Chapter 10
Land Sparing and Sustainable Intensification Within the Livestock Sector

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Abstract In this chapter, we describe the importance of cattle ranching, its origins, and its development in Brazil. We track the evolution of this value chain and identify the challenges it faces with the occupation of lands. Given the increased demand for meat in the world in the coming decades, we also present solutions to how cattle intensification and technological adoption can allow for increasing production through productivity gains, permitting crops to expand on existing degraded pasture, and therefore meeting (internal and export) market demands without the need for new deforestation.

10.1 Introduction

The Brazilian agricultural context has changed significantly in the last decades. With the increased importance of the country as an agri-environmental powerhouse, a significant commodity exporter, and a home to a large population, and given the global concerns related to climate change, we raise the question about the role of cattle ranching in the sustainability debate. We identify the challenges related to sustainable production and show that well-planned intensification can be a tool to ensure that Brazil can produce enough meat while releasing lands for crop production without the need for deforestation. Such a challenge needs to be overcome by coordinated efforts and implementation of existing policies.

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We begin the chapter by contextualizing cattle ranching in Brazil and its origins. We then turn our attention to another challenge, where we discuss the prospects for sustainable production, considering the complexity of the supply chains, the issue of pasture degradation, economic feasibility, greenhouse gas emissions, and the issue of deforestation, sectoral agreements, and traceability. In this section, we not only identify the challenges but show the potential for change.

In the following sections, we show that intensification, associated with land governance, will allow for production aligned with conservation. We discuss the issues of improved pasture management, the use of geotechnologies for supporting decision-making, and the opportunity of utilizing integrated systems, encompassing the integration of crop, livestock, and forestry. We also discuss overall property management as a tool to increase productivity and the optimization of spatial distribution, to ensure that pasture is intensified where it is most suitable. The issues related to social inclusion and the reduction of illegalities depend on strong governance which is necessary to ensure sustainable production. Finally, we end the section showing how agricultural credit can be a transformational tool, promoting intensification. We conclude the chapter with a clear message that, despite the large challenges that exist within the sector, it is possible to reconcile production to meet market demand while promoting conservation and long-term sustainability.

10.2 The General Context for Brazilian Livestock Production

The Brazilian beef cattle system is one of the most complex in the world. Cultural aspects, the relationship between sectoral agents and international markets, NGOs' positions, regional issues, production processes, technological endowments, and cattle breeds differ from state to state. Brazil has a strong internal market, exporting around 20–25% of its production. NGOs within the sector have presented demands for increased sustainability and transparency in the production process to ensure legal compliance and adherence to international demands for sustainable beef. The complexity of the beef supply chain in Brazil partly derives from the fact that it is among the oldest agricultural sectors in the country. The activity dates to the 1530s and has evolved ever since (da Silva et al., 2012). Understanding the structure and the modes of governance of the main agents involved in the system is key to defining its future development.

In Brazil, beef cattle production systems can be considered flexible and diverse. A historical economic perspective of this system illustrates the evolution of an activity that until the end of the 1990s was based on land expansion and asset valorization due to inflation. Profitability was mainly related to having large herds in ever-expanding areas and did not rely on productivity gains. With the end of hyperinflation in the mid-1990s, ranchers had to focus on increasing productivity, as this came to determine the profitability of cattle ranching. Technological improvements

regarding nutrition, sanitary issues, genetics, and monitoring and control processes have evolved ever since, with efficient and more sustainable alternatives (Wedekin et al., 2017). These technologies also adapt products to markets and consumers and, when coordinated, have the potential to optimize the system (Lemos & Zylbersztajn, 2017). The business environment in the beef industry has changed since the Plano Real – the economic plan that, in 1994, redefined the Brazilian macroeconomic structure and stabilized the currency. In the past, cattle were an asset to be transacted and hold liquid value for those who owned it. The macroeconomic transformations restructured this activity according to the logic of agribusiness and the continuous aspiration toward enhancement of efficiency. Given the highly extensive nature of this activity in terms of land use, Brazilian livestock production has been developed under a wide variety of environmental conditions, with respect to climatic characteristics and soil profile.

It is challenging to present a brief characterization of the Brazilian cattle production system. With more than 160 million hectares of pasture – 18.9% of the national territory and 45.8% of the area of rural properties[1] – any uniform definition of the forms of pasture usage or modes of production would be too simplistic. There are more than five million agricultural properties in Brazil, of which almost 50% engage in cattle ranching, and only 20.2% have already received some type of technical assistance (IBGE, 2017). According to the Municipal Livestock Research (Pesquisa da Pecuária Municipal – PPM) from the Brazilian Institute for Geography and Statistics (IBGE, 2021), there are 224,6 million animals in the Brazilian cattle herd. Mato Grosso is the state with the highest number of animals, with 32.4 million cattle, followed by Goiás with 24.3 million, and Pará with 23.9 million animals. Regarding beef production, 27.7 million cattle were slaughtered in 2021 in Brazil (SIF, SIE, SIM)[2] totaling 7.5 million tons of carcass equivalent in 2021 (IBGE, 2022). This volume is higher when accounting for uninspected slaughters. According to ABIEC (2022) in 2021, 9.7 million tons of beef were produced. Of this volume, a total of 2.5 million tons were destined for the international market, which is more than 20% of world beef exports. Projections from the Food and Agricultural Organization of the United Nations (FAO, 2018) suggest that the Brazilian bovine herd will increase by 2050. In a "business as usual" scenario, this herd should reach 264 million animals. Malafaia et al. (2021) highlight ten macro trends for the meat supply chain for 2040, some of which are related to improvements that impact productivity, traceability, and consolidation of the country as a major meat exporter. For this to occur in a sustainable way, productive intensification would need to be stimulated, as well as productivity increases. In this regard, technological adoption should be encouraged, as should compliance with environmental legislation. Public policies would need to be coordinated, and the conversion of new lands discouraged, which would help prevent illegal deforestation and land grabbing. At the same

[1] LAPIG – https://atlasdaspastagens.ufg.br/map

[2] The Brazilian slaughterhouses are classified according to the level of inspection by authorities. There are SIF (Federal Inspection), SIE (State Inspection), and SIM (Municipal Inspection) slaughter plants.

time, the beef supply chain should be strengthened and technological adoption stimulated through rural credit and technical assistance (Stabile et al., 2020). Brazil is already a large exporter and producer of beef. However, with technology adoption, appropriate conditions, and environmental governance, the country could expand its production in a sustainable manner, contributing to climate change mitigation, curbing deforestation, and increasing production through productivity gains to supply to both internal and external markets.

10.3 Challenges for Sustainable Production

10.3.1 Supply Chain Complexity

Brazil has a significant potential for sustainability improvements within beef production, but the sector faces many challenges that would need to be addressed. The complexity of the supply chain is large, as it involves many actors, directly or indirectly linked to production, as is shown in Fig. 10.1.

