifestyles' of 50% of its subsistence farmers by 2030 to reduce pressure on forests (World Bank, 2012).

Pasturelands have become a focal point of both development and conservation experts worldwide, due to their extent and to their potential with respect to the forecasted

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increase in meat consumption in the coming decades (Tilman *et al*., 2002; Bowman *et al*., 2012; Barretto *et al*., 2013; Strassburg *et al*., 2014a). 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 are 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 Southern region. These systems may include the entire production cycle, rearing and finishing phases, or finishing phase only; making use of cultivated and natural pastures, associated or not with supplementary feeding and partial confinement (Cezar *et al*., 2005).

Intensive pasture-based cattle production systems in Brazil are characterized by the utilization of improved high-yielding and high-quality grass and legume cultivars, fertilization of rotationally grazed pastures to increase forage harvest efficiency, and improved animal breeding and animal nutrition techniques. In 2006, the average pasture stocking rate in Brazil was 0.91 animal units (1 AU equivalent to 450 kg of animal live weight) per hectare. Stocking rates ranged from the lowest level (0.81 AU/ha) in the semi-arid Northeast region, to intermediate levels 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 of Brazil. Within the Legal Amazon region, stocking rates varied from 0.51 AU/ha in Amazonas and Roraima states to 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 (~159 million hectares *v.* 60 million hectares for crops) and low productivity (Valentim and Andrade, 2009) have been suggested as a priority for reconciling agricultural expansion with the reduction of its environmental footprint (Bowman *et al*., 2012; Bustamante *et al*., 2012; Martha *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 ~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 explains more than 50% of deforestation in the Amazon region (Rivero *et al*., 2009).

However, in the last decade, there was a decoupling of agriculture and cattle ranching from deforestation in the Legal Brazilian Amazon. Owing 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 6418 km^2 in 2011; INPE, 2013) while cattle numbers simultaneously increased by 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 domestic and foreign markets (MAPA/AGE, 2010). Land use models not only consider global driving forces but also 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 also depend on the dynamics of agricultural frontiers as well as on 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 some regions of Brazil are below their productivity potential (Mueller *et al*., 2012). Recent research suggests that Brazil would have enough land under agricultural production to meet future demand without deforestation, thus sparing land for nature until at least 2040 if adequate policies were put in place (Strassburg *et al*., 2014a).

In this paper we present the debate on environmental and socioeconomic synergies and risks associated with the intensification of cattle ranching production systems in Brazil. This involves both increasing productivity per unit area and reducing the 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.

Pasture intensification and the conservation of natural areas – 'The big picture'

Because agricultural intensification increases yields per unit area, it carries the potential for reducing agriculture encroachment into natural areas in Brazil, an effect usually called 'land sparing' (Phalan *et al*., 2011). Martha *et al*. (2012) have discussed that while beef production initially increased through pasture expansion, productivity gains explain 79% of the growth in beef Brazilian production between 1950 and 2006. Without this intensification, an additional pasture area that is 25% higher than the entire Amazon biome in Brazil would have been required to meet the 2006 beef-production level (Martha *et al*. 2012). Land-sparing effects varied from 8 to 73 million hectares in the 1996 to 2006 period, for South and North Brazil, respectively (Martha *et al*., 2012). Barretto *et al*. (2013) have demonstrated that pasture intensification historically correlates with a reduction in pasture area. In agriculturally consolidated areas of southern and southeastern Brazil, land-use intensification (of both cropland and pastures) coincided with either reduction of both cropland and pasture areas, or cropland expansion at the expense of pastures.

Current productivity of Brazilian cultivated pasturelands is 32% to 34% of its potential. Increasing productivity of these areas to 49% to 52% of their potential would meet all demands until at least 2040, without further conversion of natural ecosystems (Strassburg *et al*., 2014a). 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. For instance, in the Brazilian Pantanal, the use of best production practices in cattle production systems, such as rotational grazing, increased forage production and grazing efficiency, and allowed an increase in pasture carrying capacity by two to six-fold (Eaton *et al*., 2011). In Acre state (Amazon biome), improved grass–legume pastures of Massai grass–forage peanut managed under rotational stocking had an 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). Rotationally grazed pastures of Marandu grass mixed with forage peanut and tropical kudzu had an average annual carrying capacity of 2.5 AU/ha (Andrade *et al*., 2012), which is also higher than the state average (Valentim and Andrade, 2009).

