

# Lessons from the Expansion of Cattle Ranching in Brazil (2000-2023) for Sustainable and Efficient Production

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## **About Amazonia 2030**

The AMAZONIA 2030 project is an initiative by Brazilian researchers to develop a sustainable development plan for the Brazilian Amazon. By 2030, we aim to provide the conditions for the region to reach a higher economic and human development level and achieve sustainable use of natural resources.

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# Executive Summary

This document presents the lessons learned about the expansion of livestock farming in Brazil between 2000 and 2023 and strategic recommendations to promote more productive and sustainable livestock farming.

In 2023, cattle ranching occupied 64% of Brazil's agricultural area (Mapbiomas Brasil, 2023) but contributed only 17% of the sector's gross production value<sup>1</sup>. This limited performance reflects the inefficient use of land, since 64% of pastures (105 million hectares) were of low or intermediate vigor, according to data produced by researchers from the Mapbiomas network (Mapbiomas Brasil, 2023). In addition, the sector was responsible for 51% of the country's greenhouse gas emissions in 2021 (Alencar et al., 2023), mainly due to the deforestation associated with its expansion. Initiatives such as the National Program for the Conversion of Degraded Pastures (PNCPD), launched in December 2023, seek to transform 40 million hectares into productive areas over the next ten years, indicating the government's intention to modernize and improve the sector (Brasil, 2023).

The document highlights the lessons learned in 23 years of expansion in the sector, a period in which public and private policies of incentives and pressure have promoted significant advances in productivity but have also revealed the persistence of structural and environmental challenges, especially in the Amazon. Based on this analysis, recommendations are presented to make the Brazilian cattle production more productive and sustainable. These measures can align economic growth and environmental conservation to improve living conditions in regions with low socio-economic indicators associated with low land use productivity.

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<sup>1</sup> The Brazilian government estimated that in 2023, the gross value of cattle production totaled R\$206.7 billion. Of this, R\$142.7 billion corresponds to production without milk, out of an overall total of R\$1.18 trillion. Data source: Brasil (2024b)

## **Main lessons from the expansion of livestock farming (2000-2023)**

- **Factors driving the increase in livestock production and productivity**
  - Public and private pressures and incentives
    - Economic incentives and environmental and quality requirements have driven productivity growth.
    - A relevant example was China's demand for meat from young animals, with price premiums of up to 30%, which coincided with increased productivity investments such as pasture recovery, artificial insemination, and feed supplementation (feedlots). Peru's demand for animals with greater growth potential and meat quality, accompanied by higher payments, encouraged advances in animal breeding.
    - The growing demand for productivity and quality has led to a significant increase in the use of rural credit focused on productivity items, from 13% in 2013 to 23% of the total in 2023.
    - Rural credit has made it possible to invest in productive technologies, such as pasture recovery, artificial insemination, and infrastructure for rotational grazing.
- **Combating deforestation**
  - Policies such as the PPCDAm (Action Plan for the Prevention and Control of Deforestation in the Legal Amazon) and the Soy Moratorium helped reduce deforestation by around 80% between 2003 and 2012, boosting more productive farming practices.
  - Increased enforcement has raised the cost of illegal deforestation and coincided with increased investment in pasture improvements and higher productivity. In contrast, degraded pastures have decreased in the country. Research has demonstrated that in instances where enhanced environmental control has been implemented, producers have adopted methodologies to

improve productivity within existing cultivated areas, harmonizing agricultural expansion and forest conservation.

- **The persistence of deforestation and degraded pastures**
  - Despite progress, 64% of pasture areas remain in degraded conditions, representing losses of R\$27 billion annually.
  - **Brazilian cattle ranching continues to drive deforestation, especially in new frontiers.** Between 2000 and 2023, ranchers cleared one hectare of forest to form pasture for every hectare of pasture reformed in Brazil. In the Brazilian Amazon, this average was 2.35 hectares. These findings highlight the Brazilian Amazon's central role in expanding cattle ranching with a high environmental impact.
  - **Rural credit: a potential that is still under-exploited.** The resources allocated to livestock have been growing. However, they are mainly directed towards the purchase of cattle, while investments in improving productivity, such as pasture renovation and artificial insemination, remain underutilized. Studies indicate that rural credit for pasture recovery alone does not guarantee increased productivity, especially when producers do not receive proper technical assistance (Oliveira et al., 2024).
  - **Opportunity to reformulate credit and encourage sustainability.** In addition to rural credit, there is a stock of approximately R\$1 trillion in subsidized private credit, with no environmental or productive performance requirements. This reality reveals an immense potential for transformation: strategically allocating these resources could boost livestock productivity and promote sustainable practices, guaranteeing environmental conservation and the sector's long-term competitiveness.
- **Factors that facilitate the improvement of degraded pastures**
  - **Infrastructure and proximity to markets.** The improvement of pastures was more likely in areas close to meatpacking plants that export to China, roads that facilitate access to inputs, technologies and the flow of production.

- **Natural conditions.** Regions with greater water availability, flat terrain and regular rainfall are more likely to reform due to economic and environmental viability.
- **Challenges for improving degraded pastures**
  - Our analysis reveals that between 2018 and 2022, the likelihood of farmers reforming their degraded pastures was extremely low. Only 0.2% of degraded pastures had a probability of reform equal to or greater than 75%.
  - The low probability of progress in reforming degraded pastures between 2018 and 2022 reflects the region's structural conditions and public and private policies. Factors such as the scarcity of education, technical assistance, and road quality, policies favorable to deforestation that discourage productivity technologies, and the resistance of Brazilian Amazonian states to the creation of protected areas are critical examples. The high costs of reform in the Brazilian Amazon, exacerbated by the expensive transport of fertilizers and the worsening of climatic extremes, make the situation even more challenging.

## **Recommendations for more productive and sustainable livestock farming**

- **Strengthen and accelerate the fight against deforestation.**  
Reducing deforestation is essential to encourage the productive use of deforested areas. Despite progress since 2022, deforestation is still 37% above the lowest level recorded in 2012 and far beyond the target of zero illegal deforestation by 2030. Reinforcing and adopting outstanding measures is crucial to ensuring sustainability and productivity in the long term.
- Public land must be allocated according to the Constitution to prevent speculative deforestation and improve environmental monitoring. In addition to the executive branch's actions, judicial intervention is essential to ensure that the Constitution is respected and applied, which is vital for territorial planning and environmental protection.

- Another pending measure is more effective environmental control of rural credit. For example, regulating and supervising the application of private credit, which totaled R\$1.1 trillion in 2024, is an essential action. Making data on the origin of cattle accessible, as decided by the Federal Supreme Court (STF) in 2024, is also crucial to ensure transparency and environmental oversight, encouraging more sustainable practices.
- Control institutions such as the Central Bank, the Judiciary, the Public Prosecutor's Office, and the Federal Court of Auditors must expand and intensify their actions to promote the sustainability of agriculture. Recent actions by these institutions involve, for example, the control of fires, the transparency of data on the transportation of cattle, the clearance of indigenous lands, and the environmental control of rural credit. The continuity and scale of these policies are essential to face the challenges posed by electoral cycles that affect the effectiveness of public policies.
- **Focus on rural credit to improve productivity.** Linking rural credit to productivity and environmental performance targets, with appropriate technical assistance and disease prevention, can make rural credit one of the main drivers of improvements. Technical assistance, for example, has shown positive results in reducing areas of degraded pasture and increasing production efficiency.
- **Concentrate credit and infrastructure in priority areas.** Governments should focus on regions with the highest potential for adopting technologies, while abandoning infrastructure projects with low socio-economic returns that induce deforestation. This targeted approach can maximize the benefits of public and private investment, promoting sustainable development.
- **Combining productive and environmental demands.** Stakeholders in the livestock chain, such as meatpackers, supermarkets, financial agents, and meat buyers, can push for more productive and sustainable practices through clear support and demand performance commitments. An example of this is the demand from three major

organizations (the Brazilian Federation of Banks, the European Union, and the China Meat Association) for traceability of the origin of cattle. Even without a national public system for individual traceability, investors, retail chains, and meatpackers can collaborate to create a joint initiative that demands transparency and sustainability from suppliers. In addition, these agents can unify their initiatives to support environmental regularization and productive assistance for ranchers. This model of sharing pre-competitive resources has proven effective in other agricultural and forestry sectors, indicating a promising path to sustainability. In the case of controlling foot-and-mouth disease, livestock farming has already shown that sectoral partnerships are essential for solving complex problems.

## **Conclusion**

- The future of Brazilian cattle farming depends on reconciling productive growth with environmental conservation. Over the last 23 years, the expansion of cattle ranching has shown that it is possible to increase productivity while reducing deforestation through practical incentives and environmental control. However, flaws in public and private policies have prevented faster, broader, and longer-lasting progress on best practices. As a result, almost half of the pastures are degraded while deforestation for cattle ranching continues.
- Faced with the intensification of the climate crisis, primarily the reduction in rainfall, the opportunities for productive restoration of degraded pastures tend to be drastically reduced. Global warming follows immutable physical laws: the higher the greenhouse gas emissions, the faster and more intense the climate change will be. Therefore, politicians and business leaders must not hesitate. Only through robust and committed collaboration will it be possible to mitigate the environmental impacts of livestock farming and promote sustainable development in territories where the activity still operates with low productivity.

# 1 Introduction

This report presents lessons from the expansion of cattle ranching in Brazil between 2000 and 2023 for initiatives to make the sector more productive and sustainable. One ambitious initiative is the National Program for the Conversion of Degraded Pastures (PNCPD), launched in December 2023 by the federal government. This program aims to convert up to 40 million hectares of pastures into productive areas in ten years (Brazil, 2023).

The program is essential because in 2023, livestock contributed only 17% of the gross value of agriculture, despite occupying 64% of the areas in agricultural use. In addition, approximately 64% of pastures were of low and intermediate vigor, amounting to 105.5 million hectares<sup>2</sup>, or the equivalent of five times the territory of Paraná. In 2023, pasture degradation generated losses of R\$27 billion (Moitinho, 2024), representing 13% of the gross value of cattle production<sup>3</sup>. In addition to deficiencies in pasture management, Brazilian cattle farming loses tens of billions of Brazilian Reals a year due to parasites that reduce meat and milk production (Grisi et al., 2014).

Despite the underutilized areas, cattle ranching contributes significantly to deforestation in the Brazilian Amazon, where it occupies 90% of the area under agricultural use. In 2021, this activity was responsible for 51% of the country's total greenhouse gas emissions (Alencar et al., 2023), 3.2 to 14.5 times higher than emissions from energy generation and industrial processes in the country, respectively.<sup>4</sup>

To meet these challenges, increasing the productivity of deforested areas and eliminating deforestation is essential. With increased productivity, a reduction in methane emissions resulting from cattle management is also expected (Micol, 2023). Thus, integrating these strategies can promote more efficient and sustainable livestock farming.

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<sup>2</sup> Data available on the Mapbiomas platform (Mapbiomas Brasil, 2023).

<sup>3</sup> The Brazilian government estimated that in 2023, the gross value of cattle production totaled R\$206.7 billion. Of this, R\$142.7 billion corresponds to production without milk, out of an overall total of R\$1.18 trillion. Data source: Brasil (2024b).

<sup>4</sup> Estimates of greenhouse gas emissions are available at <https://bit.ly/4gWGpw2> (Climate Observatory, 2023a)

This report examines how and where livestock production expanded between 2000 and 2023, identifying the main drivers of producers' decisions, including market demands, public policies, environmental and infrastructure conditions, and deforestation restrictions. During this period, livestock production in Brazil expanded along two main paths: increasing productivity through various techniques and deforesting to form new pastures. Despite the improvement of pastures, there is still a large stock of degraded pastures. Between 2000 and 2023, farmers cleared one hectare of forest for pasture for every hectare of pasture renovated in Brazil. Ranchers in the Brazilian Amazon deforested 2.35 hectares for every hectare of pasture reformed. This finding highlights the Brazilian Amazon's central role in expanding cattle ranching with a high environmental impact and the shortcomings in improving existing pastures. For this, a specific analysis of this region was relevant.

To assess the potential for improving pastures in the Brazilian Amazon Biome, we used a program (Clark Labs, 2020) that uses the characteristics of the territory (such as the declivity of the land), the rural producers (such as the level of education) and changes in pasture vigor to estimate the likelihood of improving pasture vigor in the future. Specifically, we first analyzed which factors were associated with changes in pasture vigor between 2000 and 2019. Based on the results of this model, we estimated the probability of changes in pasture vigor between 2018 and 2022. Then, to assess the validity of this model, we compared its predictions with the actual changes in pasture vigor observed between 2022 and 2023. This robust approach allowed the model to be calibrated, explanatory variables to be analyzed, and predictions to be validated, providing valuable information for promoting sustainable pasture management. Appendix 1 details the methodology for assessing the potential for improving pastures in the Brazilian Amazon.

The lessons indicate that to promote the improvement of degraded pastures, it is necessary to combine support, such as rural credit and technical assistance, conditional on improved environmental performance (zero deforestation). The analysis also showed that pasture improvement in the Brazilian Amazon is more likely near markets (i.e., near meatpacking plants) in regions with infrastructure and water availability (amount of rainfall). Thus, the report reveals lessons on how and where to promote the most productive uses of pastures.

Box 1 describes the main characteristics of the PNCPD.