The breeding of calves is concentrated in small rural properties, while rearing and fattening occurs more frequently in medium and large ranches. According to the agricultural census, there are 2.5 million establishments with cattle ranching in the country, 24% of which are medium and large ranchers, while 76% are smallholder ranchers. On the other hand, 69% of the herd is concentrated in medium and large properties and only 31% in smallholder ranches. Tables 10.1 and 10.2 present the distribution of cattle farming by region. This poses a challenge to the supply chain, as the small ranchers, with less numerous herds, are responsible for the breeding phase. Many cattle transactions exist between small and medium/large ranchers, but data registers of these transactions are still scarce. Smallholders often have little (if any) access to credit, technical assistance, and technological assistance that would improve their productivity.

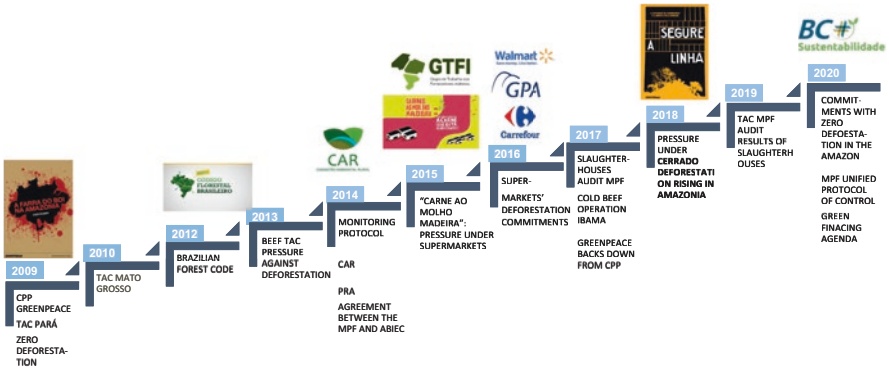

Fig. 10.1 Complexity of the beef supply chain. (Adapted from Proforest, 2017)

Table 10.1 Percentage of farms with cattle by size category and geographic region (IBGE, 2017)

	Total establishments 2.5 million	
	% of establishments by category and region	
	Medium and large producers	Smallholders
North	22.31%	77.69%
Northeast	19.42%	80.58%
Southeast	30.20%	69.80%
South	20.11%	79.89%
Center-west	35.20%	64.80%
Brazil	**23.96%**	**76.04%**

Table 10.2 Percentage of herd by size category and geographical region (IBGE, 2017)

	% of the herd by category and region	
	Medium and large	Small
North	62.98%	37.02%
Northeast	52.16%	47.84%
Southeast	66.12%	33.88%
South	61.07%	38.93%
Center-west	82.83%	17.17%
Brazil	68.96%	31.04%

Productive intensification can result in the concentration of ranching activities in medium and large establishments, which could constitute a significant social challenge, as small family producers migrate to the city or simply abandon the activity. The sector is marked by a high level of informality, and transactions take place without fiscal and health records, representing a risk to the whole herd. Experts, therefore, estimate that the Brazilian cattle slaughter is 25% higher than that reported in the agricultural census.

10.3.2 Pasture Degradation

Given that Brazil has the world's largest commercial pasture-raised cattle herd, it becomes crucial to pay attention to some aspects of pasture use, and consequently, degradation. In Brazil, pastures frequently occupy marginal areas, with low agricultural potential and with a tendency to expand to areas far from large consumer markets with poorer road infrastructure and means of transportation. These particularities make Brazilian livestock an activity that relies heavily on occupation and possession of large territorial extensions (Dias-Filho, 2014). When occupying marginal areas without proper management, pastures will naturally degrade, which is a continuous process of loss of vigor, productivity, and the ability to sustain a high

stocking rate of cattle (animal/ha) without suffering a loss of carrying capacity.[3] The more advanced the stage of degradation, the less productive the pasture is, and the greater the costs for cattle ranching intensification. The most recent data collected by the Laboratory of Image Processing and Geoprocessing of the Federal University of Goiás (Lapig/UFG) suggests that of the 160 million hectares occupied by pastures in Brazil in 2021, 46% have little or no degree of degradation, while the remaining 54% present intermediate to severe degradation, highlighting the importance of initiatives to recover these degraded pastures (dos Santos et al., 2022). Scott Consultoria (2021) has estimated the costs for the recovery of pastures in Mato Grosso in 2020. Three technological levels were listed, namely, minimum recovery, with minimum operation and inputs; normal recovery, requiring expert assistance; and recovery with high technology, according to the technical recommendations for a pasture with high productivity. With minimal recovery, the estimated cost was R$ 721.01 (U$ 151.50) per hectare. With the normal recovery, the cost was R$ 1890.06 (U$ 397.00) per hectare, and with the high technology recovery, the estimated cost was R$ 2982.18 (U$ 626.50) per hectare. That is, from the minimal recovery for high-tech, the increase in costs was 313%. This raises the important question of whether recovery costs offset the costs of intensified production. For the three technological levels used for pasture recovery, the study predicted pasture life span after recovery of 4, 7, and 10 years, and stocking rates (SR,[4] AU[5] ha^{-1} $year^{-1}$) of 0.9, 1.3, and 2.3 for minimal, normal, and high-tech recovery, respectively. The necessary pasture area after intensification can be estimated in the three scenarios, given the number of animals in the pastures. If the current herd is all kept and intensification of degraded areas is undertaken to minimal recovery, under scenario 1 (0.9 AU $ha^{-1}.year^{-1}$), 160.15 mi ha are needed. If there is a transition to scenario 2 (1.3 AU $ha^{-1}.year^{-1}$), 122.04 mi ha of pasture areas would be necessary. Finally, if the high-tech recovery is undertaken in scenario 3 (2.3 AU $ha^{-1}.year^{-1}$), 114.74 mi ha would be needed to accommodate the herd.

Considering the total pasture area in 2021, this means that when pastures are recovered, 77.2%, 58.7%, and 55.2% of the area would be required after the recoveries in scenarios 1, 2, and 3, respectively. Thus, 10.62%, 28.8%, and 32.3% of the areas currently occupied by pastures could be released to be used for other purposes without compromising the herd and productivity. However, for this to occur, it is necessary to promote technology adoption and investments in ranches.

[3] Carrying capacity, also known as grazing capacity, is the amount of forage available for grazing animals in a specific pasture or field, without suffering degradation from overgrazing (Allen et al., 2011).

[4] Stocking rate is the relationship between the number of animals and the total area of the land in one or more units utilized over a specified time, an animal-to-land relationship over time (Allen et al., 2011).

[5] An animal unit is based on the assumption that metabolic requirements are related to metabolic weight and provide the basis for comparison among different kinds and classes of animals (Allen et al., 2011).

