54ª. Reunião Anual da Sociedade Brasileira de Zootecnia
24 a 28 de Julho de 2017
Hotel Bourbon Cataratas – Foz do Iguaçu – Brasil
ISSN 1983-4357

INVITED

Fitting Brazilian livestock production to changes in natural and political environments

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Abstract
Cattle production is the human activity with largest land use. Rises in demand for cattle products and steady or lower grasslands availability are projected, impelling high rates of productivity gain. However, greater pasture production seasonality in the main producing regions will challenge exclusive pasture-fed production in Brazil. Recovery of degraded pastureland, increasing feed supplementation and feedlots, and integration of livestock production with annual crops, forestry and ethanol agroindustry are promising strategies sustainable intensification under climate change. Digital transformation empowers society to influence public policies and products chains, rapidly changing production constraints and increasing demand for information from production systems. In this context, reducing vulnerability in the international market will demand national institutions and research teams to take part on international initiatives to produce new metrics, models, methods and analysis, which have the potential to affect the cattle industry. Lack of digital literacy of smallholder farmers in remote areas is also seen as an vulnerability, because of their reduced capacity to respond to this new connected environment.

Introduction

Cattle production has historically been very successfully adapted to a large range of natural and socioeconomic conditions (Janzen et al., 2011; Byerly et al., 1978) and it is still a growing industry, playing a crucial social and economic role worldwide (Gerber et al., 2013). Brazil holds the largest commercial herd in the world (Ferraz and Felício, 2010), in 2.7 million agricultural holdings, under highly diverse natural, infrastructure and social conditions resulting in high variability of scales and technology adopted (Fasiaben et al., 2013).

Heterogeneity of production systems reflects the unmatched capacity of ruminants to produce under different climate and to use different feed resources, particularly with different types of pastures adapted to various climate conditions, in a supply chain that elaborates different business strategies. It is a pioneer activity in most remote areas but also present in industrial areas taking advantage of refused grains and industrial coproducts. Ruminants can be fed by pastures in non-arable land and under climate and topographic conditions not appropriate for cropping.

Nowadays, however, persistent increase in the demand of animal products and changes in the natural, political and technological environments challenge farmers and the whole industry to successfully adapt to the foreseen future. Previous studies have pointed to competition for scarce natural resources, such as land, water and pasture degradation, besides demands of society for eco-friendly production and animal welfare as important drivers for change worldwide (Thornton, 2010; Nonhebel and Kastner, 2011).

It is noticeable that the new challenges posed to the industry are not directly associated to consumers, but with the whole society perception of positive or negative externalities and competition for resources. This reflects the enlarged flows of information between society, government and production chain partly because of advances in technologies of information and communication. Such connectivity allows demands of consumers and the society in general to be fast and more accurately reflected into public policies, monitoring, branding and certification, resulting in new challenges and opportunities for the industry.

This paper reviews consolidated trends and foreseen emerging issues related to changes in natural, political and technological environments for livestock farming in Brazil, along with the challenges and opportunities associated.

Political and Market Environments

Contemporary society has been called knowledge society. In this society, information becomes a reference for decisions in the most diverse contexts. The higher valuation of information emanates, in large part, from the increasing level of education of the population and from its own exposure to information. The information, incorporated to knowledge, increases the relevance of new information, in an iterative and interactive process (Kanchan, 2006). It is remarkable the attention of society through channels of technical-scientific dissemination in the new media and traditional media, previously restricted to researchers and specialists. Nowadays, concerns of consumers and non-consumers about the issues of nutrition concepts, health, food security, deforestation, water resources management, energy generation, climate change, advanced genetics, pollution, animal welfare, biodiversity preservation and characteristics of productive systems and technologies rapidly shape the market and government policies, particularly in face of the new technologies of information and communication.

In the information age, democratic governments are urged to discuss and substantiate their decisions based on scientific evidence and information (Davies and Nutley, 2001), driving a movement towards evidence-based policymaking (Head, 2010).

National and international societies consolidated perceptions will also influence companies' image on their actions towards sustainability and well-being or through NGOs. An example of such influence is the soybean and cattle moratoria which involved NGOs, major private traders and the government (Gollnow and Lakes, 2014; Newton et al., 2014).

In response to pressure of civic society and NGOs, large companies decided not to buy soybeans from deforested areas of the Brazilian Amazon. An agreement was reached in 2006 and included all major Soy traders[1]. In 2008, the Brazilian government became also a signatory and gave support through Banco do Brasil e and the National Institute for Space Research (INPE[2]), and created a public governance structure which discouraged deforestation, keeping occurrence of soy plantations in illegal deforested areas being always under 1%[3].

The successful implementation of the soy moratorium led to the Beef Moratorium, celebrated by the government of the state of Mato Grosso and the four largest Brazilian meat packers[4]. The Beef Moratorium determines that meat packers will not buy from ranchers with recent or illegal deforestation, explore slavery or

1 https://www.oecd.org/environment/country-reviews/EPR-Brasil-AR-Portugues.pdf
2 National Institute for Space Research <http://www.inpe.br/ingles/>
3 http://br.reuters.com/article/businessNews/idBRKCN12J25K
4 http://www.brasil.gov.br/meio-ambiente/2014/09/dia-da-amazonia-e-comemorado-nesta-sexta-feira-5

in farms located in protected areas[5]. Four years after the moratorium started, 120 Commitment to Adjustment of Conduct agreements[6,7] were already celebrated by farmers and meat packers with the Public Prosecution Service (MPF) for environmental regularization in the legal Amazon.

In the international context, the Intergovernmental Panel on Climate Change (IPCC) is an example of how much scientific information can be influential. IPCC assess climate change and the risks it poses to give support to policy makers. Information provided by IPCC has been the basis for meetings for discussing solutions and negotiate actions of chiefs of state of almost every country in the world in the Climate Convention Conference of Parties[8] and has even been influential to a Pope´s encyclic[9].