### **Box 1.** Characteristics of the National Program for the Conversion of Degraded Pastures into Sustainable Agricultural and Forestry Production Systems (PNCPD)

The PNCPD aims to convert up to 40 million hectares of degraded pastures into productive areas in ten years. To this end, the government plans to support practices such as crop-livestock-forest integration (ILPF), improved pasture and agroforestry systems, and reduce greenhouse gas emissions. The program promises technical assistance, financing access, and advanced pasture management technologies. In addition, the PNCPD promises to make investments conditional on enterprises being registered in the Rural Environmental Registry (CAR - Cadastro Ambiental Rural) and complying with the Forest Code (Law No. 12,651 of May 25, 2012) and the Environmental Regularization Program (Decree No. 7,830 of October 17, 2012). These conditions align with the rural credit rules the National Monetary Council approved.

To manage the PNCPD, the government established the Interministerial Steering Committee, which acts as an advisory and deliberative body to define the program's guidelines, goals and actions, establish criteria for external funding and evaluation parameters, and monitor the program's implementation and effectiveness. The committee must also promote coordination between public entities and civil society organizations, periodically evaluate the implementation of the PNCPD and draw up annual reports on its effectiveness.

## 2 Transformations in Brazilian cattle ranching (2000-2023): productivity gains and deforestation expansion

### Technologies to increase production

Between 2000 and 2023, cattle production in Brazil grew significantly, driven by two main factors: productivity gains and an increase in pasture area through deforestation.

**Productivity indicators show remarkable progress.** Although the increase in pasture area in Brazil between 2000 and 2023 amounted to only 5%, the national herd grew by 40%, the number of animals slaughtered doubled, the volume of meat produced increased by 130%, and the average carcass weight rose by 15% (Figure 1). In the Brazilian Amazon, other productivity indicators have also shown significant increases (Figure 2). Meat production per hectare increased by 11% in Brazil as a whole and 13% in the states of the Brazilian Amazon (Figure 3).

**Artificial insemination has grown significantly in bovine reproduction.** Between 2000 and 2023, semen sales increased by 414%, and the proportion of cows inseminated for beef cattle more than doubled between 2012 and the three years 2021-2023, from 10% to 25% (Figure 4). In the Brazilian Amazon, the highest growth occurred in Tocantins, where a specific program supported the insemination (World Bank Group, 2024). In Mato Grosso, the country's largest beef producer, insemination rates are close to the national average (Figure 5). The use of artificial insemination makes it possible to: accelerate gains in the genetic quality of animals by using the semen of a selected bull in many cows; increase fertilization success by synchronizing the ovulation of cows in a herd; increase efficiency by reducing the time required to inseminate cows and increasing work efficiency by reducing the need to detect cows when they are

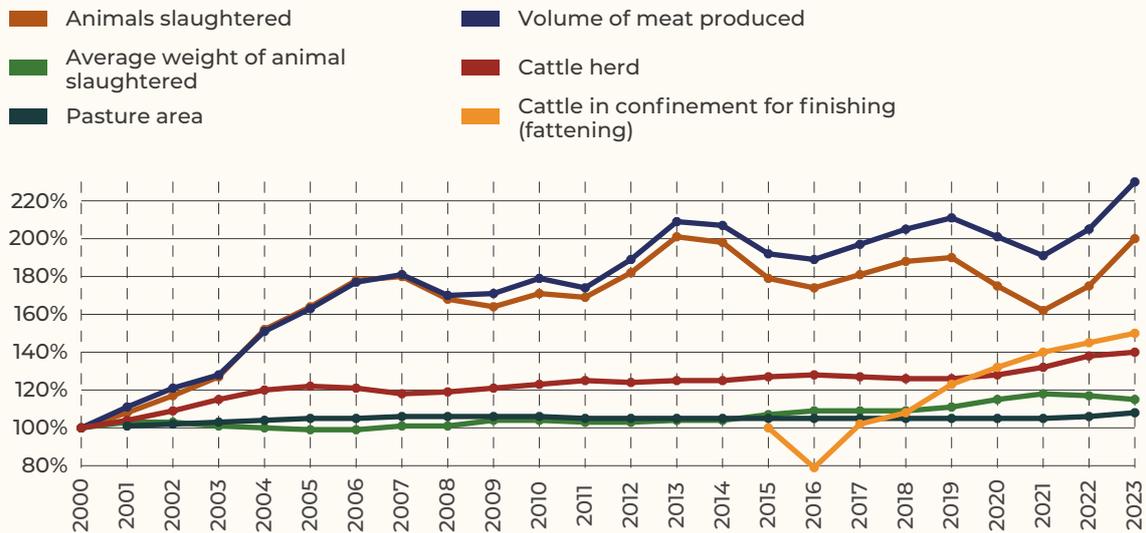
in heat or estrus (Baruselli et al., 2017; Pugliesi et al. 2024). Combining these characteristics allows for the accelerated increase of herds with greater weight gain potential at efficient costs.

In addition to reproduction, **pasture improvement has been decisive.** The proportion of high vigor pastures has increased significantly due to renovations in existing areas and the formation of pastures in deforested areas, which have high initial productivity due to the fertility released by native vegetation. Between 2000 and 2023, high vigor pastures grew by 51% in Brazil and 96% in the Brazilian Amazon. Outside the Brazilian Amazon, there was a 37% reduction in low vigor pastures. However, in the Brazilian Amazon, low-quality pasture still grew by 10%, showing the inadequate use of deforested land (Figures 6, 7 and 8).

**The growth in confinement and semi-confinement has also been significant.** Farmers have expanded the use of confinement and semi-confinement to accelerate the weight gain of animals, especially in the final fattening phase. In semi-confinement, the feed is a mixture of forage and grain, including pasture grazing. In confinement, cattle are kept in restricted areas, such as corrals or paddocks, where they receive food (a mixture of fodder and grain) and water directly in the troughs. Thus, in the Brazilian Amazon, the adoption of feedlots is more likely where grain production is on and around farms (Vale et al., 2019). Using data from the Brazilian Amazon in the cattle fattening phase, researchers estimated that feedlot systems can produce 5 to 38 times more meat per hectare than pasture-based systems and around twice as much as semi-confinement systems (Vale et al., 2019).

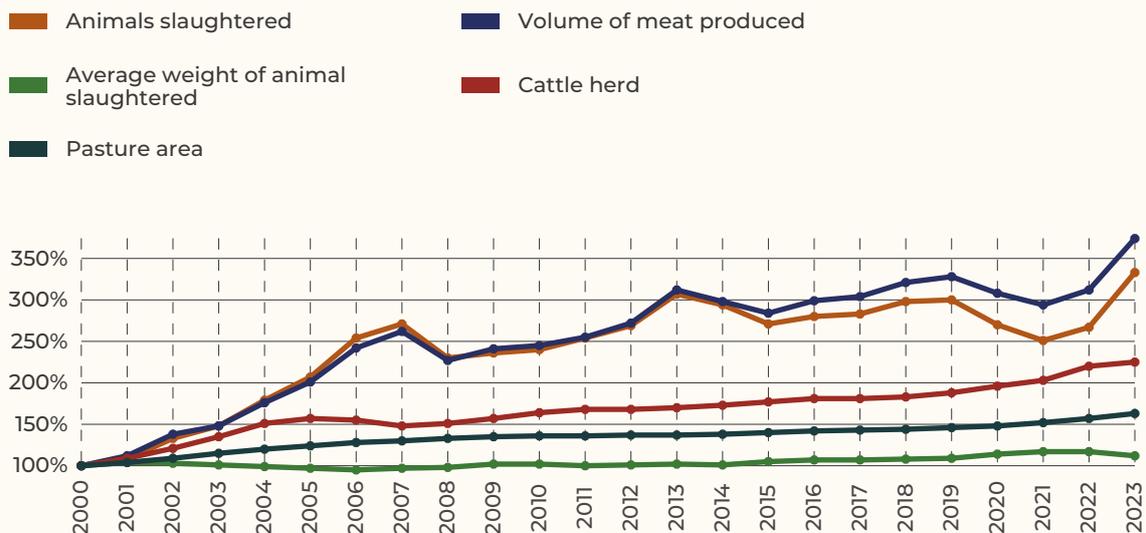
Between 2015 and 2024, the feedlot herd in Brazil grew by 53%, increasing the proportion of cattle slaughtered from feedlots from 12% in 2018 to 24% in 2021, stabilizing at 21% by 2023. In Mato Grosso, the main producing state, the use of feedlots has drastically reduced the time needed for slaughter, which has resulted in a decline in the proportion of animals slaughtered up to 36 months (from 65% to 30% between 2018 and 2023 - Figure 9). Ranchers also use confinement to standardize the weight of animals in pre-shipment operations for export, a growing practice in Pará, which leads the live cattle export market (Confina Brasil 2024, 2024).

**Figure 1.** Trends in the number of animals slaughtered, volume of meat produced, average weight of animal slaughtered, cattle herd, pasture area and cattle herd in confinement in Brazil (2000-2023)



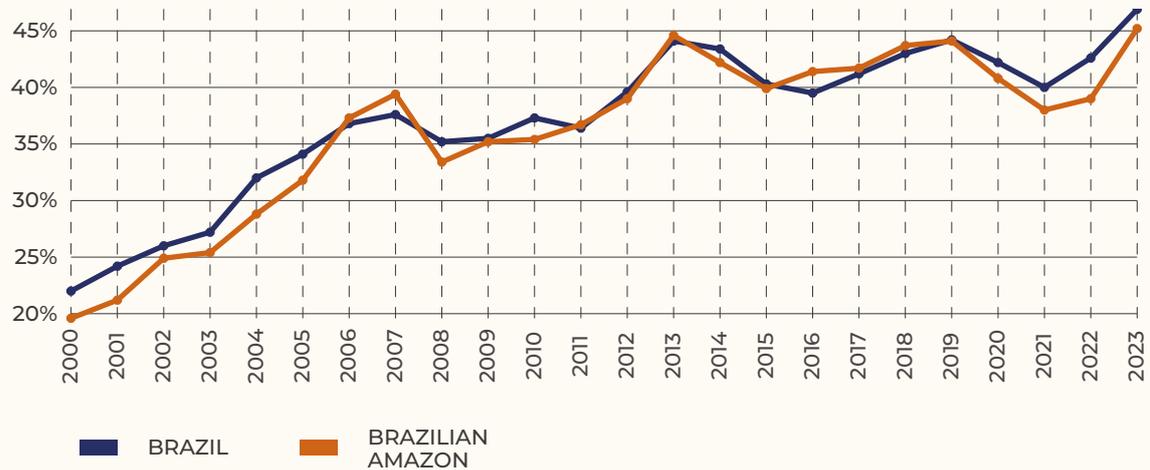
Fonte: Authors' calculations using data on animals slaughtered, volume of meat produced, average weight of animal slaughtered, cattle herd (IBGE, 2024), pasture area (Mapbiomas Brasil, 2023) and cattle herd in confinement (Junior, 2023).

**Figure 2.** Trends in the number of animals slaughtered, volume of meat produced, average weight of animal slaughtered, cattle herd and pasture area in the Brazilian Amazon states (2000-2023)



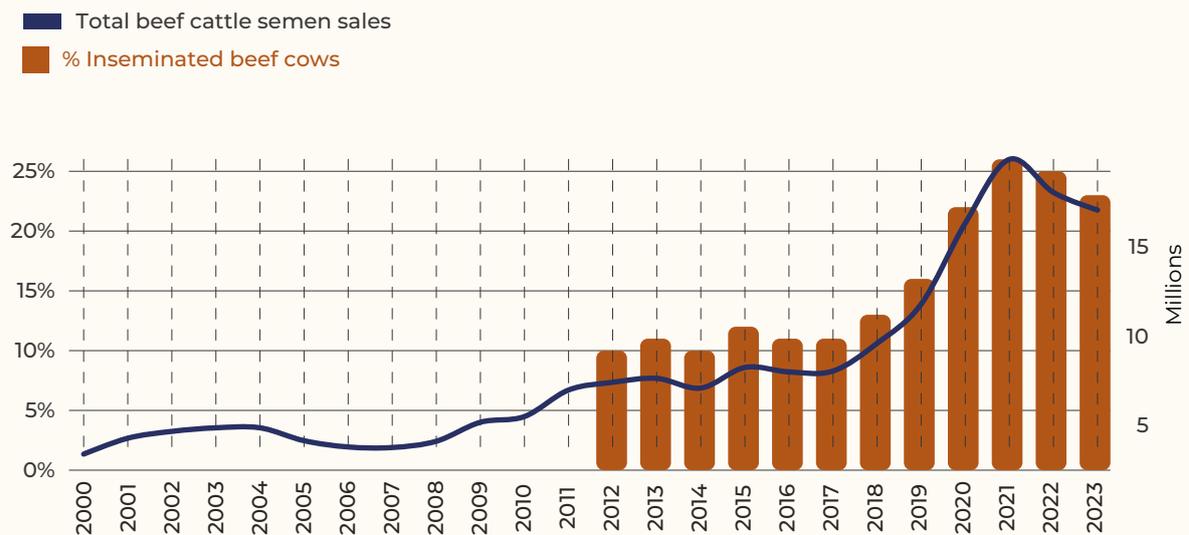
Fonte: Authors' calculations using data on animals slaughtered, volume of meat produced, average weight of animals, cattle herd (IBGE, 2024), pasture area (Mapbiomas Brasil, 2023).