10.3.3 Economic and Environmental Feasibility

Livestock ranching in Brazil has shown to be a very democratic activity, as the gains obtained by scaling production do not always overcome the advantages of managing a smaller business. The growth in profitability as the size of the property increases is not significant, contrary to what is the case with activities that demand greater investment in infrastructure for production. Much of this is explained by the predominance of pasture-based production in Brazil. Considering that around 15% of cattle are finished in feedlots and that these animals already enter the final stage with 65–75% of the slaughter weight, it can be deduced that more than 95% of Brazilian meat is produced in grazing systems. In addition to the "size" factor, El-Memari Neto (2021) highlights that other factors such as climate, soil, location, and production stage, in isolation, are not decisive to ensure positive economic results at the ranch level. On the other hand, the investment made for each kg produced, the average daily weight gain of the animals, and the amount produced per ha are the variables most highly correlated with the financial sustainability of the ranches.

10.3.4 Livestock Greenhouse Gas Emissions

Despite the potential of Brazilian forests to capture carbon, in 2020, Brazil ranked as the 12th highest global greenhouse gases (GHG) emitter, according to Climate Watch data (Climate Watch and World Resources Institute, 2022). These emissions are mainly driven by the elevation in deforestation rates. According to SEEG (2022), in 2021, the land use change sector was responsible for most of the GHG emissions in Brazil, representing 49% of the gross total or 1.19 million tons of CO2e (MtCO2e). When considering net emissions and discounting removals (carbon sequestered by secondary forests, protected areas and indigenous lands), this share decreases to 30% (362 MtCO2e) (SEEG, 2022). Most emissions from this sector (93%) are caused by land use changes, which in turn is the result of the conversion of native vegetation remaining in anthropic areas, part of which is used for agricultural and livestock production (EMBRAPA & INPE, 2018; Salomão et al., 2021). Most emissions from land use change consist of deforestation in the Amazon biome, which concentrated 78% of the sector's gross emissions in 2020 (Potenza et al., 2021). Agriculture and livestock are the second largest source of emissions in Brazil in 2021, accounting for 25% of total gross emissions (601 MtCO2e), followed by the energy sector with 18% (435 MtCO2e), industry with 4% (108 MtCO2e), and waste with 4% (91 MtCO2e) of total emissions (SEEG, 2022). Figure 10.2 presents Brazilian emissions by sector from 1990 to 2021 and illustrates the contrast between the Brazilian emissions profile and that of most industrialized countries, whose main source of emissions is normally their energy matrix (Claudio & Carlos, 2019).

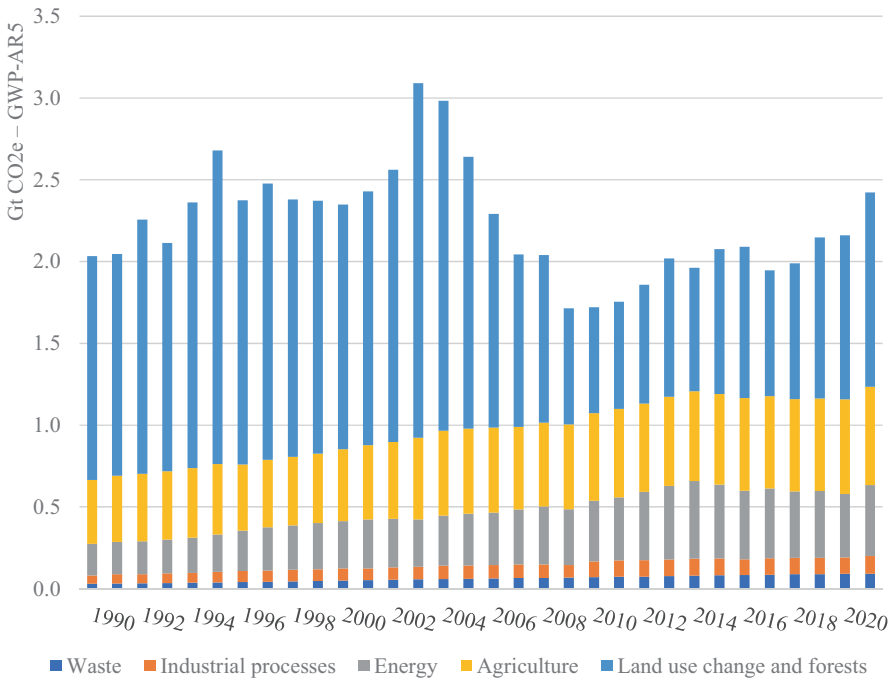

Fig. 10.2 Brazilian greenhouse gas emissions by sector from 1990 to 2021 in $GtCO_2eq$. (SEEG, 2022)

When disaggregating direct emissions from the agricultural sector, disregarding those derived from changes in land use, livestock production stands as the most emissions-intensive activity. This is mainly due to the enteric fermentation of cattle, in addition to emissions from cultivated soils, with the leaching of animal waste (Margulis et al., 2019). Some of the emissions computed as "agricultural soils" also derive from livestock activity, through leaching and degradation of waste deposited on pastures. In 2021, enteric fermentation was responsible for the emission of 383 MtCO2e (64% of total emissions from the agricultural sector), an increase of 3% compared to 2020 (SEEG, 2022). In 2020, these emissions were generated by the digestion of ruminants, mainly beef and dairy cattle, which account for 97% (Potenza et al., 2021).

10.3.5 Deforestation, Sectoral Agreements, Monitoring, and Traceability of the Chain

Decoupling cattle ranching from deforestation presents a major challenge for the Brazilian beef production chain, especially in the Amazon and Cerrado regions. The most recent data from TerraClass 2014, a program from the National Institute for Space Research (Port. INPE) that mapped land use in deforested areas up to 2014,

demonstrated that around 65% of the deforested areas in the Amazon was pasture areas in 2014, and 23% were classified as secondary vegetation (EMBRAPA & INPE, 2018).[6]

The lack of land and environmental governance as well as the existence of many non-designated public areas (around 62.7 million hectares in the Legal Amazon states)[7] encourage illegal occupation (Azevedo-Ramos et al., 2020). A study by Salomão et al. (2021) analyzing the dynamics of deforestation in public areas shows that more than 18 million hectares of public lands were cleared up to 2020, of which 75% were classified as pasture areas. The clearing of these areas has a more speculative than productive purpose since the current state of legal enforcement suggests that these illicit acts are likely to be pardoned. Subsequently, such areas may receive a land title and be sold to farmers for use as pasture and agricultural areas.

International consumers as well as retail chains and meatpackers are increasingly committed to eliminating deforestation from their supply chains. Concerns from Brazilian consumers have also increased, albeit to a lesser extent. Given the importance of reducing deforestation associated with livestock, two essential concepts are worthy of mentioning: traceability and monitoring. These terms are highly complementary but still different. While traceability relates to product identification, monitoring refers to the place of animal production or food processing (GTPS, 2022). Traceability works as a tool that aims to offer the ability to identify raw materials, inputs, and components of products or services in the process stages (origin, reception, production, transformation, and distribution). Monitoring, on the other hand, makes it possible to know everything about the life cycle of the animal since birth (GTPS, 2022). Monitoring and traceability of the livestock value chain are a complex task, considering the number of cattle producers distributed on 2.5 million rural establishments (IBGE, 2017); the many phases of livestock production; the heterogeneity of the production systems and technologies adopted; and the different profiles of ranchers, intermediaries, among others.