Intensification in frontier regions, however, may itself induce agriculture expansion by making agriculture more attractive, thus causing a 'rebound effect' (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 in turn drives deforestation (DeFries and Rosenzweig, 2010). 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). Although vast areas in the Amazon may be only marginally profitable if ranched extensively, they remain profitable when considering land speculation (Bowman *et al*., 2012). Kaimowitz and Angelsen (2008) highlighted that if intensification proves profitable, it would increase the land demand for cattle production in Brazil. Barretto *et al*. (2013) concluded that technological improvements create incentives for expansion in agricultural frontier areas, and that farmers are likely to reduce farm area only if land becomes scarce or if environmental governance effectively penalizes illegal deforestation. Policies targeting agricultural intensification, such as the promotion of low-cost credit programs and use of more advanced technologies, therefore have to combine with 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 as an example of displacement or indirect land-use change (Lapola *et al*., 2010). An associated debate relates to a supposed dichotomy between land sparing and land sharing. Which approach is more beneficial is highly context-specific and both have a role to play in biodiversity conservation (Latawiec *et al*., 2014). In Brazil, although land sparing may not be the best (or only) strategy for every local context, there is a broad consensus on its potential for reconciling agriculture expansion and natural conservation; improved pasturelands are central to this debate.

Factors related to sustainability of intensification

Management practices to increase productivity

Intensification technologies and strategies include supplementary feeding and the use of improved grass and grass–legume pasture-based cattle production systems. In the latter, pastures are sown with improved grass and legume cultivars adapted to the specific environmental conditions, that is more resistant to pests and diseases, thus producing more feed of higher nutritional value, and increasing pasture carrying capacity (Martha *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 of fodder height, which improves pasture-use efficiency and persistence, prevents overgrazing, erosion and soil compaction (Supplementary Figure S1). These systems are a central strategy being promoted in Brazil to increase carrying capacity (Andrade *et al*., 2006 and 2012; Martha *et al*., 2012). In the Brazilian Amazon, the municipalities with above-average usage of rotational grazing are characterized by ~13% higher agricultural outcomes than the municipalities with below-average usage (CPI, 2013). Eaton *et al.* (2011) showed that mean cattle weights and pregnancy rates were 15% and 22% higher, respectively, for herds using the rotational system in the Brazilian Pantanal. 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 forage, biome, season and 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, and the adoption of best soil conserving production practices, such as soil covering to prevent 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 approaches to that of increasing the productivity of pasturelands are the efforts to improve beef and dairy herd productivity by for example using improved animal breeds (improved zebu breeds, *Bos indicus*) and crossbreeding with European breeds using artificial insemination (Ferraz and Felicio, 2010).

Soil compaction

Although a number of studies from tropical countries have demonstrated advantages of adopting more intensive pasture management, it may lead to increased soil compaction from trampling and ultimately to productivity losses, if management is not performed correctly (Martinez and Zinck, 2004). Compaction of the topsoil resulting from the pressure exerted by the hooves of an increased number of cattle per unit area has been shown to negatively impact soil physical conditions: increasing bulk density and penetration resistance, decreasing soil porosity and infiltration rates. Impacts are most prominent in areas where animals congregate, for instance around field gateways and along fence lines (McDowell, 2008). Donkor *et al.* (2002) have quantified the effects of grazing intensities on surface runoff and its consequences on nutrient loss, erosion 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 legume growth, and thus nitrogen fixation in pastures (see section below). Because soil moisture is critical for soil compaction, compression of a saturated soil by squeezing out water may further lead to soil consolidation (Drewry, 2006). Grazing on wet soils should thus be avoided. In Brazil this is particularly true for widespread clay-rich acrisols (argissolos). Another strategy to prevent compaction is the re-sowing of pastures every 10 years with deep sub-surface tillage (in areas with no mechanization restriction). In addition, soils covered with vegetation (as opposed to bare soils) are more resistant to trampling (Junior *et al.*, 2009). Well-managed pastures are more productive and contain more organic matter than degraded pastures, which contributes to soil aggregation and physical protection (Fonte *et al.*, 2013).