**Figure 3.** Trends in carcass weight per hectare of pasture in Brazil and the Brazilian Amazon states (2000-2023)



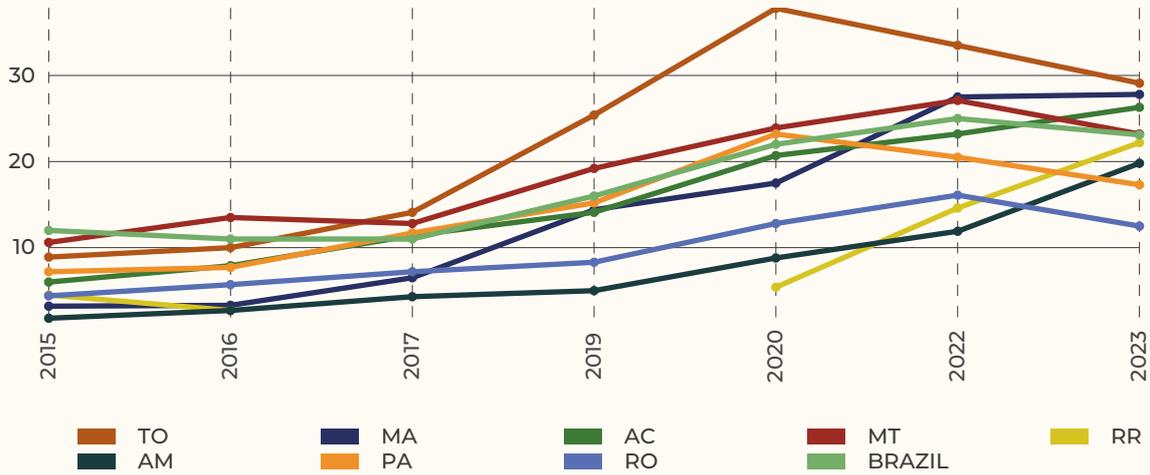
Source: Carcass weight (IBGE, 2024). Pasture area (Mapbiomas Brasil, 2023)

**Figure 4.** Trends in bovine semen sales and insemination rates for beef cows in Brazil (2000–2023)



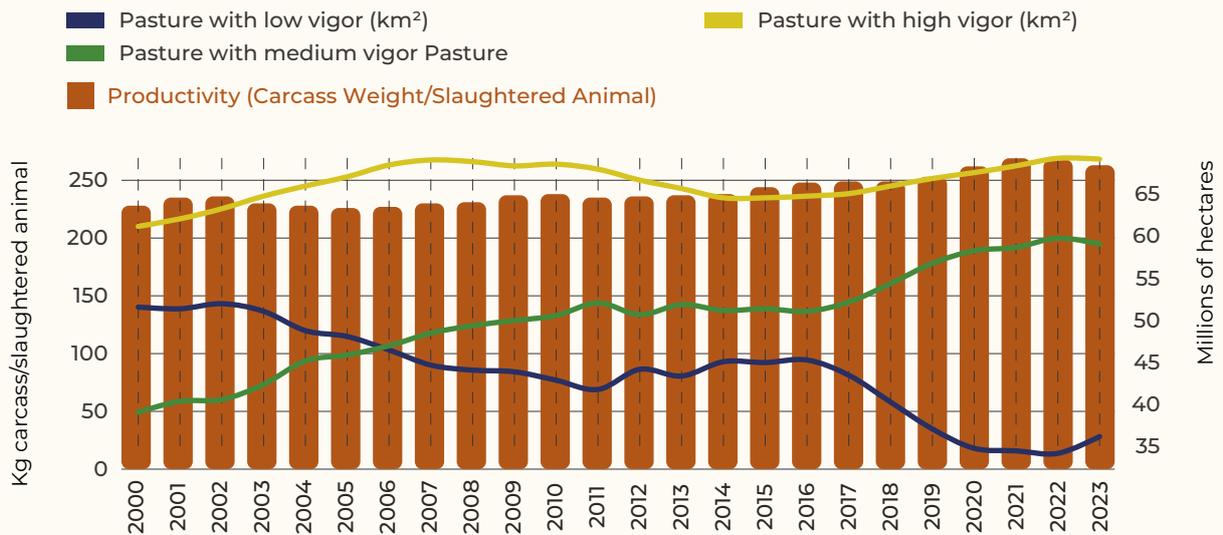
Data source: (ASBIA/CEPEA 2024).

**Figure 5.** Proportion of cows inseminated for beef production in the Brazilian Amazon states (2015-2023)



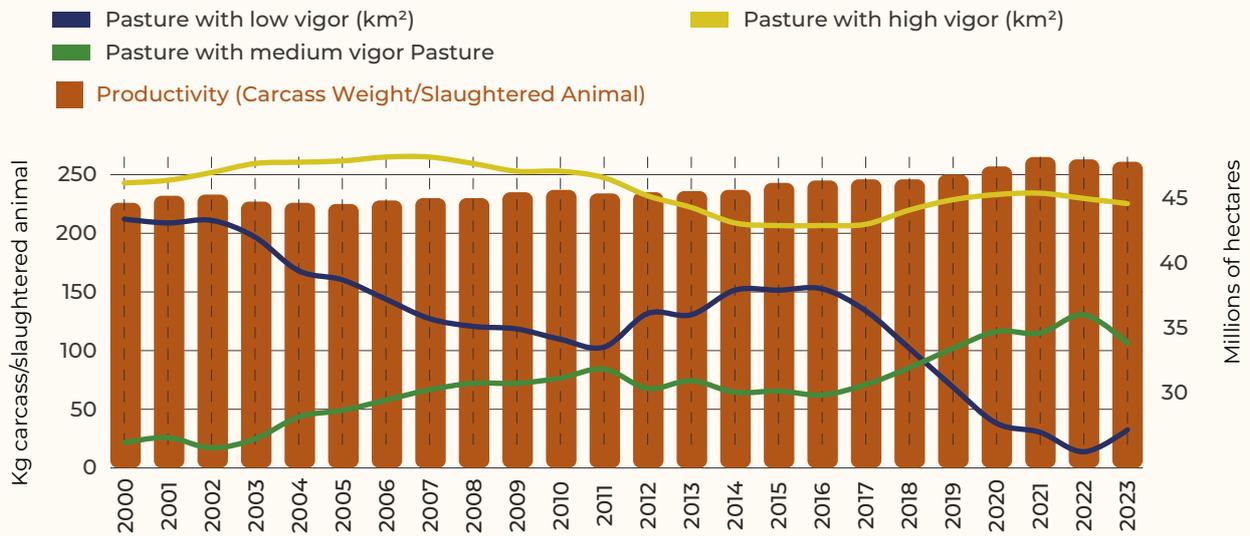
Data source: (ASBIA/CEPEA, 2024).

**Figure 6.** Hectares of pasture by pasture vigor and carcass weight of slaughtered cattle in Brazil (2000–2023)



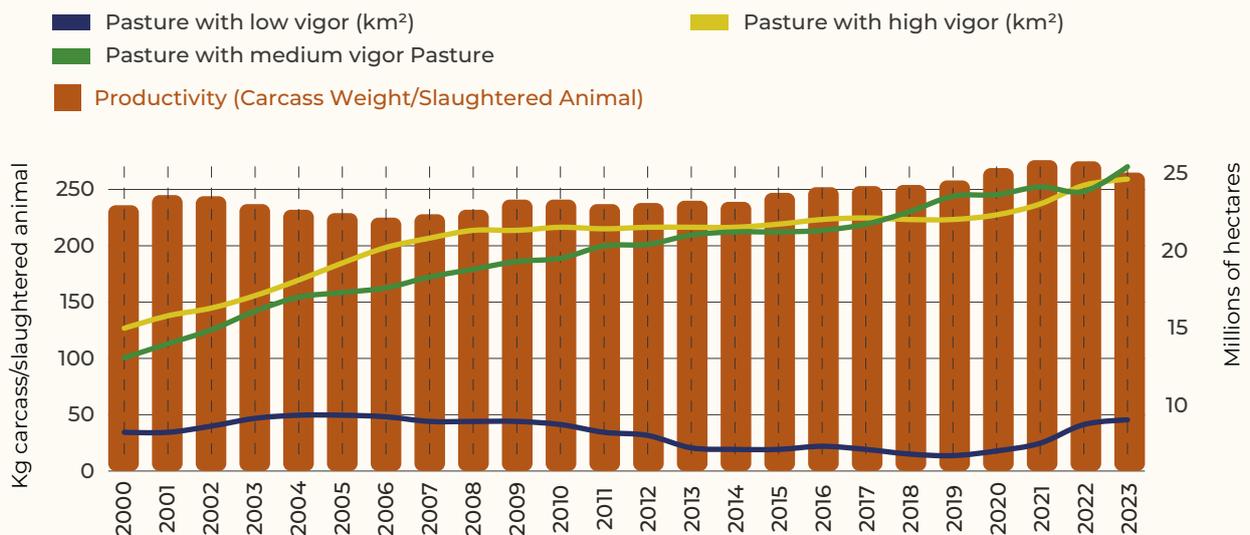
Data source: Authors' calculations with data on carcass weight and slaughtered animals (IBGE, n.d.) and pasture area (Mapbiomas Brasil, 2023).

**Figure 7.** Hectare of pasture by pasture vigor and carcass weight of slaughtered cattle in Brazil, excluding the Brazilian Amazon states (2000–2023)



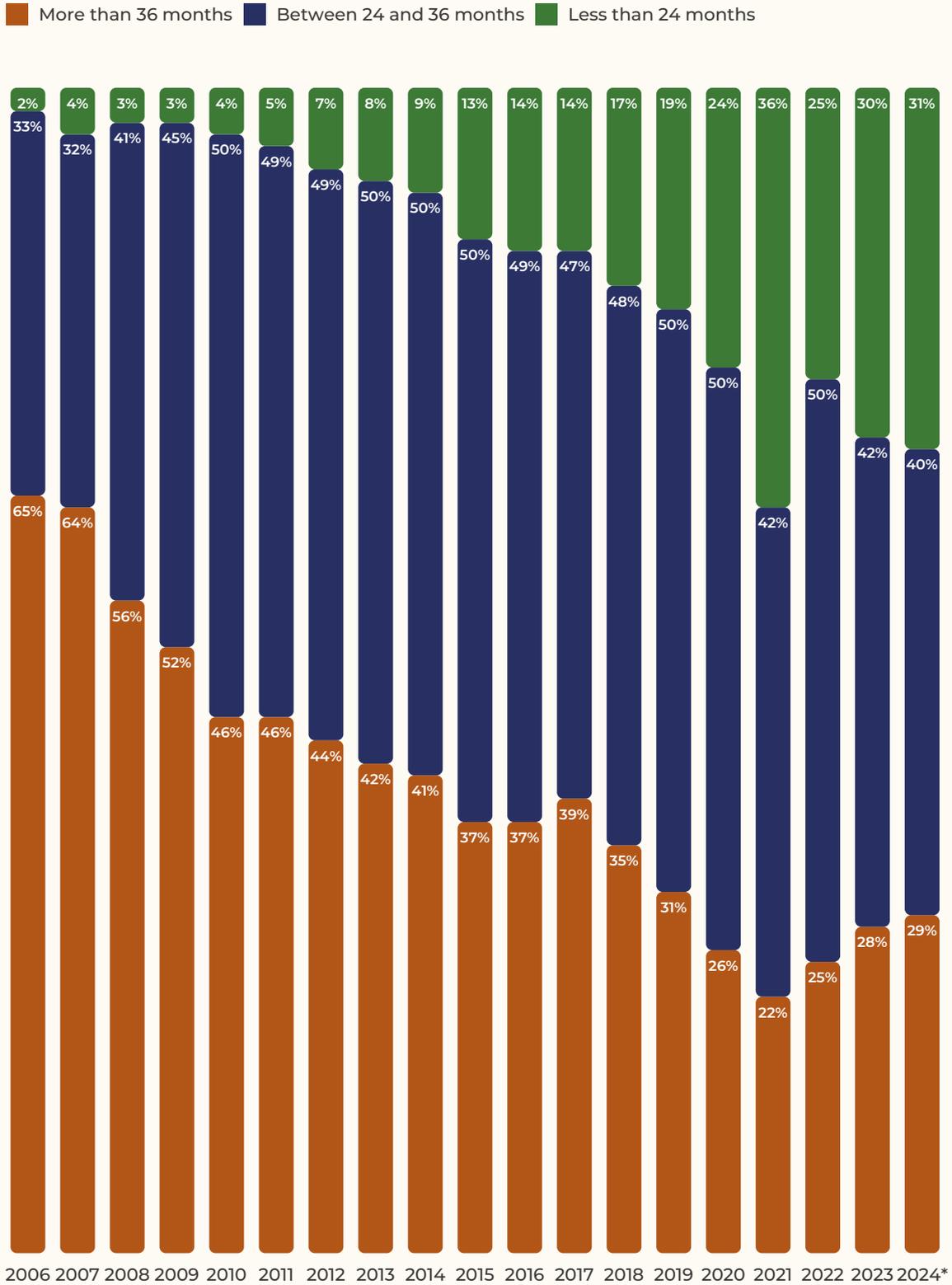
Data source: Authors' calculations with data on carcass weight and slaughtered animals (IBGE n.d.) and pasture area (Mapbiomas Brasil, 2023).

**Figure 8.** Hectare of pasture by pasture vigor and carcass weight of slaughtered cattle in the Brazilian Amazon states (2000–2023)



Data source: Authors' calculations with data on carcass weight and slaughtered animals (IBGE n.d.) and pasture area (Mapbiomas Brasil, 2023).

**Figure 9.** Proportion of cattle slaughtered by age class in Mato Grosso state



\*Until July 2024. Data source: (IMEA, 2024).