Notably, therefore, the government becomes an important customer and supplier of digital information on agriculture and, also, a client of information systems which provide evidences to support their decisions. In Brazil, a series of computerized information systems related to monitoring natural resources, production and externalities are available (Table 1). Databases with country-specific livestock production, climate and natural resources data are globally available (e.g. FAOSTAT[10], UNFCCC GHG Inventories[11]).

Table 1. Examples of Brazilian information systems for monitoring natural resources, production and externalities.

Information System	Description
Cadastro Ambiental Rural (CAR)	Public national georeferenced database of agricultural and natural land occupation by farms. It is compulsory for all farms in Brazil http://www.car.gov.br/#/sobre
PRODES - INPE	The Amazon Deforestation Monitoring Project, carried out by the Brazilian National Institute for Space Research (INPE) and since 1988 reports the annual rates of deforestation. It allows public access through the Internet. http://www.obt.inpe.br/prodes/index.php
Sistema de Rastreamento de Bovinos SISBOV	Brazilian National database of individual cattle identification to support product traceability. http://sistemasweb.agricultura.gov.br/pages/SISBOV.html
Sistema Interativo de Suporte ao Licenciamento Ambiental (SISLA)	A web-based geographic information system, developed by Embrapa and Imasul, to support environmental licensing in the state of Mato Grosso do Sul. http://sisla.imasul.ms.gov.br/sisla/pagina_inicial.php
Sistema Nacional de Informações sobre Recursos Hídricos (SNIRH)	A set of web application to allow access to hydrological data and its analysis through interactive maps and other services http://www.snirh.gov.br/
Sistema IBGE de Recuperação Automática (SIDRA)	Web-based application to access aggregated data from surveys and studies carried out by IBGE. Includes data of Agricultural Census, and annual estimates of agricultural area production and livestock numbers, slaughter, production, etc. https://sidra.ibge.gov.br/home/pms/brasil
Banco Multidimensional de Estatísticas BME	Data base for customized queries on farm-level data of the Agricultural Census and disaggregated data from other IBGE surveys. https://www.bme.ibge.gov.br/index.jsp

5 **http://www.mpf.mp.br/pgr/noticias-pgr/moratoria-da-carne-assinatura-do-tac-e-marcada-para-o-dia-11-de-maio**
6 Free translation of "Termo de Compromisso de Ajustamento de Conduta" - TAC, in portuguese
7 http://amazoniareal.com.br/empresas-fazem-acordos-da-moratoria-da-carne/
8 Convention Conference of Parties (COPs) http://unfccc.int/bodies/body/6383.php
9 http://w2.vatican.va/content/dam/francesco/pdf/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si_en.pdf
10 FAOSTAT
11 UNFCCC GHG Inventories

Agritempo	Agrometeorological monitoring system and web application to access data, maps and publications to support agricultural production https://www.agritempo.gov.br/agritempo/index.jsp

Access to stringent international markets also requires the product and production systems to be amenable to scrutiny according to metrics and standards internationally recognized. Moreover, customized requirements related to production systems (e.g. breeds, types of supplementary feed, use of hormones, antibiotics and additives, etc.), slaughter method (e.g. halal method, stunning) and product (e.g. carcass weight, traceability) and externalities (e.g. GHG emission intensities, deforestation dissociation) will depend on customers' preferences and values.

Decision-making can be highly complex, requiring combination of data from different sources and formats and, sometimes, sophisticated data analysis, which depends on carefully designed models and algorithms. Nowadays, the buzzword for this emerging field of analysis in our Petabyte era is Data Science (Provost and Fawcett, 2016). Therefore, isolated databases are not enough. Strategic and structured efforts to develop models, algorithms and computational infrastructure so that climate, socioeconomic and technological aspects, among others, can be analyzed at several levels of aggregation or scales are required. In that context, several global models of grasslands and cattle production have been developed and applied in global analysis. Examples of models already applied for cattle analysis at regional or global scale are GLOBIOM (Havlík et al., 2011), GLEAM, Passim (Ma, 2015), SimBrasil/OTIMIZAGRO, BLUM and EAGGLE (De Oliveira Silva et al., 2016).

The search for standardized methods and best practices for evaluation of sustainability of production systems is very active in the nowadays industry. One example is the Sustainable Agriculture Initiative (SAI), created in 2002, and today counting with over 70 of the major food companies and retailers worldwide (http://www.saiplatform.org/). SAI has specific working groups on dairy and beef production and has recently created a Brazilian committee. The beef working group, for instance, has the aim of achieving consensus on the quantification of GHG emissions from beef farming systems. LEAP (Livestock Environmental Assessment and Performance, http://www.fao.org/partnerships/leap/en/) is a multi-stakeholder initiative led by FAO with has similar goals. It develops comprehensive guidance and methodology for understanding the environmental performance of livestock supply chains, in order to shape evidence-based policy measures and business strategies.

Comparative analysis, also rely on metrics, and standardized methods which, generally, rely on strong scientific basis but and, also, on subjective decisions on methodological choices and available data (Plevin et al., 2013).

From the political point of view, any major player in the international market should recognize the importance of formal participation in the development of the international standards, metrics and models. For instance, ISO 14044:2006 states that lifecycle assessments reports should include review statements as well as comments by interested parties affected by the conclusions drawn from the LCA, such as government agencies, non-governmental groups, competitors and affected industries. Also, it is important the country to be able to produce its own analysis and reproduce internationally published analysis.

In the context of increased adoption of evidence-based policymaking, international negotiations associated to externalities and demands from the market and society (including NGOs) for generalized access to product and production information lead to expectation of intensification of assessments and monitoring of cattle production. The decreasing costs of monitoring, storing and communicating should contribute to that. This highly connected and monitored environment is challenging, but also represents an opportunity for producers, as superior product quality and production process may be more readily communicated. Branding and traceability will probably continue to be a strong trend. For all agents (government, food industry and retailers) it will be vital to improve the communication of benefits, signaling requirements and negotiating based on data and data analysis.