Nutrient 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 (Shelton *et al.*, 2005). In general, cultivated tropical pastures 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 (Food and Agriculture Organization of the United Nations (FAO), 2013), followed by over 11 million hectares with *Panicum Maximum* that was 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 nitrogen availability in tropical soils and can thus increase herbage mass, protein content of the ruminants diet and milk yield (Shelton *et al.*, 2005; Paciullo *et al.*, 2014). The use of legumes may diminish or entirely replace the need for synthetic nitrogen fertilizer and thus not only increase productivity but also reduce production costs and environmental footprint (e.g. nitrate leaching). In the Brazilian Amazon, farmers have established grass–legume pastures with tropical kudzu (*Pueraria phaseoloides*) which covered more than 30% of pasture area (420 000 hectares) in the Acre state in 2005 (Valentim and Andrade, 2005). Forage peanut (*Arachis pintoi*) cultivar Belmonte was also established in 138 000 hectares (Valentim and Andrade, 2005) resulting in economic benefits of US$ 38.5 million to Acre farmers in 2012. The key factors for the adoption of legumes in Acre were: (a) the availability of technology adapted to farmer's needs, (b) the strategic partnership between researchers, extension agents, farmers and public policy makers in promoting the economic and environmental benefits of using grass–legumes pastures among farmers, (c) the critical situation of farmers facing the syndrome of death of *Brachiaria brizanhta* cultivar Marandu and the growing pressure from governmental agencies to restrict deforestation, (d) the access of farmers to markets and substantial economic benefits from the adoption of legumes (Valentim and Andrade, 2005). In addition, a cow produces on average 70 kg of manure per day, which can substitute 128 kg of synthetic nitrogen and support crop cycles in the long term.

Intensification, however, may lead to excess nutrient runoff, especially when applied without appropriate training (McDowell, 2008; Herrero *et al.*, 2010). Apart from nitrogen leaching, application of phosphorus can pollute surface and ground waters if heavy rain falls soon after fertilizer application. Because concentrations of phosphorus in unpolluted waters are generally low, relatively small discharges can cause eutrophication. Drainage should therefore be adopted to prevent manure lagoons and possible release of high levels of nutrients, toxins and pathogens to surface waters. Reducing the length of the grazing season is another option to mitigate nitrogen losses, while careful application of relevant gradual-release sources can prevent adverse effects of phosphate application.

Climate change mitigation

Cattle ranching was directly or indirectly responsible for approximately half of Brazilian emissions in the last decade. The largest fraction of these emissions is associated with deforestation, with enteric emissions contributing to about 25% of total emissions and pasture burning being a minor fraction (Bustamante *et al.*, 2012). The 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 greenhouse gas (GHG) mitigation through two major routes. The first one is via the land-sparing effect, when intensification of current lands reduces deforestation. Also the conservation of natural environments could lead to more stable and resilient food systems, which are important characteristics in the context 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) have demonstrated that total emissions per animal or per production unit (e.g. kg of beef) decrease in more intensive scenarios. Reduced enteric emissions (due primarily to shorter lifespan and total herd size) and increased soil carbon content are important mitigation sources. Strassburg *et al.* (2014a) estimated that a land-sparing scenario due to intensification would mitigate 14.3 $GtCO_2$ until 2040, with 12.5 from reduced deforestation and 1.8 $GtCO_2Eq$ 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 with those in degraded systems.

However, intensification might also lead to increased emissions in case of a rebound effect, where more deforestation and related GHG emissions, take place. Another potential source of increased GHG emissions is related to over-fertilization of degraded pastures, which increases N_2O emissions.

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. Pollution from pesticide use will ultimately depend on the level of training and familiarity with the best practices of the farmer. Some of the best practices include the use of chemicals with low environmental impact (not soluble and so with less risk of water contamination). Intensive systems that use pesticides in excess may also reduce the presence of pollinators. In contrast, integrated crop–livestock–forestry that includes forage legumes and trees (for shade or as a cash crop) diversify the pasture ecosystem and benefit pollinators.

Well-managed and more diversified cultivated pastures improve ecosystem resilience (Andrade *et al.*, 2011), leading to low weed occurrence due to high competition with well-established forage species. Also, higher stocking densities contribute to increased browsing of broadleaf weeds, while weeds that are not used as livestock feed (e.g. thistles) are exposed to more physical damage by trampling. Therefore in many well-managed intensive systems there is lower usage of herbicides. Good practice also includes a routine yearly pasture-maintenance which includes trimming of possible weeds, while every 10 years it is assumed the pasture is tilled for both weed and compaction control.