## The persistence of deforestation for cattle ranching

Despite efforts to increase pasture productivity in Brazil, deforestation for pasture cultivation remains a significant factor in expanding production. Between 2000 and 2023, for every hectare of pasture reformed, Brazilian ranchers planted an average of one hectare of new pasture after clearing primary and secondary forests. In the Brazilian Amazon, the ratio between deforestation and pasture reform was 2.35 (Table 1). Notably, before a successful program to combat deforestation (Appendix 2) between 2000 and 2005, the ratio was 5.5 hectares deforested for every hectare of pasture reformed. After the successful fight against deforestation (2009 to 2013), the ratio was 0.81. However, after the loosening of deforestation controls in 2012, the ratio rose to 2.66 (2020-2023). Thus, Amazon was the only biome with a significant negative correlation (-0.79) between deforestation<sup>5</sup> and pasture reform. Similar trends, although less intense, were observed in the Caatinga (-0.38) and the Cerrado (-0.18).

However, the opening of new pastures often fails to reach its productive potential in the long term due to significant quality loss. In 2023, only 45% of pasture areas planted between 2000 and 2023 showed high vigor (Figure 10), underscoring the inefficiency of current pasture management.

In short, Brazil has made significant gains in productivity, but critical challenges remain related to deforestation and pasture degradation. In 2023, pasture degradation was equivalent to R\$27 billion or 13% of the gross value of cattle production<sup>6</sup>.

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<sup>5</sup> This analysis considered deforestation of primary and secondary forests according to Mapbiomas data. Even considering only primary forest deforestation, the correlation between deforestation and pasture reform remained high and negative (correlation coefficient -0.73).

<sup>6</sup> The Brazilian government estimated that in 2023, the gross value of cattle production totaled R\$206.7 billion; without milk, it reached R\$142.7 billion out of a total of R\$1.18 trillion. Data available in Brasil (2024b).

**Table 1.1** Annual deforestation area for pasture formation and pasture reform, ratio between deforestation and pasture reform and correlation coefficient between pasture reform and deforestation by biome and in Brazil

Transition	Amazon (ha)			Cerrado (ha)			Caatinga (ha)		
	Reform	Deforestation	Proportion	Reform	Deforestation	Proportion	Reform	Deforestation	Proportion
2000-2001	323.425	2.192.595	<b>6.78</b>	524.193	612.324	<b>1.17</b>	308.003	139.465	<b>0.45</b>
2001-2002	654.838	2.414.205	<b>3.69</b>	536.290	610.954	<b>1.14</b>	202.066	134.236	<b>0.66</b>
2002-2003	488.240	3.141.695	<b>6.43</b>	671.754	897.652	<b>1.34</b>	251.533	152.656	<b>0.61</b>
2003-2004	568.145	2.888.236	<b>5.08</b>	784.171	705.807	<b>0.90</b>	866.115	153.412	<b>0.18</b>
2004-2005	540.836	2.343.605	<b>4.33</b>	507.581	634.954	<b>1.25</b>	568.493	162.707	<b>0.29</b>
2005-2006	695.808	1.872.637	<b>2.69</b>	793.825	571.893	<b>0.72</b>	419.204	161.949	<b>0.39</b>
2006-2007	917.130	1.563.212	<b>1.70</b>	856.787	484.262	<b>0.57</b>	501.088	132.492	<b>0.26</b>
2007-2008	869.519	1.534.629	<b>1.76</b>	778.191	491.204	<b>0.63</b>	533.460	161.413	<b>0.30</b>
2008-2009	1.080.511	965.731	<b>0.89</b>	767.833	425.036	<b>0.55</b>	379.536	136.430	<b>0.36</b>
2009-2010	1.083.796	846.340	<b>0.78</b>	965.338	386.987	<b>0.40</b>	20.131	125.201	<b>6.22</b>
2010-2011	1.337.077	897.858	<b>0.67</b>	1.067.264	429.304	<b>0.40</b>	79.159	133.574	<b>1.69</b>
2011-2012	1.021.730	868.424	<b>0.85</b>	950.069	599.980	<b>0.63</b>	122.679	175.626	<b>1.43</b>
2012-2013	1.194.863	1.038.412	<b>0.87</b>	1.414.019	736.315	<b>0.52</b>	39.006	163.462	<b>4.19</b>
2013-2014	903.001	977.248	<b>1.08</b>	652.664	611.581	<b>0.94</b>	68.460	157.713	<b>2.30</b>
2014-2015	829.189	1.214.436	<b>1.46</b>	727.770	586.670	<b>0.81</b>	217.308	146.160	<b>0.67</b>
2015-2016	730.010	1.367.637	<b>1.87</b>	555.587	529.962	<b>0.95</b>	258.781	132.777	<b>0.51</b>
2016-2017	957.999	1.119.093	<b>1.17</b>	883.745	479.533	<b>0.54</b>	231.170	98.799	<b>0.43</b>
2017-2018	1.338.729	1.201.756	<b>0.90</b>	998.810	464.262	<b>0.46</b>	780.307	129.734	<b>0.17</b>
2018-2019	1.184.188	1.633.539	<b>1.38</b>	723.187	461.922	<b>0.64</b>	1.508.616	131.967	<b>0.09</b>
2019-2020	828.132	1.437.168	<b>1.74</b>	601.386	436.259	<b>0.73</b>	1.890.342	138.798	<b>0.07</b>
2020-2021	704.112	1.879.319	<b>2.67</b>	760.520	422.610	<b>0.56</b>	586.512	169.872	<b>0.29</b>
2021-2022	720.942	1.944.007	<b>2.70</b>	1.144.887	468.218	<b>0.41</b>	785.024	182.587	<b>0.23</b>
2022-2023	716.263	1.883.026	<b>2.63</b>	142.723	639.966	<b>4.48</b>	339.257	1.013	<b>0.00</b>
<b>The average ratio between deforestation and reform</b>			<b>2.35</b>			<b>0.90</b>			<b>0.95</b>
<b>Correlation coefficient between the reform area and deforestation in the biome</b>			<b>-0.79</b>			<b>-0.18</b>			<b>0.05</b>

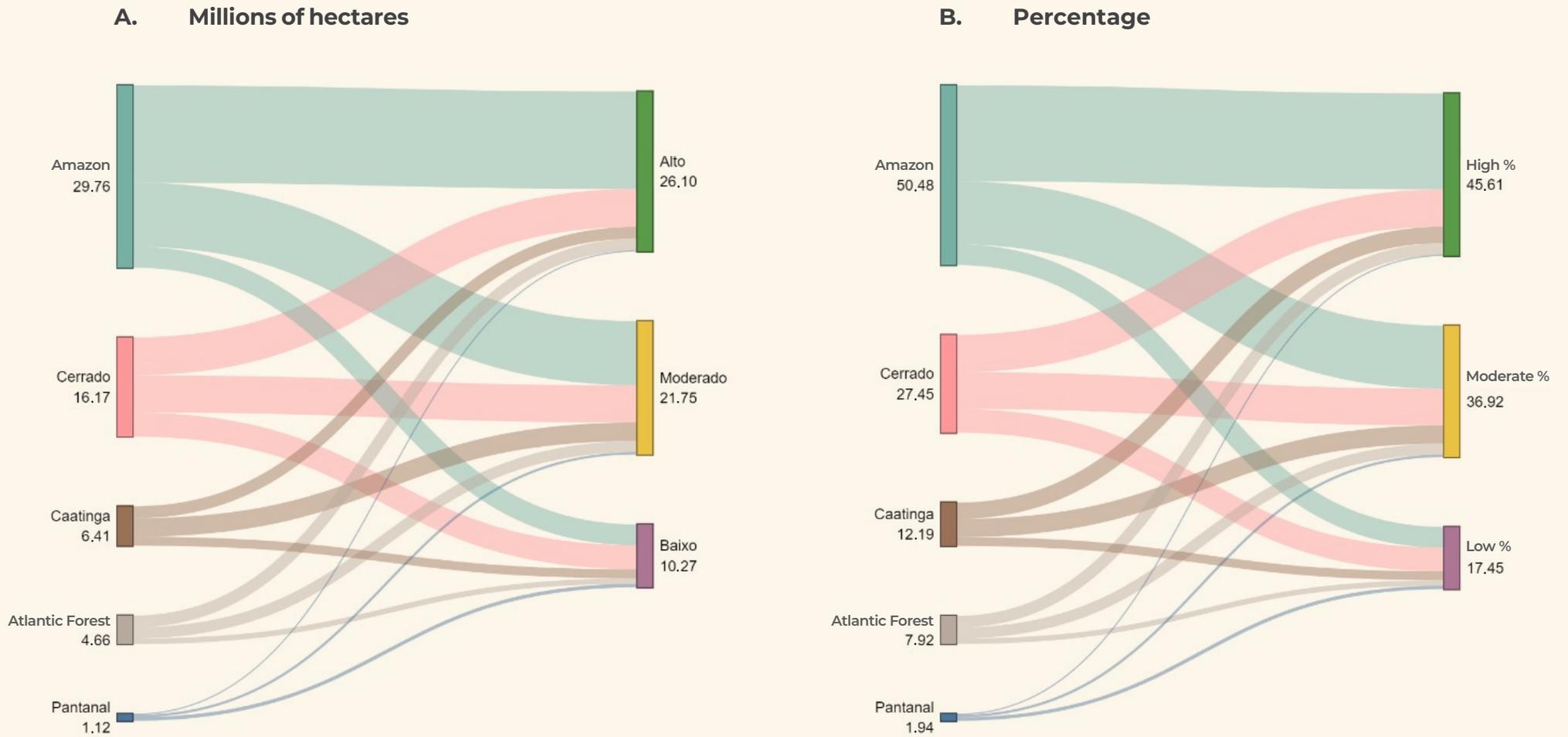
Data source: Authors' estimate based on data from Mapbiomas Brasil (2023).

**Table 1.2** Annual deforestation area for pasture formation and pasture reform, ratio between deforestation and pasture reform and correlation coefficient between pasture reform and deforestation by biome and in Brazil

Transition	Amazon (ha)			Cerrado (ha)			Caatinga (ha)			
	Reform	Deforestation	Proportion	Reform	Deforestation	Proportion	Reform	Deforestation	Proportion	
2000-2001	223.099	49.840	0.22	23.331	19.113	0.82	1.402.050	3.013.337	2.15	
2001-2002	562.577	41.448	0.07	12.777	23.323	1.83	1.968.548	3.224.166	1.64	
2002-2003	687.282	49.726	0.07	13.560	27.046	1.99	2.112.369	4.268.775	2.02	
2003-2004	973.557	43.424	0.04	15.700	29.033	1.85	3.207.687	3.819.911	1.19	
2004-2005	457.667	33.488	0.07	11.780	18.288	1.55	2.086.357	3.193.041	1.53	
2005-2006	616.713	32.288	0.05	14.639	20.356	1.39	2.540.189	2.659.123	1.05	
2006-2007	756.604	26.110	0.03	17.534	12.957	0.74	3.049.144	2.219.033	0.73	
2007-2008	694.324	25.892	0.04	24.241	14.860	0.61	2.899.735	2.227.997	0.77	
2008-2009	919.683	26.550	0.03	17.474	15.741	0.90	3.165.037	1.569.489	0.50	
2009-2010	871.859	25.696	0.03	41.261	12.741	0.31	2.982.386	1.396.964	0.47	
2010-2011	894.637	27.300	0.03	55.755	11.561	0.21	3.433.891	1.499.598	0.44	
2011-2012	587.602	30.004	0.05	84.435	9.172	0.11	2.766.514	1.683.207	0.61	
2012-2013	795.146	34.544	0.04	71.050	9.952	0.14	3.514.084	1.982.685	0.56	
2013-2014	444.065	30.259	0.07	29.786	11.421	0.38	2.097.975	1.788.222	0.85	
2014-2015	590.075	34.983	0.06	19.869	10.349	0.52	2.384.212	1.992.599	0.84	
2015-2016	462.888	28.208	0.06	17.623	14.077	0.80	2.024.888	2.072.661	1.02	
2016-2017	917.926	23.191	0.03	9.026	15.911	1.76	2.999.865	1.736.528	0.58	
2017-2018	1.037.046	23.151	0.02	7.433	15.291	2.06	4.162.326	1.834.193	0.44	
2018-2019	475.382	23.033	0.05	7.890	18.029	2.29	3.899.264	2.268.492	0.58	
2019-2020	479.592	20.740	0.04	11.952	20.618	1.73	3.811.403	2.053.583	0.54	
2020-2021	481.233	26.493	0.06	22.884	26.882	1.17	2.555.262	2.525.176	0.99	
2021-2022	1.047.019	33.836	0.03	57.116	25.973	0.45	3.754.987	2.654.621	0.71	
2022-2023	125.012	23.339	0.19	8.987	52.765	5.87	1.332.242	2.600.109	1.95	
<b>The average ratio between deforestation and reform</b>			<b>0.06</b>				<b>1.28</b>			
<b>Correlation coefficient between the reform area and deforestation in the biome</b>			<b>-0.08</b>				<b>-0.38</b>			

Data source: Authors' estimate based on data from Mapbiomas Brasil (2023).

**Figure 10.** Pasture vigor in 2023 for pastures established between 2000 and 2023, by biome



Data source: Authors' estimates with data from (Mapbiomas Brasil, 2023)

## 2.2 Factors that determined volume, methods and the geography of livestock expansion

Since 2000, ranchers have been changing where and how to increase cattle production in Brazil, influenced by market demands, public policies, environmental and structural conditions. In addition, they have also shaped part of the political and market demands on how and where to produce.