Biophysical Environment

Feed production, and particularly animal production, may be challenging for a 9 - 10 billion people world in 2050 (Smith et al., 2013). Despite calls for moderating meat consumption in human diets and movements towards vegetarian diets, overall worldwide consumption is still increasing steadily, mainly because of growing access to meat in developing countries (Delgado, 2003).

Land

Pushing up the agriculture output may test the limits of the physical environment, land availability being an obvious one, if technology in the production systems remains unchanged (McMichael et al., 2007; Godfray et al., 2010). As a matter of fact, expansion of agricultural land is undesirable as it is associated to impacts on biodiversity and ecosystems services, water cycle, and carbon storage (Lima et al., 2013).

Trends on grasslands area (Figure 1) indicate it is close to the it's attainable limits around 2000, and that further expansion of grasslands area is unlikely either in Brazil or in the World both because constraints to conversion of natural vegetation and projected expansion of land use for other food, fiber and biofuel production. More likely, it seems cattle production will have to get along with area contraction.

(a) (b)

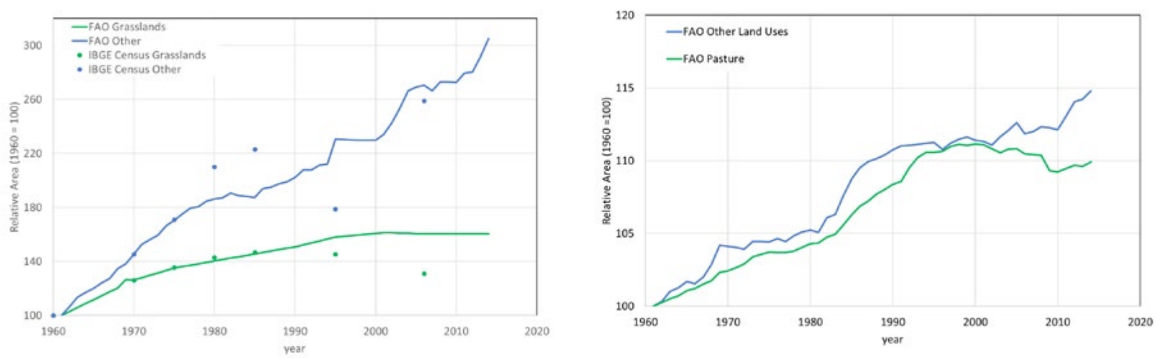


Figure 1. Relative area of pasture and other agricultural land uses in Brazil (a) and in the World (b). Area occupied in 1961 is the reference (100). Absolute areas in the reference year are 3077.9 and 1380.1 million ha (M ha) for grasslands and other agricultural uses in the world and 122.2 and 23.4 M ha for grasslands and other agricultural land uses in Brazil. IBGE census data was only available from 1970 on so its relative area was it was adjusted to match the 1970 FAOSTAT data.

Despite expansion area, cattle production is still growing steadily, but not homogeneously in different regions of the world comparing aggregated European Union and Northern America (EU+NA), against Brazil (BR) and South America (SAm). Beef production presented a strong growth in BR (+5.45 %/yr) and SAm (+2.68 %/yr) while decreased 0.3 % in EU+NA (Figure 2). Milk production also increased much faster in BR and SAm than in EU+NA.

Although the increase in overall production was partly due to fast expansion of grasslands areas in Brazil in the period 1960 - 1989 when grassland area expanded at 1.72%yr, this does not currently hold. In the period 1990 - 2014 much slower expansion rates (0.26%/yr, Figure 2) were found, and available data indicate the grasslands expansion has already ceased in Brazil (Figure 1). Productivity gains are recently more related to increased animal performance and stocking rates. Land productivity gains in the Brazilian beef production in the period 1990 - 2014 are explained by improvement of both animal performance (+2.57%/yr) and stocking rates (+1.41%/yr), while land productivity of EU+NA have decreased, despite small improvement in animal performance. For dairy Brazil presented slower gains in cow productivity that overall numbers for SAm, but still much higher than EU+NA (Figure 2).

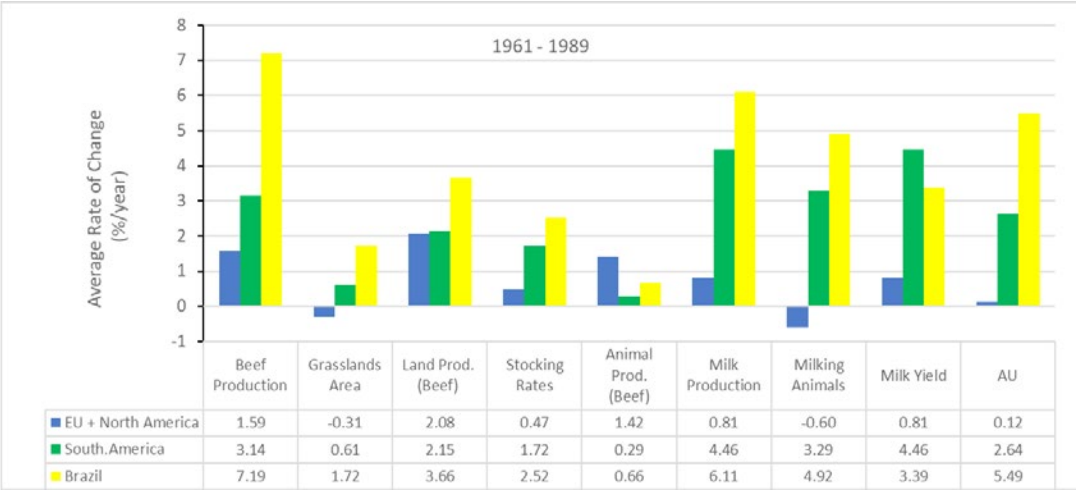
The faster increases in the Brazilian productivity can be explained by a combination of factors, including the increasing demand of a growing population and recent external market demand, constrained expansion of grasslands area due to new public policies for controlling deforestation and the still high pasture (Strassburg et al., 2014; de Oliveira Silva et al., 2015) and animal performance yield gaps. For instance, beef productivity in EU+NA was around 97 kg CWE/head/yr, it was only around 45 and 43 kg CWE/head/yr in BR and SAm, respectively.