Water resources

Animal production accounts for 29% of the total water footprint of the agricultural sector in the world and one-third of water footprint of the animal sector is related to beef cattle (Mekonnen and Hoekstra, 2012). In Brazil, the average water consumed is 16 691 l/kg of beef. The use of green water (rainwater) in the predominantly pasture-based grazing systems in Brazil is ~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 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 management practices has the potential to increase productivity per unit area while reducing water footprint per unit of animal product. However, there are cases where reversing the intensification trend was necessary due to overuse of water resources (Herrero *et al.*, 2010).

Although agricultural intensification may lead to an increase in the total volume of water withdrawals per farm, the efficiency of water use may be improved. For instance, 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 protect riparian areas. In Brazil, riparian areas are assumed to be preserved by ‘Permanent Protection Areas’ (APPs), which implies that a strip of land (which size depends on river width and farm size) should remain with native vegetation. In reality, 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 are trampling and overgrazing of stream banks, loss of stream bank stability, loosening soil and soil erosion, and declining water quality due to silting and pollution affecting aquatic and riparian wildlife (Belsky *et al.*, 1999); detrimental effects increase together with 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 (Northeast), intensification may impact on water supply. So far, less frequent problems are being observed in the Central and West regions. Good management and the enforcement of existing legislation should protect this key natural resource.

Agroforestry

Mixed agricultural systems, including agro-silvopastoral 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 within pastures, can increase meat and milk yield, and provide shade for cows thus improving animal welfare (Porfírio-da-Silva, 2004; Embrapa, 2011b; Paciullo *et al.*, 2014). For instance, Paciullo *et al.* (2014) showed that milk yield could be higher by 1 kg/cow per day in agro-silvopastoral systems compared with open pastures, but discussed that the effect was not always persistent over successive years. Transition of extensive pastoralism to agroforestry may also result in a range of socioeconomic benefits (Tilman *et al.*, 2002; Murgueitio *et al.*, 2011), 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 soil degradation, increasing biodiversity and the provision of ecosystem services, for example by increasing carbon storage (Tilman *et al.*, 2002; German *et al.*, 2006; Murgueitio *et al.*, 2011). Trees and shrubs planted in strips surrounding pasturelands also decrease soil erosion and act as ecological corridors.

Transition to agroforestry, if not properly planned, may however result in lower yields and income. Although large-scale farmers may be able to forego short-term returns, this can be more problematic for small and medium ranchers. Although shade from trees provides welfare benefits for cattle, animals aggregating heavily under the shade of trees may lead to nutrient loading and runoff, uneven grazing, soil compaction and soil erosion. In addition, water-demanding trees may negatively impact those farms that 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 can increase the profitability of production chains. For instance, 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-legume pastures resulted in net annual benefit of US$ 3.45 billion (US$ 1.00 = R$ 2.3) for

Brazilian farmers in 2012 (Embrapa, 2013). Similarly, converting low-productive pasturelands into silvopastoral systems can increase and diversify the output per unit of area (German *et al.*, 2006). In Mato Grosso state, intensification resulted in an increase by 62% of farm revenue, and in 20% higher live weight gains, thus reducing the time before cattle were slaughtered (Centro de Estudos Avançados em Economia Aplicada – Cepea/Esalq – da Universidade de São Paulo, 2012). If premiums are offered to farmers committed to comply with environmental and social guidelines of sustainable production, their products will also benefit from added value. Payment for Environmental Services (PES) schemes, including REDD+ (Strassburg *et al.*, 2009), will thus benefit farmers that provide carbon sequestration or more local ecosystem services.

Other studies have discussed that intensification may not be the best strategy to reduce deforestation. Historically, land occupation in Brazil has been strongly correlated to land tenure, which may compensate the positive benefits from intensification (Fearnside, 2002). There are further 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). Some policy options to mitigate this risk include: taxes and removal of subsidies for unsustainable practices, implementation of new regulations or enforcement of existing ones (such as Brazilian economic and ecological zoning), incorporating landowners in any process of technological improvement, payments to farmers (either as incentives or as PES) or consumer incentives such as pricing and labeling livestock products to reflect their environmental footprint (Tilman *et al.*, 2002). For instance, the Brazilian National Law No. 12.651 from May 25, 2012 (the so called '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, as well as natural vegetation surrounding rivers and other special areas such as mountaintops.