### **Changes in demand have influenced production methods and geography.**

The increase in foreign and domestic demand between 2000 and 2023 has driven increased production and productivity. Exports grew 800% from the 2000s onwards, made possible by advances in health control, such as eradicating foot-and-mouth disease. This disease previously restricted exports (P. Barreto et al. 2017). Between 2000 and 2023, the percentage of beef produced in Brazil for export increased from 5% to 22%, while the value exported grew from US\$835 million to US\$10.5 billion, according to data from the Brazilian Association of Meat Exporting Industries (ABIEC, n.d.). China emerged as the leading destination, increasing its share from 0.2% to 60% of the total volume exported, according to data from the Ministry of Development, Industry, Trade and Services (Brazil, n.d.).

To meet demand, ranchers have responded by improving productivity (especially outside the Brazilian Amazon) and increasing pasture areas (mainly in the Brazilian Amazon).

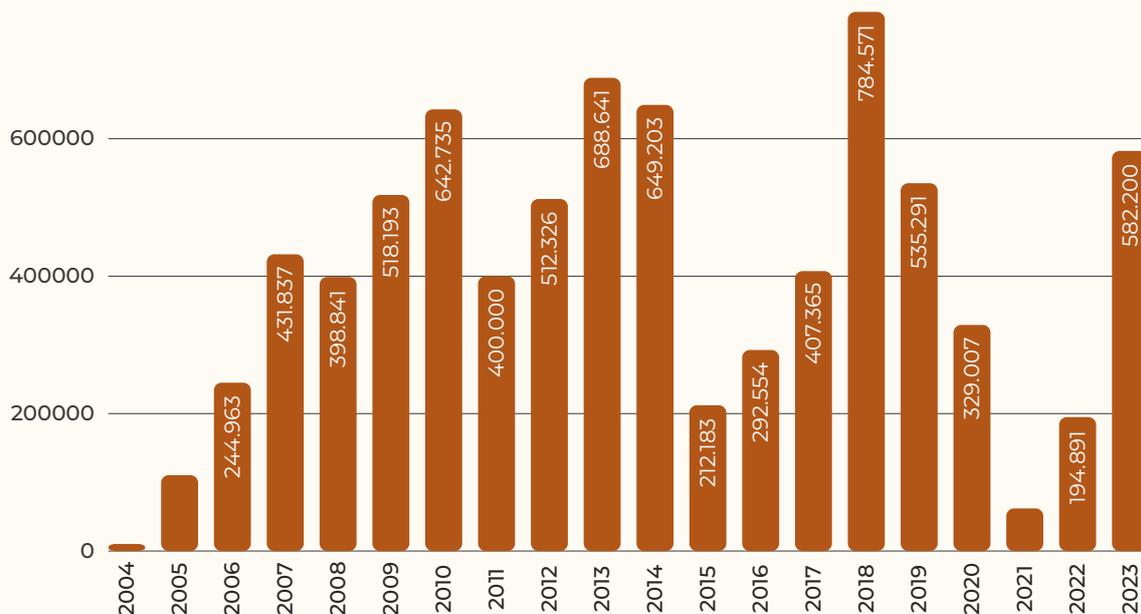
Since 2015, the demands and premiums of the Chinese market have been followed by an increase in productivity. The Chinese demanded meat from animals no older than 30 months and offered prices up to 30% higher than the market. By 2022, the price of the arroba for the Chinese market, called “China beef” by the sector, was R\$20.00 to R\$30.00 higher than the conventional price, stimulating higher profit margins and technological advances. The increase in exports to China coincided with an increase in high vigor pastures, a reduction in low vigor pastures, a gain in average carcass weight, the use of feedlots for fattening, and the adoption of artificial insemination for breeding cattle. Increased Chinese demand for high-quality beef and other international markets

coincided with more deforestation in the Brazilian Amazon (Zu Ermgassen et al., 2020). This influence can be direct and indirect. For example, the increase in cattle confinement has coincided with live cattle trade between states, amplifying the long-distance impact of cattle ranching. For instance, Acre has mainly exported calves of up to 12 months to the states of Mato Grosso (38%), Amazonas (27%) and São Paulo (24%) (Fernandes et al., 2024).

The growth in live cattle exports (Figure 11) also coincided with the use of technology to increase production. For example, the export of young cattle for fattening in Peru, which paid up to 53% more than the domestic market, led ranchers in Pará to adopt artificial insemination to speed up cattle reproduction. Pará has thus become the largest exporter of live cattle. Until July 2024, the state of Pará led live cattle exports, accounting for 51.41% of the total, with 238,582 heads sent abroad (Scot Consultoria, 2024). In addition to local production, Pará began re-exporting calves from neighboring states, such as Tocantins<sup>7</sup>.

<sup>7</sup> Information from a farmer and a consultant from Pará.

**Figure 11.** Number of live cattle exported by Brazil (2004-2023)

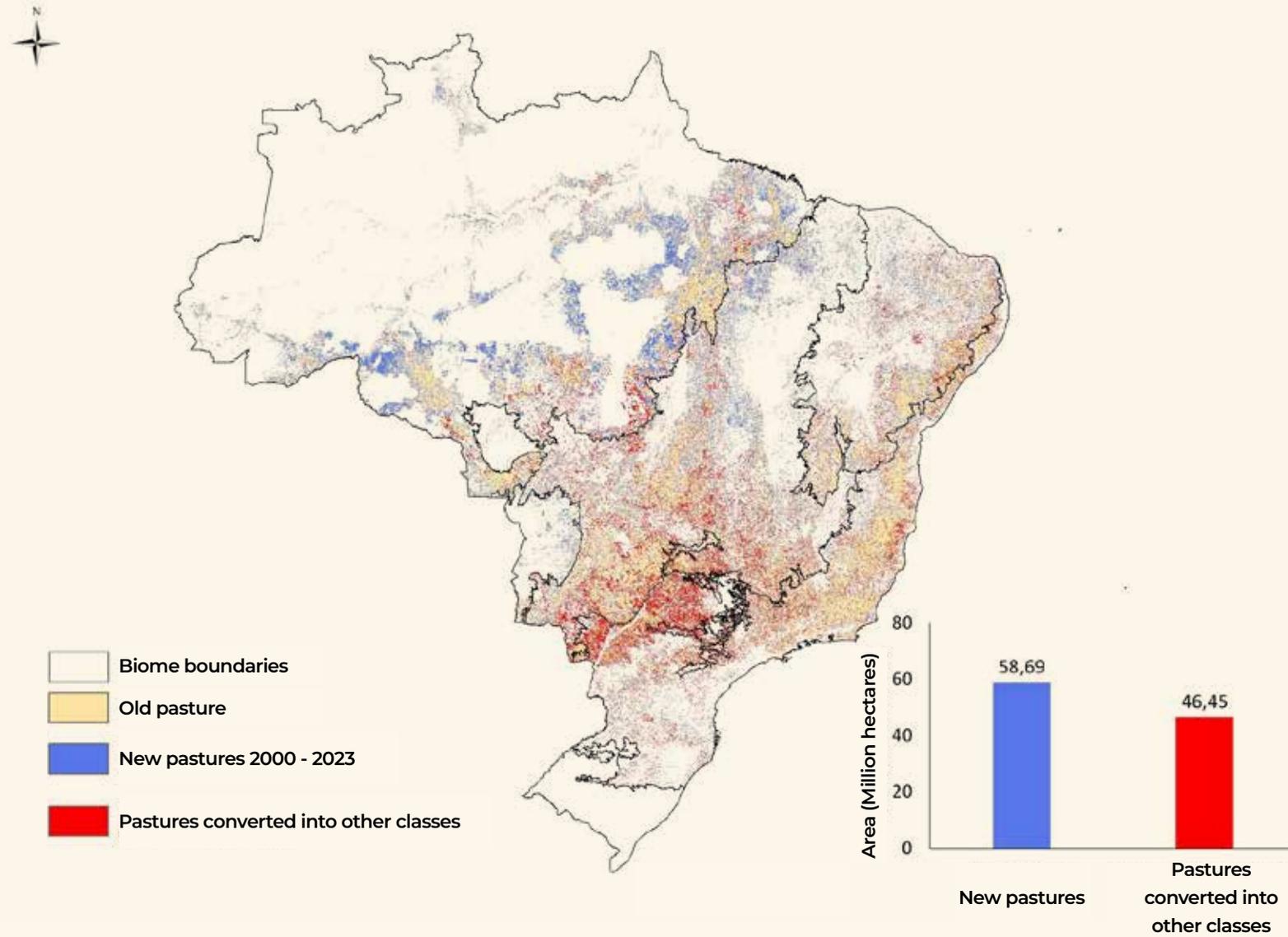


Data source: Scot Consultoria (2023).

The increase in agricultural exports has also influenced the location of livestock farming. Agricultural plantations on degraded pastures, especially in the Center-South of Brazil, displaced part of cattle raising to new frontiers in the Cerrado and Amazon between 2000 and 2023 (Figure 12).

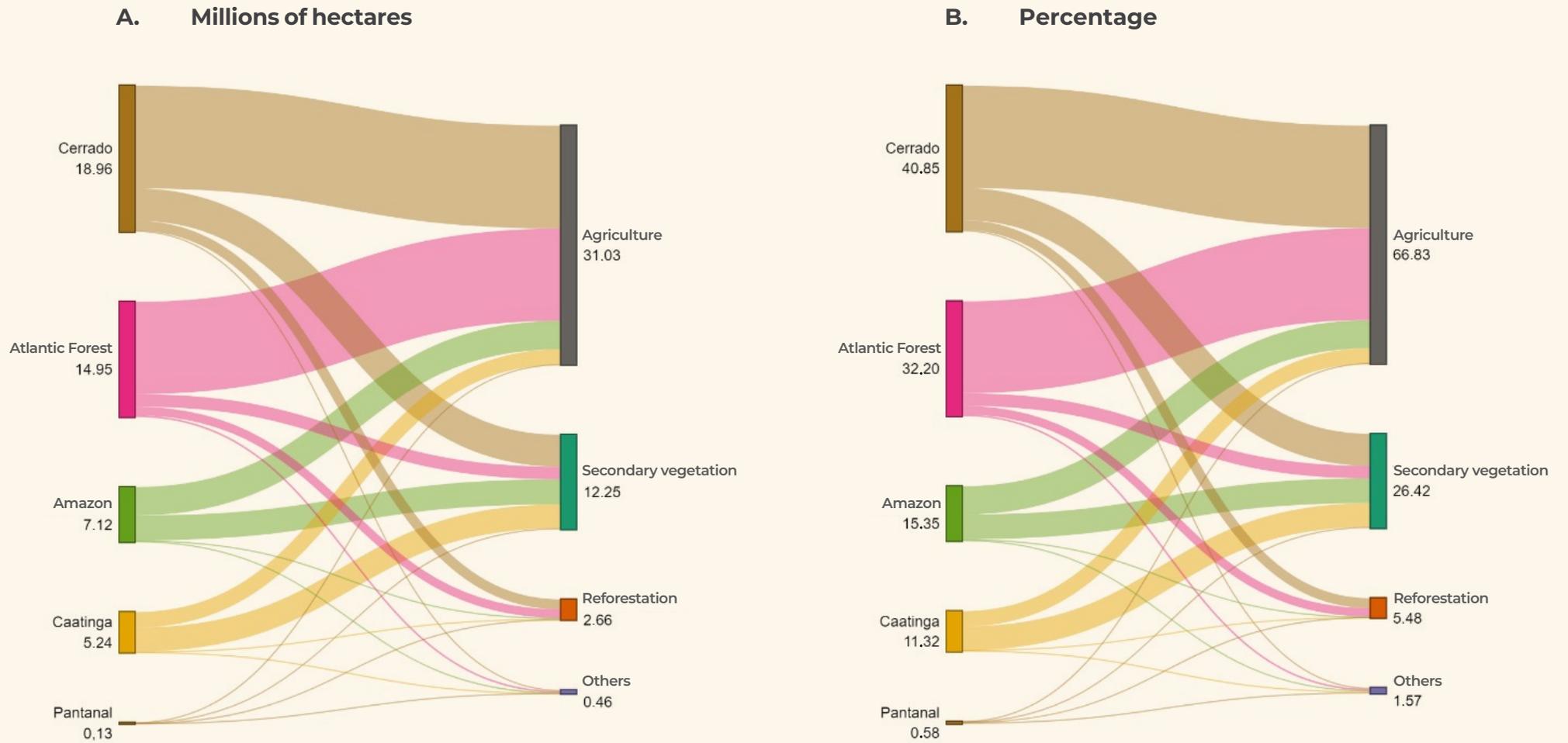
Of the pastures converted to other uses in Brazil, two-thirds were destined for agriculture (Figure 13). In addition, in 2023, around 26% of the areas that ceased to be pastures in the country were secondary vegetation, indicating some regeneration of native vegetation (Figure 13). In the Amazon, almost half of these areas had secondary vegetation in the same period, highlighting the significant failure and waste associated with deforestation to form pastures.

**Figure 12.** Changes in pasture areas in Brazil (2000 and 2023).



Data source: Prepared by the authors with data from Mapbiomas Brasil (2023).

**Figure 13.** Area of pasture converted to other land cover classes between 2000 and 2023 by Brazilian biome



Data source: Prepared by the authors with data from Mapbiomas Brasil (2023)

**Environmental control has boosted productivity improvements.** From 2003 onwards, reactions against deforestation and the change of federal government resulted in various public and private policies for forest conservation. Implementing programs such as PPCDAm (Action Plan for the Prevention and Control of Deforestation in the Brazilian Amazon) and the Soy Moratorium reduced deforestation by around 80% between 2003 and 2012 (details of the policies in Appendix 2). These policies, together with support for producers, helped the adoption of more productive practices in the following years. This period also coincided with the growth of high vigor pastures and increased average carcass weight of slaughtered animals. In contrast, the area of low vigor pastures fell (see figures 6, 7 and 8). These changes indicate an increase in the cost of illegally clearing private or public land because of the increased risk of punishment. As expected, studies have shown that in regions where deforestation has been reduced, ranchers have increased their use of techniques to increase productivity in areas that have already been deforested (Alix-Garcia and Gibbs, 2017; Garrett et al., 2018).