According to Gasques et al. (2014) the total-factor productivity (TFP) of the Brazilian agriculture is among the largest in the world, increasing on average 3.52%/year in the period 1975-2012, and remaining high (4,06%) at the end of that period (2000–2012).

Livestock and Food Supply for the period 2015/16 - 2025/26, indicate that the growth of Brazilian Agricultural output will still be based on productivity gains (Brasil, 2016). Projections by MAPA (Brasil, 2016) for the period 2015/16 - 2025/26 and OECD-FAO (2015) suggest beef production will keep intense grow, at rates of 2.4 %/year, based both on increases in domestic consumption (1.6 %/yr) and exports (3.1 %/yr). MAPA emphasizes that increased production should continue to be achieved based on productivity gains (Brasil, 2016). Without expansion of grasslands area, Brazilian beef productivity of land, ca. 49 kg CWE/ha/yr in 2014, will rapidly converge to aggregate levels of land productivity of developed northern countries, ca. 60 kg CWE/ha/yr, but will still be far from EU average (113 kg CWE/ha/yr).

It is not realistic, however, to expect that productivity grows indefinitely in Brazil and in other developing countries. Yield gaps make still unclear when potential economic yield will become an important limitation in the Brazilian context. Modeling studies suggest that feeding the whole world with beef rich diets in 2050 may pose highly constrained conditions and intense international trade if current natural vegetation cover is to be maintained (Erb et al., 2016). However, published simulation studies suggest projected demands to 2050 can still be attained only through productivity gains, i.e. without further deforestation (Gouvello et al., 2010; Strassburg et al., 2014; de Oliveira Silva et al., 2016). Although the level of productivity required from Brazilian production is attainable, clearly the next steps on productivity improvement will be more challenging. Until the 90's a large part of stocking rates and animal performance improvements were attributed to the substitution of natural to improved pasture species and animal genetic improvement. More recently increased adoption of feed supplementation and feedlots, as well as restoration of degraded pastures, became important components of productivity gains. Future gains will be more challenging and will probably rely on further restoration of degraded pastures but also fertilization of productive pastures, investments on pasture and genetics, improved nutrition, besides appropriate infrastructure for more intensive systems. Supportive environment for growth will require low cost credit and attractive returns (see section Adaptation and opportunities and Figure 4).

(a)



(b)

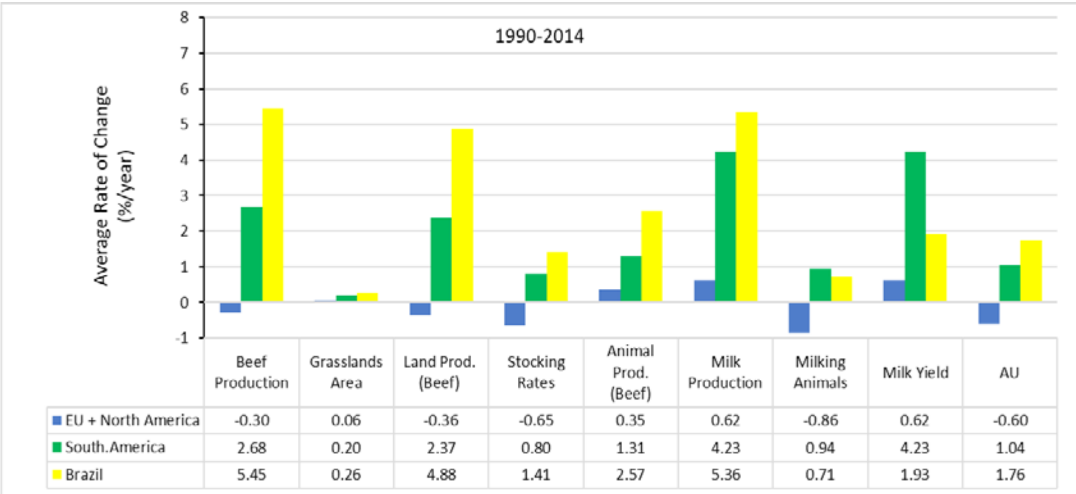


Figure 2. Average rates of change in production, land use, land productivity animal stocks and animal performance in different regions of the world for the periods 1961-1989 (a) and 1990 - 2014 (b) estimated from FAOSTAT[12] data. European Union and North America (EU + North America) data were aggregated and compared with South America and Brazil.

Adaptation and opportunities

Sustainable intensification and mitigation

Sustainable agricultural intensification (SAI) has been advanced as an approach to the issue of food security under the pressure of population growth, dietary shifts in developing countries and vulnerability to climate change (Garnett, 2013; Godfray and Garnett, 2014). The basic principle of SAI relies on the process of producing more food from existing land in ways that place far less pressure on the environment, and do not undermine our capacity to continue producing food in the future (Garnett et al., 2013). In Brazil, despite the significant productivity increases over the last three decades (Martha et al., 2012), challenges remain, both to reverse the economic losses from grassland degradation, and to accommodate growing demand while avoiding the conversion of natural habits. The SAI debate highlights elements of resource use efficiency in production combined with the management of demand and the need to reduce consumption of livestock products (Garnett, 2013, Smith, 2013). De Oliveira Silva et al. (2016), conversely, identified conditions in which reducing beef demand in Brazil could lead to increased greenhouse gas emissions, while increased production, combined with SAI could potentially reduce emissions through increased carbon sequestration of restored pastures, provided livestock production is decoupled from deforestation. Their study also highlights

12 FAOSTAT <http://www.fao.org/faostat/en/#home>

the role of livestock products demand on the SAI, meaning demand, combined with effective deforestation control policies are determinant drivers on the transition to sustainable agriculture. Figure 3 shows emissions intensities according to baseline demand projection (BAU), lower (BAU-30% to BAU-10%) and higher demand scenarios (BAU+10% to BAU+30%) under controlled (Decoupled livestock-deforestation) and uncontrolled deforestation (Coupled livestock-deforestation).