Since 2009, the country's main meatpackers have signed agreements with civil society and the Federal Public Ministry to monitor cattle suppliers to avoid direct sourcing of animals from farms in the Amazon biome with illegal deforestation. Since then, several initiatives have been undertaken by meatpackers and other actors in the product chain (as can be seen in Fig. 10.3). Among these measures, the Conduct Adjustment Term (TAC) and the Public Livestock Commitment (CPP) stand out; the TAC is an initiative of the Federal Public Prosecutor (MPF) and the CPP a voluntary protocol initiated by Greenpeace.

[6] The TerraClass project's objective is to qualify deforestation in the legal Amazon, based on the deforested areas mapped and published by the PRODES Project (Monitoring the Brazilian Amazon Forest by Satellite) and satellite images. It presents the results of the mapping of the use and coverage of the land in the Legal Amazon for all deforested areas mapped by PRODES until 2014 (INPE, 2022).

[7] The National Register of Public Forests shows 62.7 million hectares of non-designated public forests in the Legal Amazon states (North region and Mato Grosso state), out of 63.2 million hectares in Brazil (SFB, 2020).

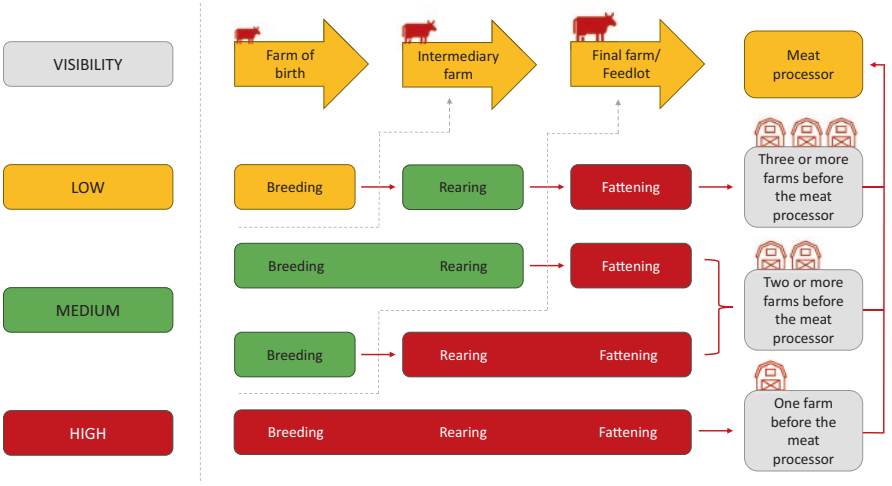

Fig. 10.3 Historical perspective on the monitoring and traceability of the beef system targeting deforestation. (Adapted from Harfuch, 2021)

In these two agreements, the monitoring of the origin of cattle is the main strategy to ensure that animals do not originate from deforested areas. The participating companies have agreed to trade only with livestock properties that comply with the environmental and social rules provided for in the agreement. Among these rules is the pledge not to purchase livestock from areas deforested after 2009 or originating from properties with labor analogous to slavery (Armelin et al., 2020). Both agreements represent important initiatives for mitigating deforestation in the Amazon. The fact that these agreements only monitor the last property the animal passed through before reaching the slaughterhouse (direct supplier) is a limitation, meatpackers and other actors in the retail chain thereby risk selling products from animals that may have passed through properties with deforestation (Armelin et al., 2020).

The MPF was also at the forefront of another important initiative aimed at reducing deforestation. An agreement was signed in 2014 between the Brazilian Association of Meat Exporting Industries (ABIEC) and the MPF for technical cooperation for sustainable livestock ranching in the Legal Amazon. This agreement requires the exclusion of ranchers who do not comply with the Forest Code,[8] that is,

[8] The Forest Code (Law n. 12,651/2012) presents the regulatory framework and the process that rural properties or possessions need to follow to comply with their environmental requirements. It establishes minimum areas of native vegetation on rural properties, which may be Legal Reserves (RL) or Permanent Preservation Areas (APP). APPs are mandatory preservation areas close to water courses, sloping areas, etc. If there is no minimum vegetation covered in these areas, they must be recomposed. RLs are calculated as percentages of rural property areas, varying according to the biome in which the property is located. For a comprehensive analysis of the Brazilian Forest Code, see "The Brazilian Forest Code: the challenges of legal implementation."

the slaughterhouses linked to ABIEC do not trade with these ranchers. The main goal of the action is to ban slaughterhouses that produce meat from areas with socio-environmental problems (MPF, 2014).

In 2016, Greenpeace also led another important campaign to reduce deforestation associated with livestock: *Carne ao Molho Madeira.*[9] This campaign encourages companies involved in the livestock chain (farms, slaughterhouses, and supermarkets) to commit to zero deforestation in the Amazon (Greenpeace, 2015). As part of the campaign, in 2015, seven Brazilian supermarkets (which represent approximately two-thirds of all national retail sales) were evaluated and ranked according to a methodology that estimates the risk/potential of these supermarkets buying meat from deforested areas. Following pressure from the *Carne ao Molho Madeira* Campaign, many large supermarkets made public zero deforestation commitments in 2016. However, these commitments face great obstacles to implementation, as supermarkets report much difficulty tracking animals in the early stages of their life cycle.

Due to international environmental pressures, the Central Bank of Brazil (BC) instituted a new agenda that sought to contribute to the allocation of resources for the development of a more sustainable economy. In 2020, the BC became a supporter of the Task Force on Climate-related Financial Disclosures (TCFD), which is a measure that meets the requests of the G20 to consider the risks to financial stability associated with climate change within the scope of the Financial Stability Board (FSB). Among these measures is the control of deforestation in Brazil as part of the BC sustainability strategy (BC# Sustainability agenda), launched in 2020 (Banco Central, 2022a). In 2021, the BC launched public consultations to improve the management of climate, social, and environmental risks as part of financial market regulations. Among them, socio-environmental restrictions for rural credit takers have been improved, and Brazil's Central Bank BC was expected to launch incentives for rural credit aligned with sustainability goals in 2022. However, until the closing of this chapter, no further details on this matter were announced.

Finally, traceability and monitoring of the beef value chain still needs to be improved in Brazil, given its complexities. For this purpose, it becomes necessary to work with a point of departure in the regulatory framework to take action throughout the chain (governments, producers, and financial markets). On the other hand, there are important advances in monitoring deforestation associated with livestock activities, especially with the development of more efficient monitoring technologies from the birth of the animal to slaughter.

[9] "Carne ao Molho Madeira" translated into English means "Meat in wood sauce," the choice of this name refers to a dish commonly served in Brazil (with brown beef sauce). The words associated with this dish can have a double meaning since the name of the dish combines meat and wood in the term, which can be associated with deforestation from livestock production.