**Rural credit is a facilitator of increased production and productivity.** The adoption of agricultural technologies in Brazil has been significantly facilitated by the expansion of the Safra Plan, a government program that provides subsidized rural credit, influenced mainly by demands from the rural sector (Neto 2018). The resource allocated for the 2020-21 Safra Plan was 257% higher in real terms (737% in nominal terms) than in 2003-04 (Figure 14).

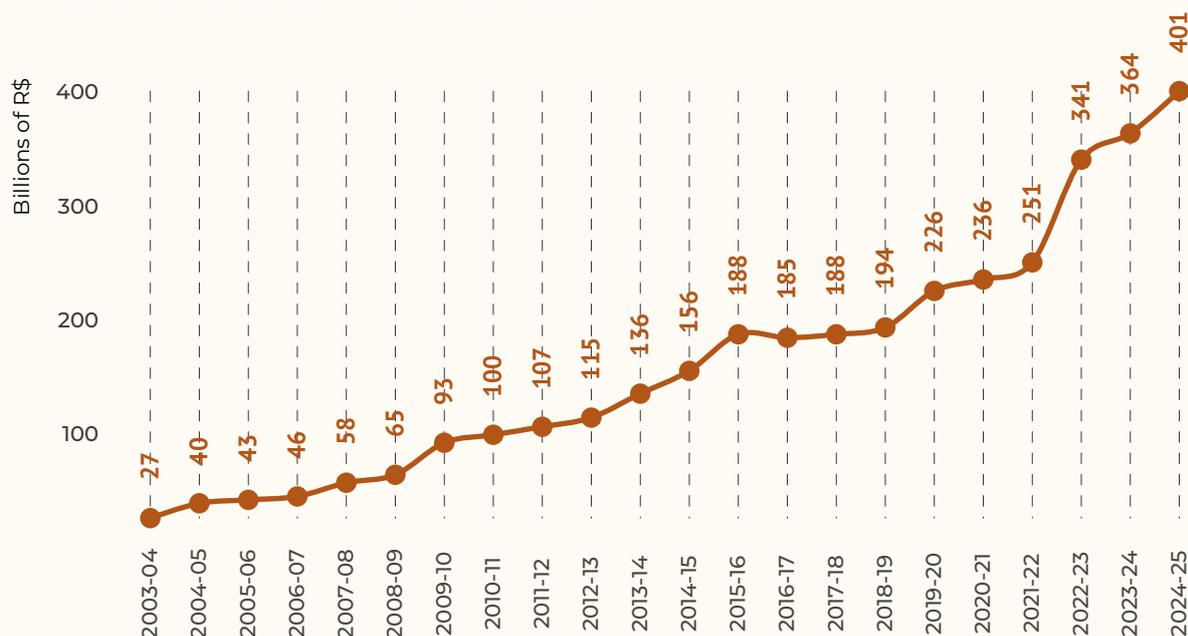
In addition to the increase in the volume of credit between 2013 and 2023, the contracting of credit for products associated with increased productivity increased in Brazil and the Brazilian Amazon states. In Brazil, the proportion of these items rose from 13% in 2013 to 22% in 2023 (Figure 15), while in the Brazilian Amazon states, the increase was from 14% to 25% in the same period (Figure 16). This trend was similar in the five states that concentrated 92% of the region's herd (Mato Grosso, Pará, Rondônia, Tocantins and Maranhão), as seen in Appendix 3.

The main loan products for these productivity investments included soil and pasture improvements, infrastructure for rotational grazing (such as fences), and water collection and distribution systems. In addition, investments in

irrigation have grown, indicating a response to rainfall reduction. These investment profiles followed similar trends in Brazil and the Brazilian Amazon states (Figures 17 and 18). Appendix 4 contains maps illustrating the decrease in rainfall in different regions, helping to visualize the areas most affected by drought. Data from the MapBiomas Project (2022) presents information on the increase in irrigation in Brazil, showing how agriculture has adapted to climate change, especially in regions where dry seasons have become more intense.

Despite progress in environmental controls on rural credit, subsidized private credit using new instruments—often without the same regulations—has grown rapidly. The credit stock from these new instruments in October 2024 reached R\$1.13 trillion (around 10% of Brazil’s GDP in 2023). It was 551% higher than in October 2020 (Figure 19). These loans may have contributed both to improving productivity and, at least indirectly, to inducing deforestation. For example, a recent analysis revealed that private credit was associated with deforestation in Rondônia. This link was due to the lack of robust environmental criteria for granting financing, which allowed resources to be directed towards activities promoting the expansion of deforested areas (Bronoski, 2025)

**Figure 14.** Evolution of programmed resources for rural financing of the Safra Plan in Brazil in nominal values

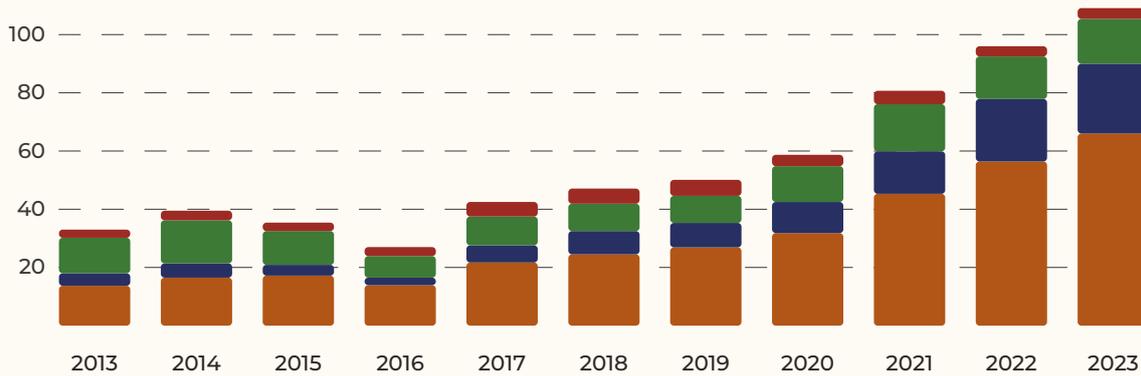


Data source: Brazil (n.d. b) (n.d. c) (n.d. d).

**Figure 15.** Purpose and type of rural credit product contracted for cattle ranching in Brazil (2013-2023)

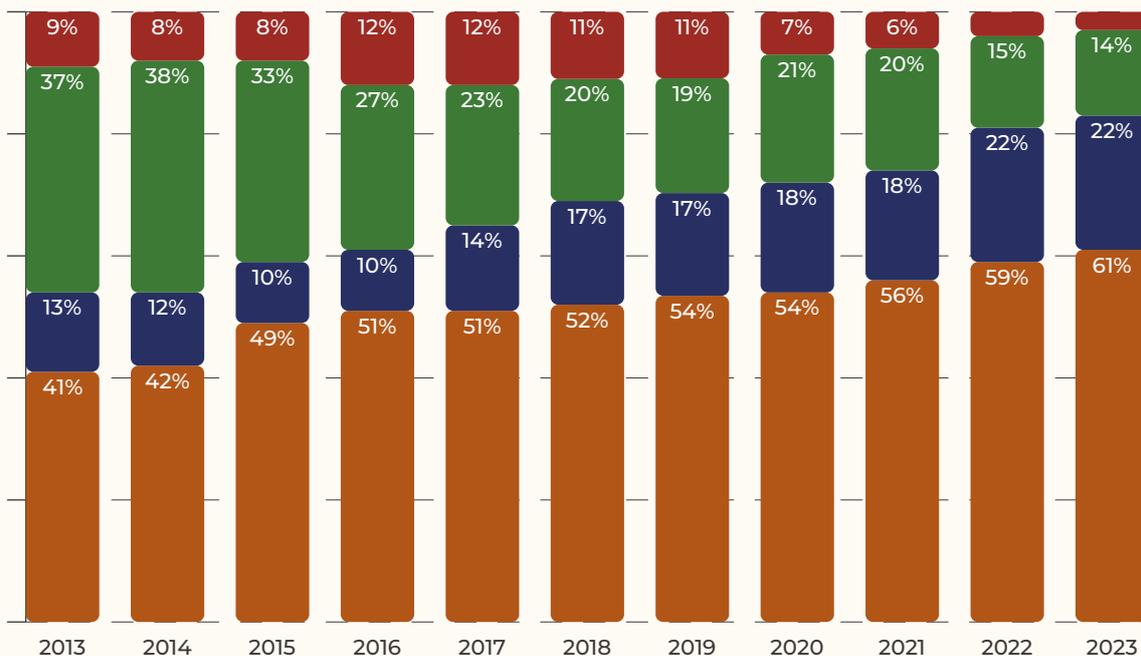
**A. In nominal Reals**

■ COSTING - CATTLE 
 ■ INVESTMENT - INCREASING PRODUCTIVITY  
■ INVESTMENT - CATTLE 
 ■ OTHER



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
<span style="color: #8B4513;">●</span> COSTING - CATTLE	R\$ 13.658	R\$ 16.452	R\$ 17.202	R\$ 13.865	R\$ 21.650	R\$ 24.454	R\$ 26.925	R\$ 31.814	R\$ 45.259	R\$ 56.376	R\$ 65.978
<span style="color: #00008B;">●</span> INVESTMENT - INCREASE PRODUCTIVITY	R\$ 4.309	R\$ 4.861	R\$ 3.709	R\$ 2.626	R\$ 5.884	R\$ 7.984	R\$ 8.448	R\$ 10.674	R\$ 14.625	R\$ 21.495	R\$ 23.961
<span style="color: #008000;">●</span> INVESTMENT - CATTLE	R\$ 12.237	R\$ 14.834	R\$ 11.609	R\$ 7.411	R\$ 9.884	R\$ 9.358	R\$ 9.298	R\$ 12.347	R\$ 16.166	R\$ 14.578	R\$ 15.393
<span style="color: #8B0000;">●</span> OTHER	R\$ 2.846	R\$ 3.279	R\$ 2.863	R\$ 3.120	R\$ 4.974	R\$ 5.203	R\$ 5.480	R\$ 3.909	R\$ 4.626	R\$ 3.481	R\$ 3.706

**B. In percent**

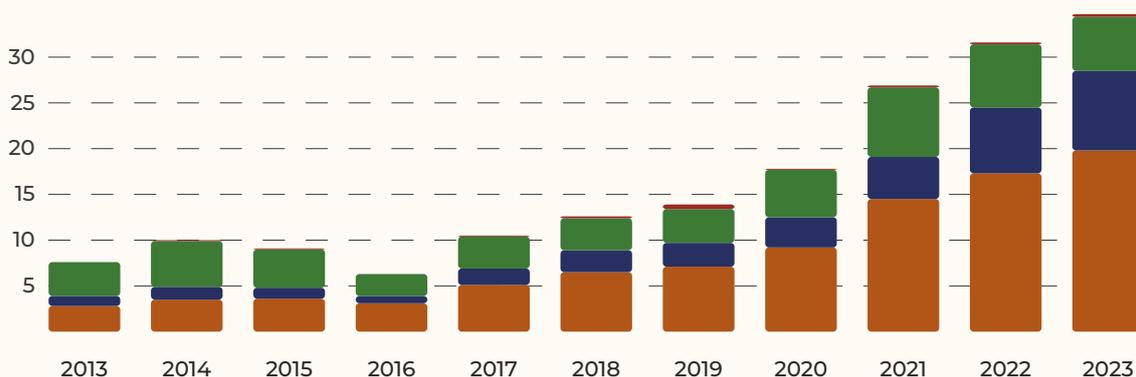


Fonte de dados: Cálculos dos autores com base em dados do Banco Central do Brasil (s.d.).