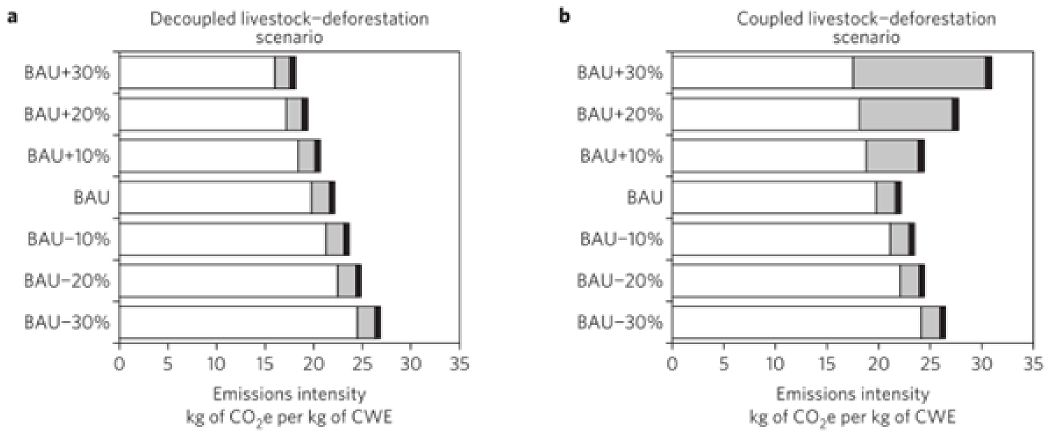


Figure 3. Emissions intensity analysis. **a**, Emissions intensity as a function of demand scenario for the decoupled livestock–deforestation scenario. **b**, Emissions intensity as a function of demand scenario for the coupled livestock–deforestation scenario. Carbon footprint calculated as the average value from 2010 to 2025, showing the sum of farm emissions: animals and pasture (emissions by degradation or carbon sequestration and nitrogen fertilizers nitrification; white), deforestation emissions (grey) and LCA emissions from inputs and farm operations (for example, fertilizers, seeds and machinery operations; black). Source: De Oliveira Silva et al. (2016)

It has been demonstrated that GHG mitigation through livestock management can be delivered at relatively low costs (Cohn et al., 2014; Strassburg et al., 2014). In a study for the Brazilian Cerrado, De Oliveira Silva et al. (2015) showed that strategic SAI could be delivered at “negative costs”, i.e. by targeting specific measures the livestock sector has the potential to reduce emissions while increasing profitability, including pasture restoration and cattle feed supplementation. They estimate that around 24% of livestock emissions could be abated at negative costs, with most reductions from increased pasture productivity and avoided deforestation.

Besides demand and effective deforestation policies, cattle prices are determinant on the cost effectiveness of SAI measures. Figure 4 shows sensitivity analysis of cattle prices against average pasture productivity (in tons of dry matter per hectare) and farmer’s profit in the Cerrado beef cattle systems.

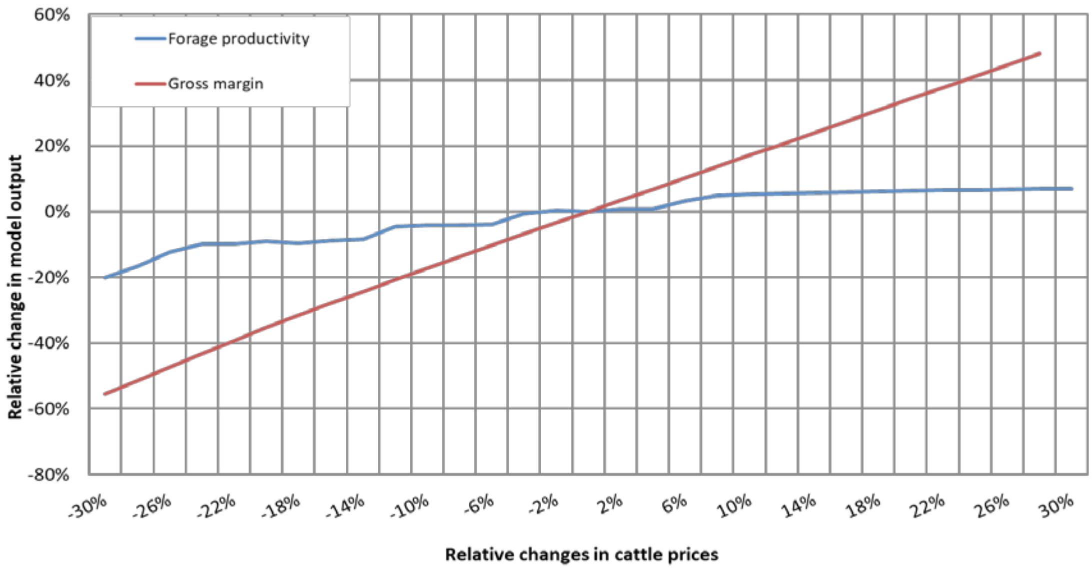


Figure 4. Sensitivity analysis of cattle prices versus pastures forage productivity and gross margin for representative beef cattle systems in the Cerrado.

Figure 4 shows that a reduction of 20% on cattle prices could lead to a 40% drop on gross margin and reduction of 10% of pasture forage productivity. Lower prices means farmers have less incentive to restore their degraded pastures and to increase animal number, reducing profitability. Analogously, higher prices, provided own capital or government subsidized rural credit is available, would work as an incentive to increase animal numbers and pasture restoration. A variation of +20% over cattle prices would increase pasture productivity and profit by 6% and 34%, respectively.