10.4 Intensification as a Pathway to Increase Production Without Deforestation

In the past two decades, it has been demonstrated in Brazil that it is possible to intensify animal production in pastures without clearing new areas – even combined with the reduction of areas occupied with pastures (see Fig. 10.4).

Brazil has a significant potential for sustainability improvements within beef production, but the sector is marked by a series of challenges that must be addressed. The complexity of the supply chain is large, as it involves many actors, directly or indirectly linked to production, as is shown in Fig. 10.1.

The improvement in livestock production efficiency cannot be understood by focusing on one single factor or cause. This highlights the importance of describing how efficiency gains are achieved without the need to expand pasture areas. We thus emphasize the main tools to achieve these objectives, which characterize the management of pastures.

10.4.1 Pasture Management

Pasture management relies on the manipulation of the soil-plant-animal complex in order to obtain desired results (Allen et al., 2011). Several strategies exist for this purpose, such as pasture fertilization, control of grazing heights, the use of dietary supplementation for animals, pasture irrigation, and control of invasive plants and pests, among other new technologies. The use of new and more productive forage cultivars, adapted to local conditions and with embedded technologies, has

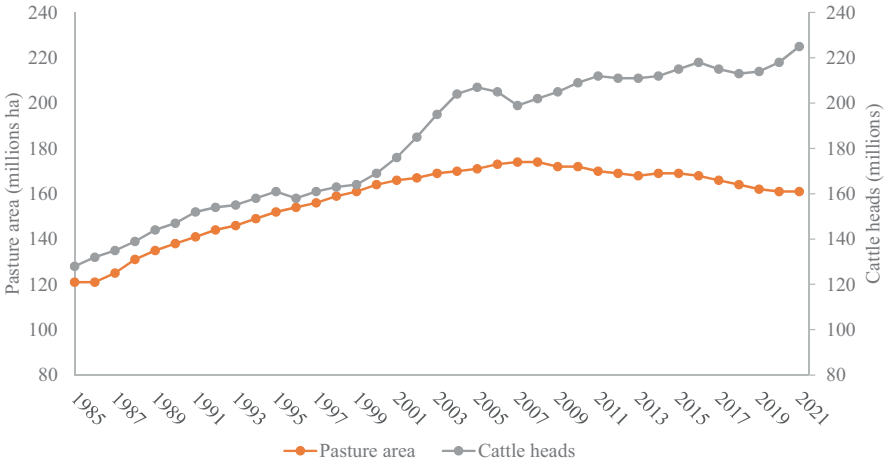

Fig. 10.4 Pasture area (ha) and cattle herd (animal units – AU) in Brazil. (Parente et al., 2019; IBGE, 2022)

contributed to the increase of animal production in pastures. The continuous introduction of new cultivars is thereby key to improving sustainability outcomes. When analyzing some Brachiaria[10] cultivars released in the last decade, we observe, for example, that the cultivars BRS Ypyporã, BRS Paiaguás, Sabiá, and Braúna function by reducing the monoculture of the Marandu cultivar throughout Brazil. These cultivars thereby become alternatives for forage production, as they are adapted to more specific soil and climate conditions. The occurrence of insect pests in pastures has made it difficult to obtain greater profitability in a sustainable way in production systems, mainly due to the significant reductions in pasture productivity caused by such damages. The main pests in Brazil today are the spittlebugs, defoliating caterpillars, and the brown stink bug, which in recent years have caused difficulties for producers by contributing to the degradation of pastures. In this regard, biological control practices have a great potential for controlling these insects, in addition to being a viable, economic, and ecological tool (Souza et al., 2019). Unlike chemical products, biological control of pests in pastures does not pollute water and soil. In entomology, biological control has been used to describe the use of live predatory insects, entomopathogenic nematodes, or microbial pathogens to suppress populations of different pest insects. Biological control practices have increasingly been gaining space in Brazil because of the engagement of Embrapa and private companies through research associated with new technologies and training and dissemination programs.

New technologies related to pasture fertilization in Brazil are continuously being developed, especially those relying on alternative fertilizers, due to the fact that the country depends on importing a substantial share of these products. 2021 was a record year for Brazil's import of fertilizers, which reached a level of more than 41.6 million tons (CONAB, 2022). With the high prices of these imports, efforts to introduce more affordable fertilizers or alternative strategies have been gaining ground. This is the case of the intercropping of leguminous plants with pastures grasses, the use of organic residues from industries or animal husbandry (manure), the use of remineralizers such as rock dust, and applications of inoculants based on nitrogen fixing bacteria in pastures, in addition to foliar fertilization.

The use of biological inputs to improve the efficiency of nitrogen fertilizers is an alternative to growing grasses in tropical regions, as it aims to reduce fertilizer costs and environmental risks, especially with nitrogen leaching. Therefore, inoculation with bacteria capable of fixing atmospheric nitrogen (N_2) or supporting plant growth by other mechanisms, such as the production of phytohormones, is presented as an important sustainability strategy (Hungria et al., 2016; Marques et al., 2017; Costa Leite et al., 2018). Another strategy that has been gaining prominence is the use of practices associated with animal welfare. In extensive systems, especially in tropical regions, excessive heat can cause stress and physiological discomfort in cattle,

[10] *Brachiaria* is a genus within the Gramineae family, native to the African continent, and therefore considered exotic in Brazilian territory. It is a genus with plants very adapted to the edaphoclimatic conditions of Brazil. It is estimated that the genus occupies approximately 80% of the cultivated pastures in Brazil nowadays.

in addition to a decrease in animal welfare. Thus, productive systems capable of mitigating heat through trees are essential for the sustainability of livestock in the tropics (Laura et al., 2015).

10.4.2 Technology Adoption

Another technology that can contribute to greater efficiency in the use of pastures in Brazil while averting an increase in cultivated areas is called Precision Animal Science. This technology relies on geoprocessing using spectral information obtained from satellite or aerial images, or by the use of sensors such as spectroradiometers and portable chlorophyll meters that generate vegetation indices (VI). When associated with field evaluations, such as forage mass produced, pasture height, nitrogen content among others, these VIs allow for real-time pasture evaluation with high accuracy throughout extensive areas, taking into account the heterogeneity of the pasture (Xue & Su, 2017; Tong et al., 2019). Thus, Precision Animal Science supports decision-making to develop strategies with the objective of producing more without degrading the pasture or deforesting new areas. Decision-making ranges from adjusting the number of animals in pastures depending on the amount of forage available to controlling invasive plants in pastures.

Geoprocessing can also be used for planning fieldwork using aerial images or photographs, such as, for example, selection of grazing sites, and sites for collecting forage and/or soil samples. This technology can also be used for identification, quantification, and tracking of animals in a given area, which normally is a complex task in extensive areas of pastures. This quantification of animals permits assessing the stocking rate (SR), which is essential for a more intensive and sustainable pasture management. Tracking provides the standardization and identification of cattle, which favors meat exports to specific markets, and facilitates the management of herds on the properties.