Phelps *et al.* (2013) showed that future agricultural land rents will increase as productivity increases, which may raise 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 conflicts, potentially leading to deforestation (Phelps *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 therefore need to remain competitive against rising agricultural land rents (Phelps *et al.*, 2013).

Transition to improved, more intensive cattle farming requires not only initial financial investment (e.g. for fencing, 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 toward better-managed systems.

Small-scale 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 an anonymous questionnaire, the cattle ranching producers from the Amazon region (municipality of Alta Floresta in Mato Grosso state) highlighted that the most important difficulties associated with intensification are insufficient funds and difficulties in getting credit, e.g. due to bureaucracy (A. E. Latawiec, B. B. N. Strassburg and H. N. Alves-Pinto, unpublished data). Similar concerns were mentioned by small and large-scale farmers. Competition for skilled workers and technical assistance were also listed among the most difficult bottlenecks. Another critical factor is the capacity of farmers to adapt to change within complex intensified systems. A significant challenge is the training of people from different sectors along the beef supply chain, from those directly dealing with cattle health management to those working for slaughterhouse companies, or involved in the distribution of intermediate and final products (McDermott *et al.*, 2010). Intensification of pasturelands may lead to job gains or losses depending on the labour-intensity of the new techniques. Due to refinement and increased complexity of pasture management it is possible that the system will require more workers, and thus create new jobs. However, it is also possible that farming system efficiency and mechanization will finally lead to a reduction in jobs in the rural sector, although increasing jobs in sectors directly and indirectly related to the production of machinery. Mixed cropping activities may diversify farm production, thus guaranteeing better resilience to market variation and demand factors. Studies have discussed that women may increase their participation along the supply chain with intensification (White *et al.*, 2013). On the other hand, increased production may raise the importance of formal markets and strengthen vertical chains, making it more difficult for small producers to contribute to the supply chain (McDermott *et al.*, 2010). Understanding winners and losers and the social aspects of adoption of more intensive systems is thus 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 systems (Bowman *et al.*, 2012). Improper management of low-productive pastures provides insufficient feed, while implementing better-managed intensive systems ensure animal nutritional balance, provide clean water, shade and supply of mineral salt, concomitantly improving the animal's immune system. This not only improves animal health but also results in better productivity, improved fertility and higher liveweight gains. Intensification can also improve animal health through vaccination, and control of endo- and ecto-parasites through rational application of antibiotics. However, there is evidence that the most intensive-production strategies may lead to congenitally harmed animals or influence animal welfare in different ways. It is therefore important to monitor intensive systems, so that animal welfare is not compromised. Appropriately stocked and managed grassland–ruminant systems that employ a wider ethical framework can be a sustainable way for producing high-quality products, while providing improved standards of animal welfare (Costa *et al.*, 2013) and minimizing environmental impacts.

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 their environmental footprint. Increasing animal production while reducing its environmental footprint represents a great scientific, technical and social challenge, 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 existing pastures and reclamation of degraded land. It was not the goal of this paper to promote pasture intensification nor do we state that this is the only way to achieve food security and environmental benefits. However, we do argue 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 the potential to spare land and diminish negative environmental pressures it is not a universal panacea for addressing all impacts associated with land conversion. Importantly, the challenge is context- and location-specific, especially where it relates to promoting sustainable development and improving rural livelihoods (Garnett *et al.*, 2013). 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 and sustainable development in rural economies.

A large proportion of agricultural land extension is to provide extensive pasturelands in Brazil, and worldwide, and intensification thus offers one of the greatest opportunities to mitigate adverse effects of expanding agriculture. A mechanism of economic incentives to farmers needs to be established as a buffer against a rebound toward deforestation in the likely scenario of economic conditions driving toward more intensive and sustainable livestock production systems globally (Strassburg *et al.*, 2014b). Combined with a landscape approach (DeFries and Rosenzweig, 2010), sustainable pastureland intensification can facilitate the achievement of social, economic and environmental objectives. If farmers can perceive, and be properly rewarded for, the environmental benefits derived from sustainable pasture intensification, this may create a strong economic incentive for a transition away from the extensive, low productivity and environmentally expensive traditional systems that still predominate in the tropics.

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Supplementary material

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