Investments to growth and intensification of cattle production will be required, otherwise it would become an important bottleneck to meet demand and to promote sustainable intensification (Gouvello et al., 2010). Recent public policies to provide credit to sustainable intensification. such as the ABC program, and the rise on beef prices expected for the next decade (USDA, 2016), if realized, may help to provide appropriate conditions for growth. However, Brazilian beef production systems are heterogeneous (Buainain and Batalha, 2007) with producers adopting the latest technology but also by producers with very rudimentary management practices and degrade pastures (Buainain and Batalha, 2007, Fasiaben et al., 2013). Such heterogeneity may lead to deep variation in optimal technologies of production systems adoption and adds complexity to the elaboration of appropriate public policies which can preserve vulnerable producers.

Available pathways for intensification

A series of technologies are available for increasing productivity allowing a more environment friendly food production that will not compromise our future. The adoption of such technologies is pivotal in the accomplishment of sustainable production scenarios in the future. One important thing to notice is that, preferably, they should not be perceived as segmented technologies, but that they can present very interesting synergies when used together in optimized production systems. Best routes for intensification are still not clear but will be probably a mix of options, including pasture restoration, integrated systems (integrated crop-livestock-forestry, sugarcane and livestock integration), and feedlots, used in most diverse combinations to suit specific circumstances. Some of the utmost readily options will be presented below, briefly recollecting recent historical developments, describing their main characteristics and examining current and future trends that may contribute to make them feasible pathways for sustainable food production.

Crop-Livestock systems

A series of technologies are available for increasing land productivity and may affect stocking rates and animal performance in different proportions. Best pathways for intensification are still not clear but will be probably mix of the different options, including from pasture restoration to integrated crop-livestock-forestry systems and feedlots, each best to a specific context.

The connection of beef cattle production and agriculture in Brazil goes back to the first decades of the 20^{th} century and was intensified in the decades of 1960 and 1970 when huge new areas were opened, especially the Middle-West (Cerrados), due to fiscal incentives (Zimmer et al. 2011). Nevertheless, land was used for cropping for just one or two years after deforestation and not in an integrated rotation as we consider today.

To be considered and integrated system, at least two activities must come in succession, meaning they use the same area in successive periods of time (Balbino et al., 2011). This distinction is important because sometimes producers with separate activities at the same farm believe they have an integrated system when logically if they occur in unrelated areas, they cannot benefit directly from one another.

In the decade of 1980, inflation rates were at historical peaks and cattle, as a real asset, was very much valued, allowing margins no matter how it was produced. Pasture degradation was one of the results of this low investment culture. In 1994, a very successful government plan, called "Plano Real" brought much more economic stability for the last thirty years, forcing the entire supply chain to intensify the business (Carvalho and Oliveira, 2017). Unfortunately, despite greater productivity it is accepted that about 80% of pasture land in Brazil is somewhat degraded (Zimmer et al. 2011).

Crop-Livestock integration is one of the options to both improve economic margins and restoring pastures, therefore research in this area regained interest since the stabilization of Brazilian economy. Integrated systems improvements in efficiency are in line with the growing ecological awareness and the search for more sustainable solutions. The magnitude of the effect is well exemplified by comparison of fattening phase on degraded pastures versus the potential of well managed recovered pastures by crop-livestock: 30 kg beef/year/ha vs. 450 kg beef/ha/year (Kichel et al., 2014).

There is a reasonable number of studies on pasture ecosystems in the Amazon, Cerrado and Atlantic Forest biomes indicating that soils under well managed pastures or CLI systems may have carbon levels similar or superior to the native vegetation (Cerri et al., 2006; Jantalia et al., 2006; Macedo et al., 2012).

Precursors of solutions and transfer of technologies to recover sown pasture areas with integrated crop-livestock systems (ILP) are the Barreirão System (Kluthcouski et al., 1991) and the Santa Fé System (Kluthcouski et al., 2000). Currently, there is research in all Brazilian biomes with a great variety of systems where the animal component can be beef cattle, dairy cattle or sheep, the silvicultural component a fruit tree (cashew, for example) or for timber (eucalyptus, teca, native trees, etc.) and the crop component one of many options like corn, sorghum, soybean, sunflower, sugarcane, etc. (Kichel et al., 2014).

The interest to incorporate the forest component is more recent and can be related to the growing need of cultivated trees, for wood and cellulose, and the natural increase in availability of marginal areas that are unfit to agriculture (Macedo, 2010).

In 2009, at COP-15 in Copenhagen, Denmark, Brazil voluntary presented a bold list of voluntary actions that included incorporate 4 million hectares of pasture recovery with crop-livestock -forest integration, equivalent to 18 to 22 Mt CO2eq mitigation potential. This goal was then included in a national program to promote specific agricultural activities based on agricultural best management practices configuring a low carbon agriculture (LCA) (Brazil, 2010) that also included: restoration of degraded pastureland, increased no-tillage agriculture, promotion of biological nitrogen fixation, establishment of plantations of commercial forests and forestation and recycling of industrial and animal wastes (Gouvello et al., 2010).

By the time of the ratification of the Paris Agreement on Climate Change by the Brazilian government in 2016, another five million hectares with ICLF systems, totaling nine million hectares until 2030 to be accomplished.

One typical trend in the adoption of integrated systems is that more farmers in the crop business start to work with livestock than the opposite. Usually this is attributed to the higher management skill demanded by crop than livestock production, a new activity that would be less challenging.

The fact is that beef cattle producers are increasingly adopting integrated systems. One of the greatest bonuses of ICL systems in the Brazilian Cerrado is the fact it provides high quality pasture in the end of the rainy season, allowing animals unexpected performances in the dry season supplemented only with a mineral mixture.

In Table 2, we compare the advantages and challenges for moving from the crop business to livestock and vice-versa. One common advantage is land valuation.