Silvopastoral systems or livestock-forest integration[11] are systems in which forage, animals, and tree components simultaneously or sequentially occupy the same area. These systems reduce the negative environmental impacts inherent to conventional systems of livestock production in pastures, as they favor the ecological restoration of degraded areas. These systems can also improve the conditions for the development of forage and the productive and reproductive performance of the animals. Moreover, they can also help to diversify the production of rural properties, generating profits and additional products, such as wood and fruits, and support the intensification and sustainable use of the soil, in addition to several other benefits (Franke & Furtado, 2001).

[11] See Chapter "Crop-Livestock-Forest Integration Systems as a Sustainable Production Strategy in Brazil" for a comprehensive analysis of integrated systems.

10.4.3 Sanitary Control and Property Management

The increase in animal production in pastures also relies strongly on the health of the herd. Brazilian livestock is based on a strong structure of prevention and control of the main problems that can lead to losses in productivity or pose health risks to consumers. This is due to the strong presence of the official health defense and science and technology institutions. Vaccination campaigns for foot-and-mouth disease, elimination of outbreaks dates back to 2001; brucellosis, control of bovine tuberculosis through the National Program for the Control and Eradication of Bovine Brucellosis and Tuberculosis, implemented in Brazil in 2001; and the control of ticks, horn flies, and other parasites have become part of the sanitary management of the herd. Thus, sanitary precautions provide tools and solutions to guarantee productivity and profitability to producers. An important measure related to the sanitary management of the herd is compliance with mandatory immunization schedules, according to the instructions recommended by official animal health programs operating in Brazil.

The stabilization of the Brazilian economy in the 1990s represented a significant turning point in the management of livestock properties. Until the mid-1990s, livestock was regarded as an important mechanism to reserve capital, where animals with greater liquidity (finished animals for slaughter) were overvalued in relation to other products, making cattle ranching a very profitable activity, despite not focusing on productivity gains. However, nowadays the profit margins are lower for livestock production, which necessarily results in the need for more efficient management practices for natural and financial resources. More technical management of the production is the only way to keep beef cattle attractive to investors. Indeed, most Brazilian cattle ranchers still view the activity as a way to stock value; according to the IBGE Agricultural Census, 70.9% of ranch managers are over 45 years of age (IBGE, 2017).

Given the predominance of grazing systems in the production of beef cattle in Brazil, the main limitations concerning productivity are related to inefficient management of pastures. It is possible to maintain a year-round daily weight gain above 0.600 kg per animal on pasture in Brazil. However, to reach this level, adequate management of forage production and supply throughout the year is essential. The growth rate of forages is very low during the dry period of the year. On the other hand, tropical forages, when well-managed, offer good preservation of productive value during the dry season, permitting the maintenance of the animals' weight gain. Reserve strategies for younger forage plants combined with pasture fertilization and diet supplementation allow animals to gain significant weight at any time of the year in the pasture.

10.4.4 Optimization of Spatial Distribution

The great challenge of the beef value chain is the socioeconomic and environmental management of the territory, in line with the agreements signed with civil society and the MPF. In this sense, the clustering of sustainable origination of livestock has the potential to address these complex problems. Clustering is the act of grouping elements. In the case of spatial clusters, these can be defined as the part of a map in which the occurrence of cases of a phenomenon of interest is discrepant from the rest of the elements of the same map (Tavares, 2009). The aim is to group elements/individuals based on the similarity between them, allowing the groups to have greater homogeneity within them and heterogeneity between them.

The specific notion of a cluster of sustainable origination of livestock can be defined as the areas under the economic influence of the slaughterhouses. In this case, priority should be given to the intensification of local livestock – in addition to complying with environmental regulations. This supports herd health and lowers logistical costs, resulting in sustainable livestock production with improved meat quality and traceability of its origin (Harfuch et al., 2017). According to Harfuch et al. (2017), the main criteria for the delimitation a cluster of sustainable origination of livestock are:

- Concentration of the number of animals, pasture area, and the number of slaughterhouses.
- Potential risk of deforestation in the territory.
- Opportunity for productive expansion of agriculture and livestock intensification.
- Environmental regularization through compliance with the Brazilian Forest Code.
- Preestablished institutional arrangements between slaughterhouses, ranchers, governments, financial market, and other agricultural subsectors.

Brazil has many meatpacking plants with the potential to adopt a more integrated and efficient territorial management through the implementation of clusters. An example is the northern region of the state of Mato Grosso. A study of the management potential to develop this region as a cluster by Harfuch et al. (2017) identified an area of 19.9 million hectares, 8 slaughterhouse plants, and 1.51 million animals slaughtered in 2014. The cluster had the following land use distribution: (1) 56% of native vegetation, (2) 27% of pasture, and (3) 5% of agriculture. It was also observed that the area of this cluster has environmental liabilities under the Forest Code, with a Permanent Preservation Areas (APP, in Portuguese *Áreas de Preservação Permanente*)[12] deficit estimated at 106.6 thousand hectares and 1.18 million

[12]APP are those protected under the law, whether or not covered by native vegetation, with the environmental functions of preserving water resources, the landscape, geological stability, biodiversity, and the gene flow of fauna and flora; protect the soil; and ensure the well-being of human populations. The suppression of vegetation in APPs can only be authorized in case of public utility or social interest; otherwise, deforestation in the area is prohibited. The number of hectares of APP that a rural property must have depends on the type of region, and this information is present in the Brazilian Forest Code (Senado Federal do Brasil, 2022).

hectares in Legal Reserve[13] (RL, in Portuguese *Reserva Legal*) liabilities. In other words, the cluster area needs environmental compliance through the recovery of native vegetation (or compensated in other native vegetation areas in the case of RL). In the pasture area, an intensification potential of 4.96 million hectares is observed. This intensification process could lead to the release of 1.42 million hectares, which could be used to fulfill the deficit areas of APP and RL (regulating the environmental situation) and additionally raising income by permitting the leasing of a pasture area for soybeans.

Finally, an integrated landscape approach combined with low-carbon practices and climate resilience would also be part of the solution, whose sustainable origination cluster is a win-win alternative for the value chain. The slaughterhouse should assume the role of manager of the territory in which it has economic influence. Cattle ranchers could have a guarantee for the purchase of cattle, access to credit for sustainable intensification, and environmental regularization of the property and would still benefit from higher income from the activity and property appreciation. Governments and civil society would also benefit from this transformation in the value chain, which could boost compliance with environmental legislation and agreements signed within the meat chain. For financial institutions, these clusters would facilitate the integrated management of risks (economic, social, environmental, and climate) and the definition of environmental, social, and governance (ESG) parameters to finance the different links in the beef chain.

10.4.5 Social Inclusion, Reduction of Informality, and Illegalities

Productive intensification on small properties through technological adoption, access to credit, and technical assistance can have a transformative effect. Small properties (below 300 hectares estimated by the authors) of low productivity that adopt the full cycle of livestock production are not economically viable in the Amazon or the Cerrado, unless they intensify 100% of their productive area, from a medium to a high production technology (6–18 @/ha/year). Thus, intensification, associated with productive diversification, can provide a solution to keep producers in business (Harfuch et al., 2017).