**Figure 16.** Purpose and type of rural credit used to boost cattle productivity in Amazon states, in millions of Reals (2013–2023)

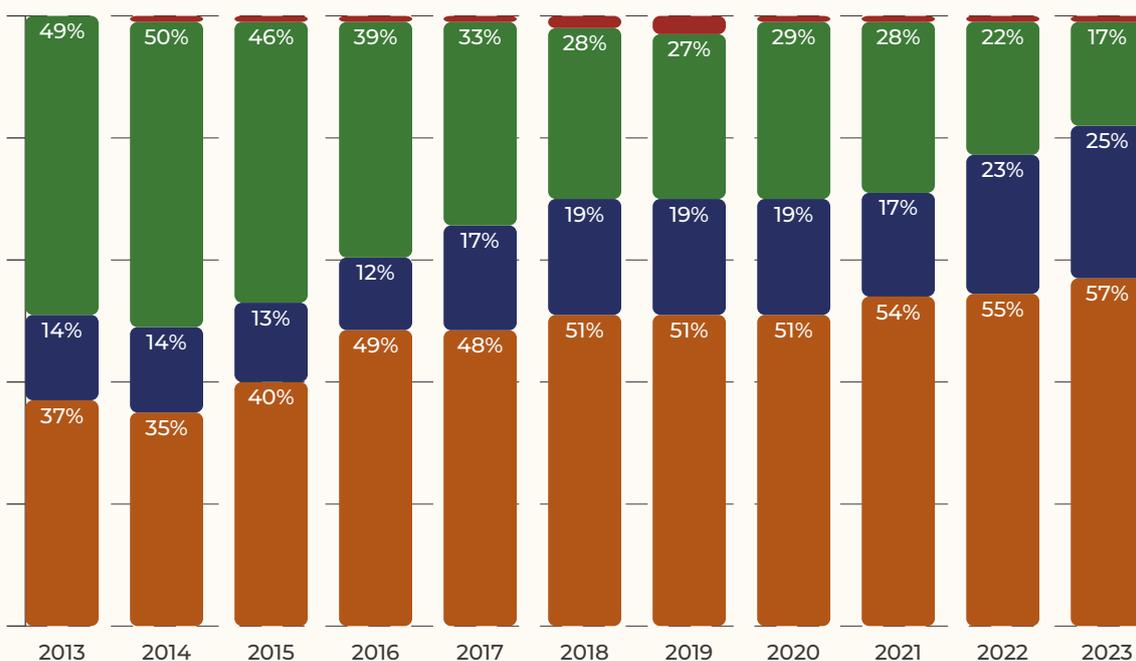
**A. In nominal Reals**

■ COSTING - CATTLE 
 ■ INVESTMENT - INCREASING PRODUCTIVITY  
■ INVESTMENT - CATTLE 
 ■ OTHER



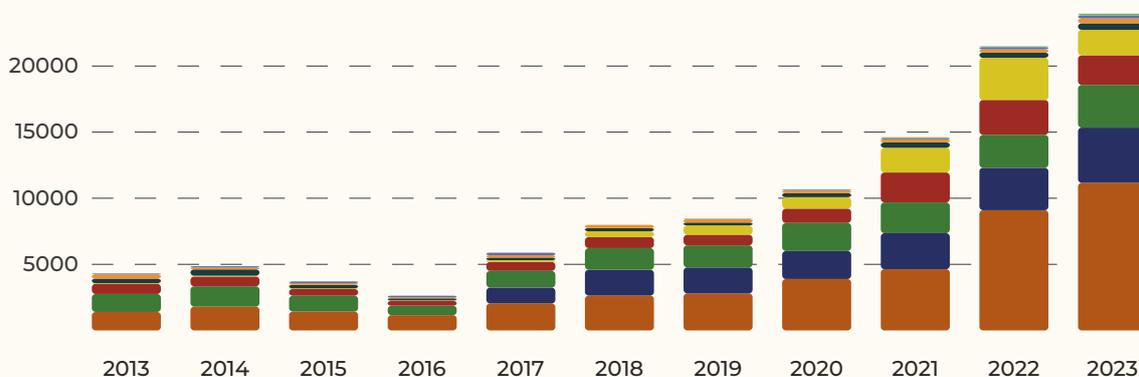
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
<span style="color: #8B4513;">●</span> COSTING - CATTLE	R\$ 2.832	R\$ 3.542	R\$ 3.570	R\$ 3.075	R\$ 5.068	R\$ 6.451	R\$ 7.132	R\$ 9.198	R\$ 14.491	R\$ 17.344	R\$ 19.816
<span style="color: #00008B;">●</span> INVESTMENT - INCREASE PRODUCTIVITY	R\$ 1.057	R\$ 1.393	R\$ 1.213	R\$ 783	R\$ 1.833	R\$ 2.370	R\$ 2.581	R\$ 3.321	R\$ 4.567	R\$ 7.230	R\$ 8.690
<span style="color: #008000;">●</span> INVESTMENT - CATTLE	R\$ 3.723	R\$ 5.011	R\$ 4.150	R\$ 2.440	R\$ 3.535	R\$ 3.548	R\$ 3.746	R\$ 5.232	R\$ 7.610	R\$ 6.915	R\$ 5.862
<span style="color: #8B0000;">●</span> OTHER	R\$ 31	R\$ 89	R\$ 72	R\$ 33	R\$ 120	R\$ 214	R\$ 466	R\$ 123	R\$ 180	R\$ 159	R\$ 270

**B. In percent**



Data source: Authors' calculations based on data from the Central Bank of Brazil (n.d.).

**Figure 17.** Nominal value of rural credit contracts\* for cattle ranching by product type in Brazil (2013–2023)

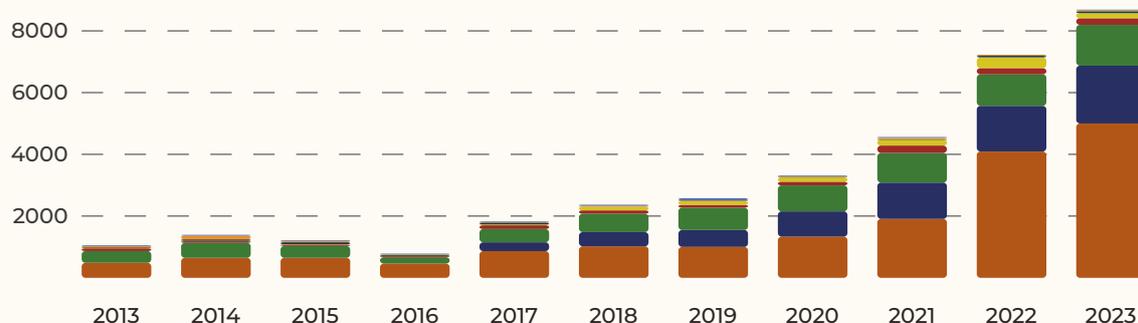


	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Investment - protection, fertilization and intensive soil correction	R\$ 1.396.6	R\$ 1.800.8	R\$ 1.430.8	R\$ 1.155.9	R\$ 2.040.0	R\$ 2.638.1	R\$ 2.802.1	R\$ 3.889.7	R\$ 4.632.8	R\$ 9.092.3	R\$ 11.165.4
Investment - terraces, gates, boreholes, corrals, troughs, fences, scales					R\$ 1.200.3	R\$ 1.955.2	R\$ 1.961.9	R\$ 2.118.6	R\$ 2.722.1	R\$ 3.209.3	R\$ 4.176.0
Investment - pasture	R\$ 1.361.6	R\$ 1.538.5	R\$ 1.196.3	R\$ 718.2	R\$ 1.264.9	R\$ 1.631.5	R\$ 1.672.1	R\$ 2.120.5	R\$ 2.327.3	R\$ 2.493.6	R\$ 3.227.9
Investment - irrigation	R\$ 772.4	R\$ 735.9	R\$ 507.1	R\$ 358.4	R\$ 682.4	R\$ 837.4	R\$ 803.1	R\$ 1.083.4	R\$ 2.263.2	R\$ 2.639.8	R\$ 2.238.0
Investment - implementation of energy technologies renewable, environmental, and small applications hydropower, rural electrification	R\$ 45.2	R\$ 66.3	R\$ 52.5	R\$ 39.9	R\$ 125.2	R\$ 436.5	R\$ 706.0	R\$ 867.3	R\$ 1.870.0	R\$ 3.185.3	R\$ 1.927.0
Costs - vaccines, mineral salts and medicines	R\$ 344.7	R\$ 475.5	R\$ 260.4	R\$ 154.9	R\$ 201.6	R\$ 243.8	R\$ 215.3	R\$ 308.7	R\$ 406.0	R\$ 399.4	R\$ 495.6
Investment - construction/rehabilitation of dams/tanks, water catchment systems/water catchment, retention and utilization systems/drilling of wells, cisterns/tanks	R\$ 321.8	R\$ 146.8	R\$ 131.5	R\$ 87.1	R\$ 177.5	R\$ 229.7	R\$ 253.7	R\$ 188.7	R\$ 233.9	R\$ 248.7	R\$ 371.2
Costs - pasture and grass	R\$ 64.3	R\$ 94.6	R\$ 128.5	R\$ 111.4	R\$ 186.1	R\$ 3.9	R\$ 27.2	R\$ 74.2	R\$ 88.8	R\$ 161.5	R\$ 214.6
Investment - acquisition of traceability systems of cattle and buffaloes								R\$ 7.0	R\$ 64.6	R\$ 55.2	R\$ 127.4
Investment - free stall cattle confinement					R\$ 1.6	R\$ 2.8	R\$ 0.7	R\$ 5.4	R\$ 4.9	R\$ 3.8	R\$ 9.4
Investment - acquisition of computer equipment and telecommunications, including software acquisition					R\$ 1.4	R\$ 2.5	R\$ 2.5	R\$ 8.3	R\$ 9.0	R\$ 1.4	R\$ 4.4
Investment - insemination artificial and semen acquisition, animal eggs and embryos	R\$ 1.9	R\$ 2.4	R\$ 1.7	R\$ 0.8	R\$ 2.6	R\$ 3.1	R\$ 3.3	R\$ 2.5	R\$ 2.4	R\$ 4.5	R\$ 4.2

\*Data in ascending order of values in 2023.

Data source: Authors' calculations based on data from the Central Bank of Brazil (n.d.).

**Figure 18.** Nominal value of rural credit contracts\* for cattle ranching by product type in the Brazilian Amazon states (2013–2023)