Table 2. Advantages and Challenges related to integrated system adoption according to the producer background (Crop to Crop-Livestock or Livestock to Crop-Livestock)

Moving from/to	Advantages	Challenges
Crop/ Crop-Livestock	Decreased total risk Daily liquidity and improved cash flow Increased Yields on Crop Less problems with some pests and weeds	Buying animals in great lots and of good potential Manage the animals and pasture
Livestock/ Crop-Livestock	Increased profitability Improved pastures (including in the beginning of the dry season)	Higher total risk Need to dismantle original fence and related structures for supplement and water and providing a new one.

ICLF systems improve soil's chemical, physical and biological properties, help to prevent erosion, promote carbon capture and the conservation of water resources and biodiversity. The annual crop improves soil fertility, while pasture improves soil physical properties. Increases in soybean yields from 180 to 720 kg/ha have been reported in areas previously cultivated with maize intercropped with perennial forage grasses (Kichel et al., 2012; Franchni et al., 2015).

One practical aspect of ICLF is that the best combination of years of pasture and crop is not necessarily the same for profitability and sustainability. The time recommended to keep pastures in the area regarding the physical conditioning of the soil and nematode control is 24-36 months, but less time with pasture crops have higher profitability. (MANUAL MACEDO, personal communication).

Crop-Livestock-Forestry and Silvopastoral Systems

The inclusion of the forest component in diverse integrated systems contributes to land use efficiency and has positive impacts on microclimate and carbon sequestration (Carvalho et al., 2001a; Macedo, 2009; Almeida, 2010; Alves et al., 2014).

Animal welfare improves as the shade of the trees brings more thermal comfort to the animals. Reductions of up to 3.7 % in Temperature and Humidity Index, 10.2 % in the Black Globe Temperature and Humidity Index, and 28.3 % of the Radiant Thermal Load in the shade were reported by Karvate et al. (2016). Unfortunately, at the same time pasture productivity decrease greatly (Macedo, personal communication) as less light reaches the canopy. Reductions up to 50% has been already reported (Behling Neto et al., 2012)

Another aspect, which can sometimes be even more determinant in intake, is the architecture of the canopy. When shaded, the forage tries to compensate elongating (Sousa et al., 2007), what makes the canopy less dense, reducing the bit size that has a strong correlation with intake (Carvalho et al., 2001). With the combination of less forage mass and its lower density, animal production can be expected to reduce, even though forage grown on shade can have better nutritive quality (Sousa et al., 2007; Moreira et al., 2009; Behling Neto et al., 2012).

On the other hand, pasture systems with 250 to 350 eucalyptus trees/ha, for cutting at eight to twelve years of age, can produce 25 m^3/ha/year of wood (Ofugi et al., 2008) equivalent to 5 t/ha of C or 18 t/ha of CO2eq. This value would be equivalent to the neutralization of the emission of GEEs of about 12 adult cattle/ha/year (Giolo and Medeiros, 2013). That fact is being capitalized by the development of a protocol of certification on systems for meat production that neutralizes their GHG emissions under a conceptual brand called Neutral Carbon Brazilian Beef. In this protocol, the presence of trees is required, in integrated silvopastoral systems (livestock-forest, ILF) or agrosilvopastoral (crop-livestock-forest, ICLF), through processes parametrized and audited with technical support from Embrapa.

In ICLF, less light reaching the plants also decreases crop production, which is more noticeable when the crop runs short of rain and the competition for water between the crop and the tree intensifies. Shading is critical in different phases depending on the type of crop. For instance, for soybean light is more critical when flowering, while for corn in the stage of grain filling, that will increase the heterogeneity of the corn cob. Soybean as a C4 type plant is less affected by shade.

The adoption rate of integrated systems was far more successful than anticipated and by now we reached 11.5 million hectares of integrated systems with the prevalence for ICL in relation to silvopastoral systems. The potential area to ICLF in Brazil have already been estimated to be about 45 million ha (Kichel et al., 2011), although other researchers consider 20 million ha a more realistic number.

Feedlots

Initially the feedlot operation was motivated by the large differential of cattle prices between rainy and dry season, typical of the 80's and 90's. Feedlots were closer to the consumer markets and far from the grain producing areas that were more expensive due to freight costs. Consequently, diets had higher content of roughage.

Currently feedlot operations are moving nearer the agricultural regions, what makes concentrate cheaper. In a first survey on the content of concentrate in the diet the average was 71,2% (Millen et al., 2009) compared to 79,0% in the second survey five years latter (Oliveira and Millen, 2014). Concentrate percentage in the diets keeps going up. As a matter of fact, diets denser in energy mean less operational costs, as it is less bulky, and less area to produce the roughage. In addition to that, these diets are more biological efficient and, as they stimulate fat deposition, the animal finishes sooner. Greater feed efficiency and less time to finish are two characteristics that are aligned to make production more sustainable. This is particularly interesting because one of the explanations to better efficiency is less methane lost per kilo of dry matter.

Feedlots in Brazil incorporated in different production systems as a finishing tool, as well to improve pasture management, as the heavier animals enter the feedlot enter the feedlot at the beginning of the dry season. Currently only 12.9% of animals come from feedlots (Carvalho and Oliveira, 2017) and they are slaughtered at 24 months of age after 83 days (Oliveira and Millen,2014, ABIEC, 2016), so they spend 89% of their lives on pasture. Considering the proportion of the lifetime the animals are kept grazing; Brazilian beef is 99% based on pasture. As typically 1/4 of the weight is gained in the feedlot (Table 3), it is possible to estimate that 98% of the 9,5 million tons of meat are produced based on grass.

Table 3. Comparison of US and Brazil feedlots for slaughter carcass weight (SCW), slaughter liveweight (SLW), slaughter age (SAge), duration (DFP), average daily gain (ADG), initial liveweight (ILW), and proportions of liveweight gain LWG/SLW and lifetime DFP/SAge.