The reduction of informality in the sector – something that happens with better sanitary, fiscal, and environmental governance – would provide full information about the origin of the animals, allowing any sanitary issue (e.g., foot-and-mouth or mad cow diseases) to be managed quickly. In addition, the value chain actors can

[13] The RL is defined by the same law as the APP (Brazilian Forest Code). The RL is an area located inside a rural property or possession that must be destined for permanent preservation. It must be ensured that in the RL area, there is (i) sustainable use of natural resources; (ii) conservation and rehabilitation of ecological processes; (iii) conservation of biodiversity; and (iv) shelter and protection of native fauna and flora (Senado Federal do Brasil, 2022).

seek to charge the market for preferential market access or differentiated prices for delivering a product that complies with environmental legislation and adheres to principles of animal welfare and sanitation.

10.4.6 Agricultural Policy and Rural Credit

In the 2010s, there was a reduction in the total pasture area (mainly pasture with a severe degree of degradation), while the cattle herd grew, showing an increase in the productivity of livestock activity, as earlier presented in Fig. 10.4. Public policies provided important incentives for the restoration of areas with degraded pastures, contributing to their recovery (in addition to the intensification of livestock activities). The Low Emission Plan for Agriculture, so-called ABC Plan, can be highlighted in this regard (Brasil, 2011; Lima et al., 2020). Under the aegis of the National Policy on Climate Change (PNMC), the ABC Plan has become one of Brazil's main strategies for achieving the commitments made in the UN Conventions on Climate Change.

Considering that agriculture and land use are the main sources of GHG emissions, the ABC Plan was relatively successful in promoting the technological transition to low-carbon agriculture in the past decade (2010–2020). The plan contained the following voluntary targets: (1) recover 15 million hectares of degraded pasture; (2) implement four million hectares of integrated systems (crop-livestock-forest, among other combinations); (3) increase no-tillage by eight million hectares; (4) expansion of the biological nitrogen-fixation technique to another 5.5 million hectares; (5) expansion of planted forests by three million hectares; and (6) improvement of the management of animal waste for bioenergy by 4.4 million cubic meters (m^3) (Brasil, 2011).

To support the fulfillment of these goals, the federal government provided a special line of credit to finance the adoption of sustainable technologies/projects through the ABC Program. In the first decade since it was launched, from 2011/2012 to 2021/2022, the total rural credit borrowed under ABC Program sum amounted to 24 billion reais (nominal values) (as detailed in Fig. 10.5) (Banco Central, 2022b). The preliminary survey of the results of the ABC Plan carried out by the Brazilian Ministry of Agriculture (MAPA) shows that around 52 million hectares saw the implementation of some ABC technology between 2010 and 2018. The recovery of degraded pastures alone accounted for 26.8 million hectares in the period (MAPA & Brasil, 2021).

The ABC Program only represented 0.93% of the total allocation of the agricultural rural credit policy (crop years 2011/2012 to 2021/2022), as can be seen in Fig. 10.6. There was nonetheless a growth in the provision of this credit by 110,49% during this same period, according to available data from the Central Bank of Brazil (Agroicone based on Banco Central, 2022b). Despite the rapid growth of the credit line, there are opportunities to further increase the adoption of low-carbon technologies and sustainable development through rural credit in Brazil. In this sense,

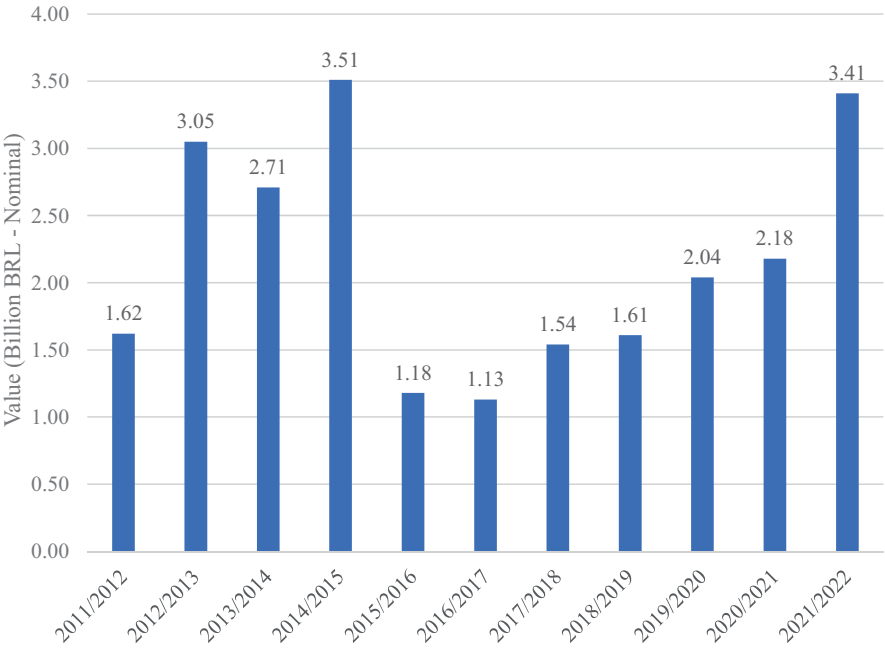

Fig. 10.5 Rural credit contracted per year in the ABC Program (billion of nominal reais – R$), crop years 2011/2012 to 2021/2022, Brazil. (Reproduced from Agroicone based on Banco Central, 2022a)

promoting greater access to the ABC Program (or Pronaf ABC+[14] for family farmers) for small- and medium-sized rural producers as well as ensuring a better distribution of resources regionally in the country would be important steps to advance policies aimed at sustainable development and GHG mitigation in the agricultural sector (Lima et al., 2020).

Of the R$ 13.04 billion of resources taken from rural credit of ABC Program for investment purposes between the crop years 2011/2012 to 2021/2022, only R$ 2.95 billion (23%) were allocated to "pastures." Figure 10.7 shows the allocation of resources to livestock through rural credit from the ABC Program. At least 29% of rural credit from the ABC Program is linked to livestock (pasture and cattle). In addition, part of the resources linked to intensive soil correction and fertilization was also used in improvements in pasture areas.

In 2021, the Brazilian federal government launched the Adaptation and Low Carbon Emissions in Agriculture Plan – ABC+ aimed at the period from 2020 to 2030. The ABC+ presents substantial differences when compared to the first ABC Plan (2010–2020), with more ambitious GHG mitigation goals, which jointly aim

[14] Pronaf ABC+ are investment credit lines that finance ABC+ plan practices and technologies. They were launched only in July 2022, although Pronaf already financed ABC plan in the first cycle 2010–2020 without explicit credit lines as since 2022.