Country	SCW (kg)	SLW (kg)	SAge(d)	DFP (d)	ADG (kg/d)	ILW (kg)	LWG/ SLW	DFP/ SAge
USA	388	626	570	135	1.80	437	0.39	0.24
Brazil	244	459	732	83	1.38	345	0.25	0.11

Sources: Livestock Marketing Info. Center (Lakewood, CO), Oliveira & Millen (2014)

The number of confined animals varies from year to year depending on the price of the ingredients, of the unfinished animal to be confined and on the expectation about the selling price of the finished animal. Yet, since the beginning of the adoption of feedlot Brazil experienced a trend of growing adoption.

Sugarcane-livestock integration

Brazil is the world's largest sugarcane producer, with a cultivated area of 9.1 million ha, (CONAB, 2016) and has the largest cattle commercial herd with 215 million heads (IBGE, 2016). These two supply chains have a long-standing collaboration, butstill limited to the use of coproducts of the sugarcane industry by the livestock sector.

After the oil crisis of 1973, the Brazilian government created the "Proalcool" program with the objective of reducing our oil dependency in which, along with incentives to produce ethanol, engine technology was developed to use this fuel. With a great number of new distilleries mainly spread in the Southeast region, the opportunity of ranchers to use sugarcane industry byproducts increased. In the 1980, many experiments with different coproducts were performed. Works with *in natura* sugarcane bagasse, steam treated bagasse, yeast, filtercake, molasses and even vinasse were performed but some proved to be less suitable for animal production, like filtercake and vinasse, and others, like yeast and molasses, were redirected for more profitable alternatives of use.

Apart for some sugarcane distilleries that keep feedlots in their plants with diets containing some of their coproducts and residues, the main coproduct currently being used is *in natura* sugarcane bagasse in feedlots. The content of sugarcane bagasse in the diet is low, just to provide the fiber requirement to proper rumen function that, in the case of sugarcane bagasse as low as 9% of the dry matter (Bulle et al., 2002).

Very recently, new developments like second generation ethanol (produced from any fibrous material) and ethanol plants that use both sugarcane and corn, renewed the interest to integrate this bioenergy sector with livestock. The expansion of biofuels production based on food crops has given rise to the "food vs. bioenergy" debate, and exploring synergistic effects of integration could be a good response. It is possible to produce energy and feed more efficiently and, therefore expand biofuel production without a proportional demand of new areas for livestock production, decreasing the need for land use and the impacts of agriculture expansion.

Among the ideas to make it possible we have: new treatments of *in natura* sugarcane bagasse, high quality protein from culture cultivation on distilleries residues, corn co-products (DDG and DDGS) available ingredients for diets and many other possibilities related to the agricultural integration between sugarcane and other crop cultures.

Tackling vulnerability to a changing climate

There are still severe limitations on vulnerability studies related to cattle production worldwide, which are even greater in Brazil. From the available information it is possible, nevertheless, to produce a qualitative evaluation of the possible adaptations.

In the Midwest, the main cattle producing region of Brazil, longer periods of water deficit (Carvalho et al., 2013; PNMC, 2013) are expected due to climate change. Also, higher incidence of parasites and number of days of heat stress may impact production (Scholtz et al., 2013).

Adaptation options to longer droughts and higher seasonality of forage production can be used (or increase the use) of supplementary feed and feedlots, or more conservative stocking rates (Reeves and Bagne, 2016) which may either raise production costs or decrease productivity. Integrated crop-livestock, breeding season and strategies of animal purchase and sales may also be used to balance feed supply and demand (Barioni et al., 2013)

Continues efforts in genotype and environment match are required to sustainably increase production in a changing climate future. Drought resistant pasture species should also be sought in the most vulnerable regions. Heat stress is particularly important in high performing animals and may change the selection criteria and geographic distribution of breeds and lineages, or require further heat stress measures such as shade, cooling and diet changes (Gauly et al. 2012; Scholtz et al., 2013). Higher incidence of parasites and diseases, associated with increased temperatures, is an important issue for animal production (Fox et al., 2015). Both, heat stress and higher incidence of parasites may result in the adoption of zebu breeds in some regions nowadays dominated by European breeds in Brazil.

Conclusion

Growing demand for food and constraints to area expansion, competition for land, new demands on sustainability, higher demand for product and production information and stricter control by the government and by the industry, need for adaptation to climate change and enhancing the sector image to the urban consumers are clear trends for the cattle industry in the future.

Desired outcome of a production system by producers, traders, government, NGOs and in different countries is often not aligned. Increasing information flows in the chain may allow faster evaluation of tradeoffs and convergence of interests but will also demand more proactive work on negotiations. In a highly monitored environment, it is a healthy posture for the sector to openly discuss policies, regulations, incentives and evaluation measures but also be fully compliant to them.

Overall, the Brazilian cattle production industry and public policies are quickly responding to the new environment, particularly through sustainable intensification of production. The most promising initiatives to date are related to pasture recovery, integrated crop-livestock-forestry and feed supplementation with byproducts of food and energy industries. Literature review and data analysis indicate that, in general, the country has the technological, natural and institutional conditions to adapt to the foreseen future scenarios.

Nevertheless, the asymmetry between growing demands for digital information, decision support, planning and monitoring and the digital inclusion and capacitation of farmers is a vulnerability of Brazilian farming, particularly of smallholder farmers in remote areas. Finally, the to reduce vulnerability it is strategic that the Brazilian institutions and research teams take important roles on international initiatives to produce new metrics, models, methods and analysis, which have the potential to affect the cattle industry.

It is important to note, also, that the optimal or desired situation is a moving target. The current system may be sub-optimal in the future and may need adaptation, but also, the implementation of upcoming optimal system may be also currently sub-optimal. In an environment of changing climate and society, strategies will need periodic reevaluation. In a first glance the moving target optimal may forward the idea that adaptation measures should only be taken when the change is already in place. However, taking such reactive posture may also be unsafe. Successful adaptation requires strategic planning and anticipated actions, based on the best available information and correction of the goals whenever new information demands so. Connectivity and appropriate use of decisions analysis tool will be a major challenge to any industry to be adjusted to the future demands, and it include beef and dairy.

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