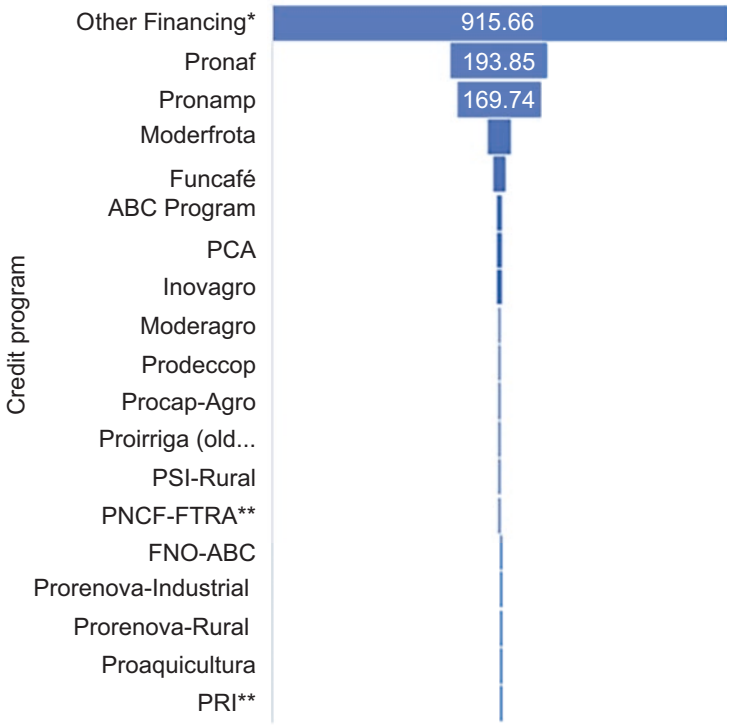

Fig. 10.6 Rural credit resources contracted by program, in billions of nominal reais – R$, crop years 2011/2012 to 2021/2022. (Reproduced from Agroicone based on Banco Central, 2022b)
Other Financing*: financing without link to a specific credit program
PNCF-FTRA**: National Land Credit Program
PRI***: Investment Reinforcement Program (CIRC 3745)

to reach an area of 72.68 million ha by 2030. Table 10.3 presents the goals of the ABC+ Plan (MAPA, 2021).

Additionally, the entire set of objectives, strategies, actions, activities, and goals are based on three conceptual bases that govern the ABC+ structure for the new 2020–2030 cycle. These are integrated landscape approaches; adoption and maintenance of sustainable production systems, practices, products, and processes (SPS ABC); and interconnection between mitigation and adaptation to climate change. In this way, ABC+ guarantees the foundations of an institutional ecosystem oriented toward sustainability in agriculture, defining an operational plan with well-established goals and actions. Along with reducing deforestation, ABC+ is Brazil's main strategy under the Paris Agreement. It is up to the state, civil society, and the private sector to promote such actions, in partnership with the state and municipal spheres, always in line with policies to encourage sectoral, financial, technological, and market innovations.

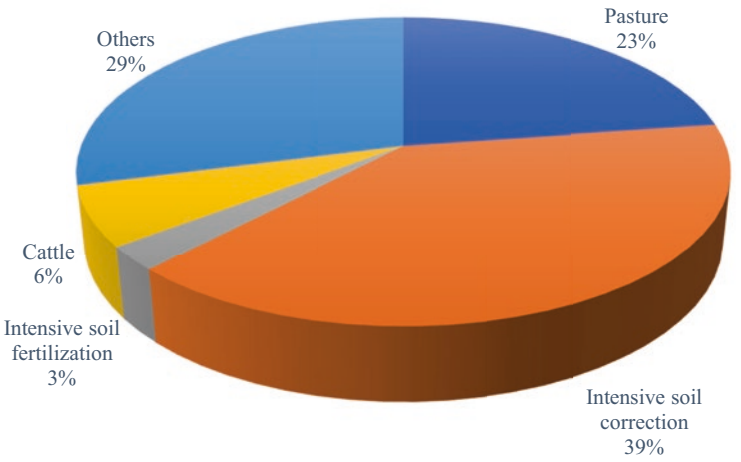

Fig. 10.7 Rural credit contracted per year in the ABC Program per product, in % of value contracted, crop years 2011/2012 to 2021/2022. (Reproduced from Agroicone based on Banco Central, 2022b)

Table 10.3 ABC+ plan goals (MAPA, 2021; MAPA & Brasil, 2021)

SPSABC	Target	Potential mitigation (Million Mg CO2eq)
Degraded pastures recovery	30 million ha	113.7
Crop-livestock-forestry integration systems	10 million ha	34.11
Agroforestry systems	0.10 million ha	37.9
No-till grain systems	12.50 million ha	46.71
No-till vegetables system	0.08 million ha	0.88
Planted forest	4 million ha	510
Bio inputs	13 million ha	23
Irrigated systems	3 million ha	50
Intensive termination (IT)	5 million of animals	16.24
Animal production residue management	208.40 million m^3	277.8
Range in hectares, millions of m^3, and number of animals	72.68 million ha + 208.40 million m^3 + 5 million of animals	1110.34

10.5 Conclusions

Although Brazil faces challenges arising from the territorial occupation pattern and limited access to technologies by ranchers, and from deforestation and emissions from livestock production, since the early 2000s, the profile of the activity has changed significantly. With a growing national and international demand for Brazilian beef, the country is in a favorable position to remain a major producer and exporter of beef. The adoption of pasture management technologies, the

introduction of new varieties of grass, genetic improvements in the herd, the adoption of geotechnologies, and significant improvements in property management have allowed for significant productivity increases, with noticeable gains in production linked to a reduction in the pasture area. This has permitted the expansion of other productive activities.

Advances, such as the significant adoption of integrated production systems, also allow for an increase in productivity per hectare but underscore the need for predictability of rainfall cycles. Although livestock production may occur in marginal areas for agriculture, both Brazilian livestock and agriculture are largely dependent on rainfall. Thus, it is highly important to mitigate the effects of climate change by maintaining rain patterns. In this regard, the reduction of deforestation is a long-term natural "insurance" that contributes to climate change mitigation, guaranteeing the viability of the activity from north to south of the country. The challenge that the country faces is not linked to production itself but to a confusing/opaque environmental and land governance system, which emits mixed signals and promotes perverse incentives that make illegal activity, such as land grabbing, attractive. The alignment of public and private policies must send a clear signal to producers that improving productivity is the way to go instead of expanding areas. Brazil possesses the opportunity to increase beef production, promote social justice, and serve the domestic and foreign markets efficiently and competitively in the international context.

Finally, it is necessary to develop a positive, inclusive, and transformative agenda for livestock, with a focus on the sustainable intensification of the activity, which becomes necessary both to increase its competitiveness and to achieve socio-environmental goals in the long term. Here we have highlighted some of the challenges that sustainable cattle ranching in Brazil faces, as well as solutions to these challenges. We have shown, however, that by proposing targeted intensification, utilizing existing tools (geotechnologies, genetics, pasture management, credit, etc.) aligned with increased governance and market demands, Brazil can increase its beef output, allowing for agricultural expansion to occur in existing pasturelands, while meeting both market demands and conservation needs.

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