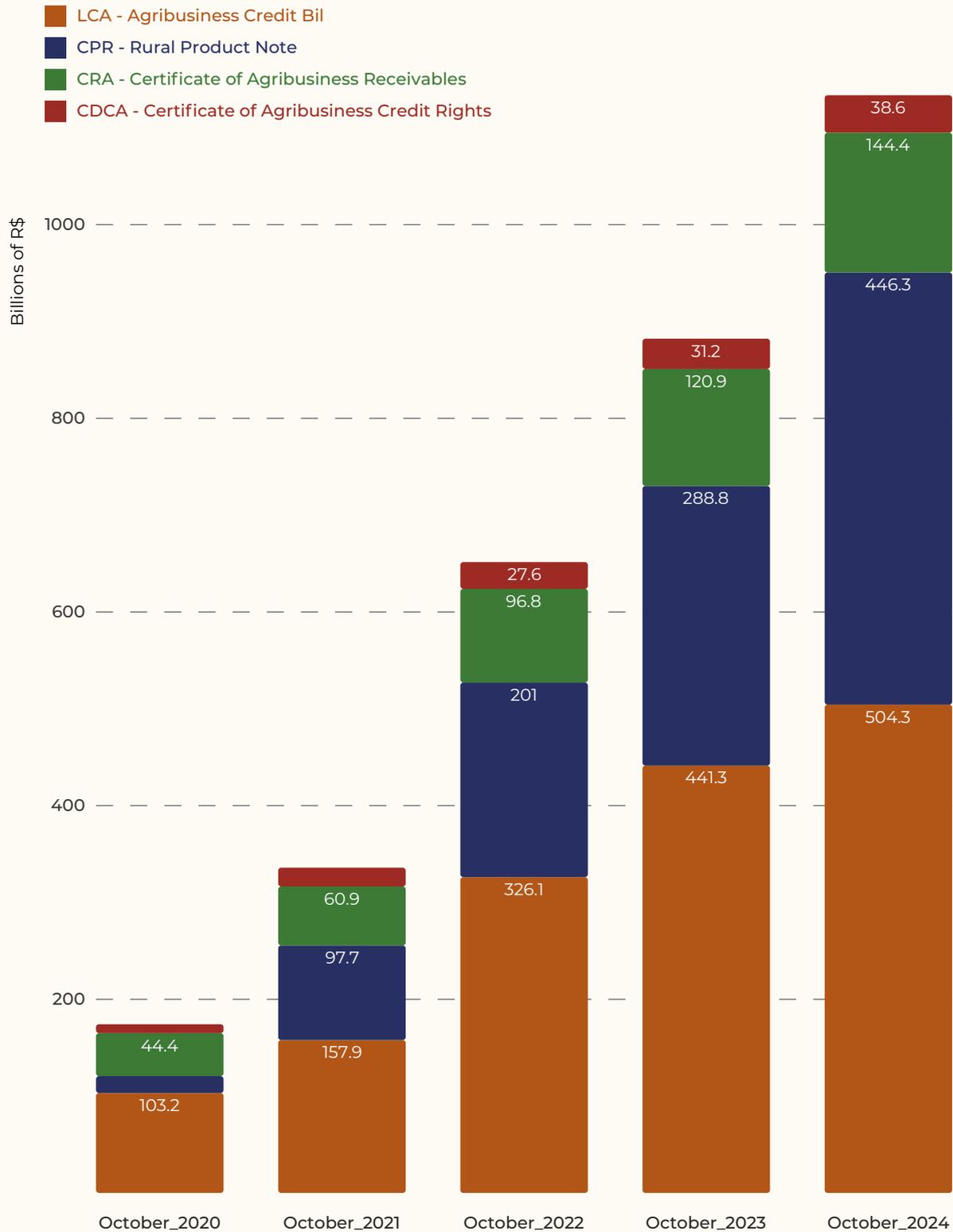


	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Investment - protection, fertilization and intensive soil correction	R\$ 486.0	R\$ 648.2	R\$ 647.9	R\$ 461.2	R\$ 864.5	R\$ 1.020.2	R\$ 1.001.3	R\$ 1.333.7	R\$ 1.909.0	R\$ 4.091.6	R\$ 5.000.5
Investment - terraces, gates, boreholes, corrals, troughs, fences, scales					R\$ 286.6	R\$ 460.6	R\$ 548.1	R\$ 818.7	R\$ 1.175.9	R\$ 1.479.7	R\$ 1.873.1
Investment - pasture	R\$ 380.6	R\$ 484.1	R\$ 383.6	R\$ 206.0	R\$ 429.2	R\$ 596.6	R\$ 724.3	R\$ 841.4	R\$ 958.7	R\$ 1.020.6	R\$ 1.321.8
Investment - irrigation	R\$ 89.4	R\$ 53.8	R\$ 44.2	R\$ 33.0	R\$ 121.8	R\$ 106.7	R\$ 89.7	R\$ 119.4	R\$ 241.5	R\$ 200.9	R\$ 212.7
Investment - implementation of energy technologies renewable, environmental, and small applications hydropower, rural electrification	R\$ 9.9	R\$ 11.4	R\$ 10.6	R\$ 8.3	R\$ 26.6	R\$ 115.4	R\$ 117.2	R\$ 137.4	R\$ 183.4	R\$ 349.4	R\$ 165.9
Costs - vaccines, mineral salts and medicines	R\$ 22.3	R\$ 49.0	R\$ 65.7	R\$ 40.9	R\$ 61.9	R\$ 21	R\$ 17.9	R\$ 21.3	R\$ 24.0	R\$ 52.5	R\$ 63.4
Investment - construction/rehabilitation of dams/tanks, water catchment systems/water catchment, retention and utilization systems/drilling of wells, cisterns/tanks	R\$ 43.0	R\$ 117.2	R\$ 33.1	R\$ 16.7	R\$ 22.8	R\$ 31.5	R\$ 12.6	R\$ 20.2	R\$ 43.0	R\$ 28.4	R\$ 28.8
Costs - pasture and grass	R\$ 25.6	R\$ 29.2	R\$ 27.4	R\$ 17.0	R\$ 19.1	R\$ 34.9	R\$ 68.6	R\$ 23.8	R\$ 23.7	R\$ 5.2	R\$ 19.1
Investment - acquisition of traceability systems of cattle and buffaloes					R\$ 0.1	R\$ 0.5	R\$ 0.5	R\$ 4.3	R\$ 6.6	R\$ 0.0	R\$ 1.8
Investment - free stall cattle confinement								R\$ 0.1	R\$ 0.5	R\$ 0.1	R\$ 1.6
Investment - acquisition of computer equipment and telecommunications, including software acquisition					R\$ 0.1	R\$ 0.1	R\$ 0.0	R\$ 0.2	R\$ 0.5	R\$ 1.3	R\$ 1.0
Investment - insemination artificial and semen acquisition, animal eggs and embryos	R\$ 0.3	R\$ 0.2	R\$ 0.2	R\$ 0.1	R\$ 0.5	R\$ 1.0	R\$ 0.4	R\$ 0.2	R\$ 0.1	R\$ 0.4	R\$ 0.4

\*Data in ascending order of values in 2023.

Data source: Authors' calculations based on data from the Central Bank of Brazil (n.d.).

**Figure 19.** Trends in agribusiness's outstanding subsidized private credit



Data source: Data compiled from Boletim do Agro - Finance - November 2024 (Brazil, 2024a).

## 2.3 Factors associated with pasture improvement in the Brazilian Amazon

We used a mathematical model to estimate the probability of improvement of degraded pastures (Figure 20). We analyzed 17 different factors and found that 12 significantly explained the location of changes from low and medium vigor to high vigor pastures between 2018 and 2022 (Table 2). We could explain 88% of the reforms during this period with these factors. The measure of ability (0.7)<sup>8</sup> indicates that the model's accuracy identified real relationships between the variables, i.e., these relationships were not random. To validate the model's effectiveness, developed with data from 2018 to 2022, we tested its ability to predict pasture renovations in 2023. The model got 72% of the locations of these renovations right, indicating that the explanatory factors can predict with reasonable accuracy where farmers tend to renovate their pastures under current conditions.

The most relevant factors in explaining pasture improvement were the distance from high vigor pastures, the slope of the land, the density of grain storage silos, the water available in the soil and the density of meatpacking plants that export to China (Table 2). Other relevant factors included the distance from official roads, the percentage of producers who received technical assistance and the percentage of producers who completed high school. This analysis confirms the importance of natural factors, infrastructure, the market and the condition of producers for adopting technologies. These factors facilitate the production and transportation of meat. The greater likelihood of improved pastures around meatpacking plants exporting to China shows that farmers are using technologies to produce “China beef”, which is beef from younger cattle at a higher price.

We highlight examples that show how the chance of improving pastures varies in different areas. In the northeast of Pará, there is great potential for enhancing pastures due to the abundance of water (rainfall), proximity to highways and the presence of meatpacking plants, including one that exports to China (Figure 21). In contrast, central-western and southeastern Pará have moderate

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<sup>8</sup> The Skill Measure is the difference between the accuracy of the model and the accuracy expected at random (Ngoy et al., 2021).

and low potential for pasture improvement, respectively, due to lower rainfall and limited road access, which hinder transportation.

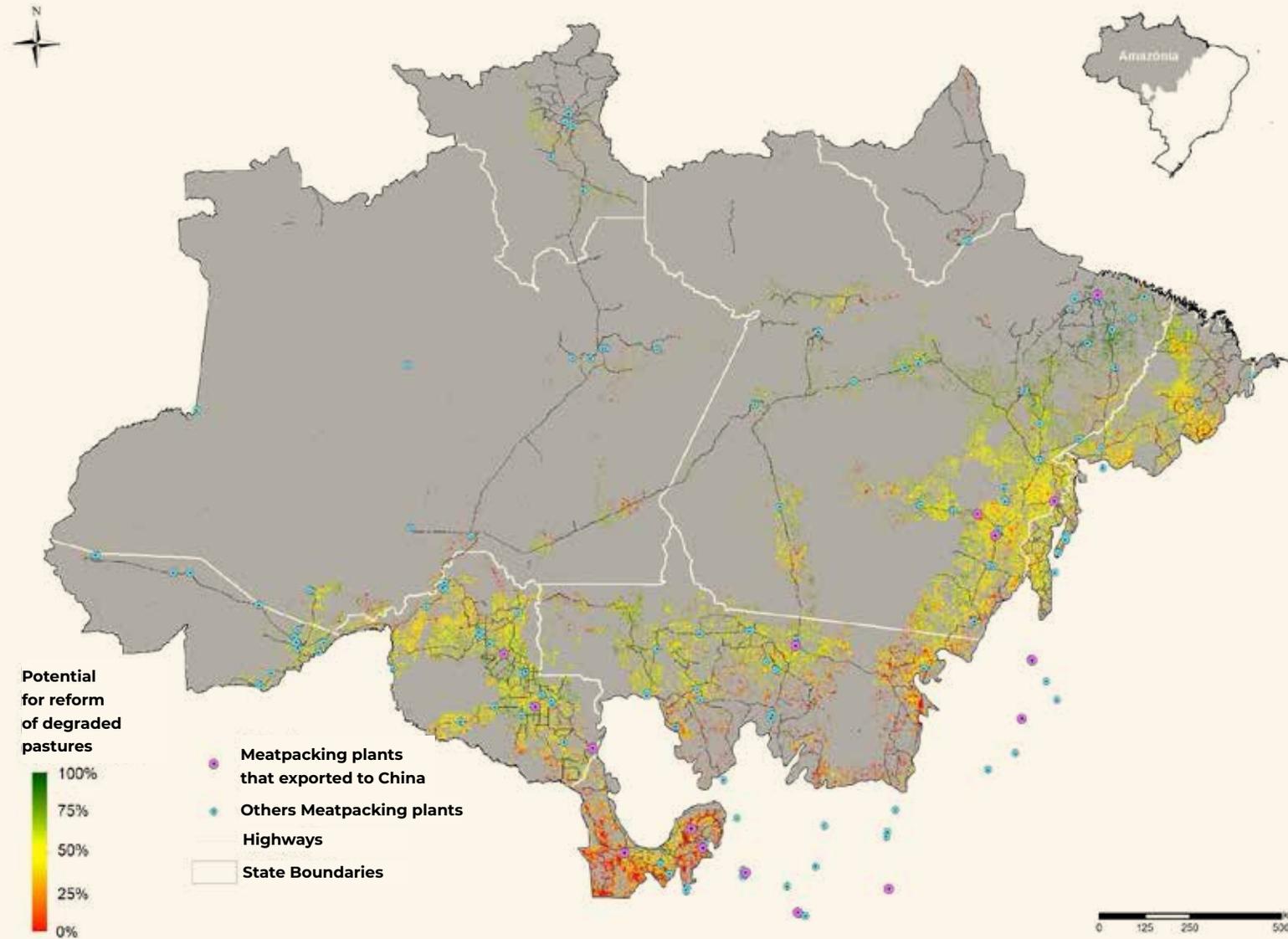
The potential for intensification is higher in the northwest of Mato Grosso, where rainfall is more frequent. However, despite the proximity of highways and exporting meat-packing plants in the southwest of this state, the potential for improving pastures is limited by the low rainfall (Figure 22). This limitation may have been worsened by the recent trend of declining rainfall in the region (Appendix 4 and Mapbiomas Project (2024)). The need to adapt to the reduction in rainfall is evidenced by the increase in irrigation in Mato Grosso for grain production (Mapbiomas Project, 2022) and pastures (Figure 32 in Appendix 4). This strategy makes it possible to increase meat production, despite the difficulties in improving pastures.

**Table 2.** How accurate the model is at estimating where pasture can be improved — and which factors matter most

Modeling variables	Accuracy (%)	Model skill measure <sup>9</sup>	Order of influence of variables
With all the variables	87.5	0.75	-
Distance from highly vigorous pastures	62.9	0.26	1
Terrain slope	84.8	0.70	2
Density of silos	85.8	0.72	3
Available water in the soil	85.8	0.72	4
Density of meatpackers exporting to China	86.1	0.72	5
Density of deforested areas	86.9	0.74	6
Precipitation	87.2	0.74	7
Carbon in the soil	87.4	0.75	8
Distance from embargoed areas	87.4	0.75	9
Distance from official roads	87.5	0.75	10
Technical assistance in rural establishments	87.7	0.75	11
High school graduation rate for rural producers	88.1	0.76	12

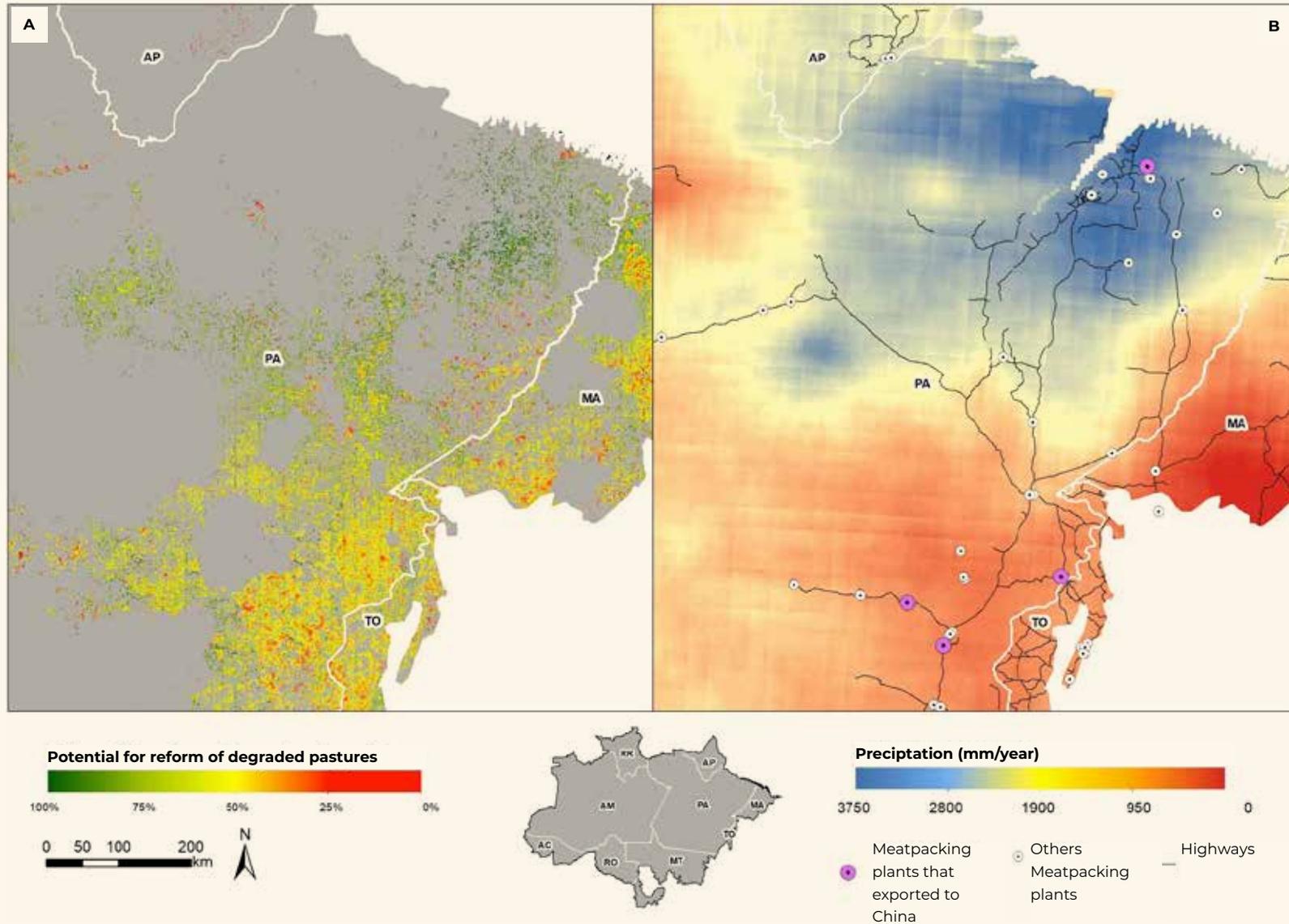
<sup>9</sup> The model's Skill Measure is the difference between the model's accuracy and the accuracy expected at random (Ngoy et al., 2021).

**Figure 20.** Probability distribution of low- and medium-vigor pastures being converted to high vigor (through pasture reform).



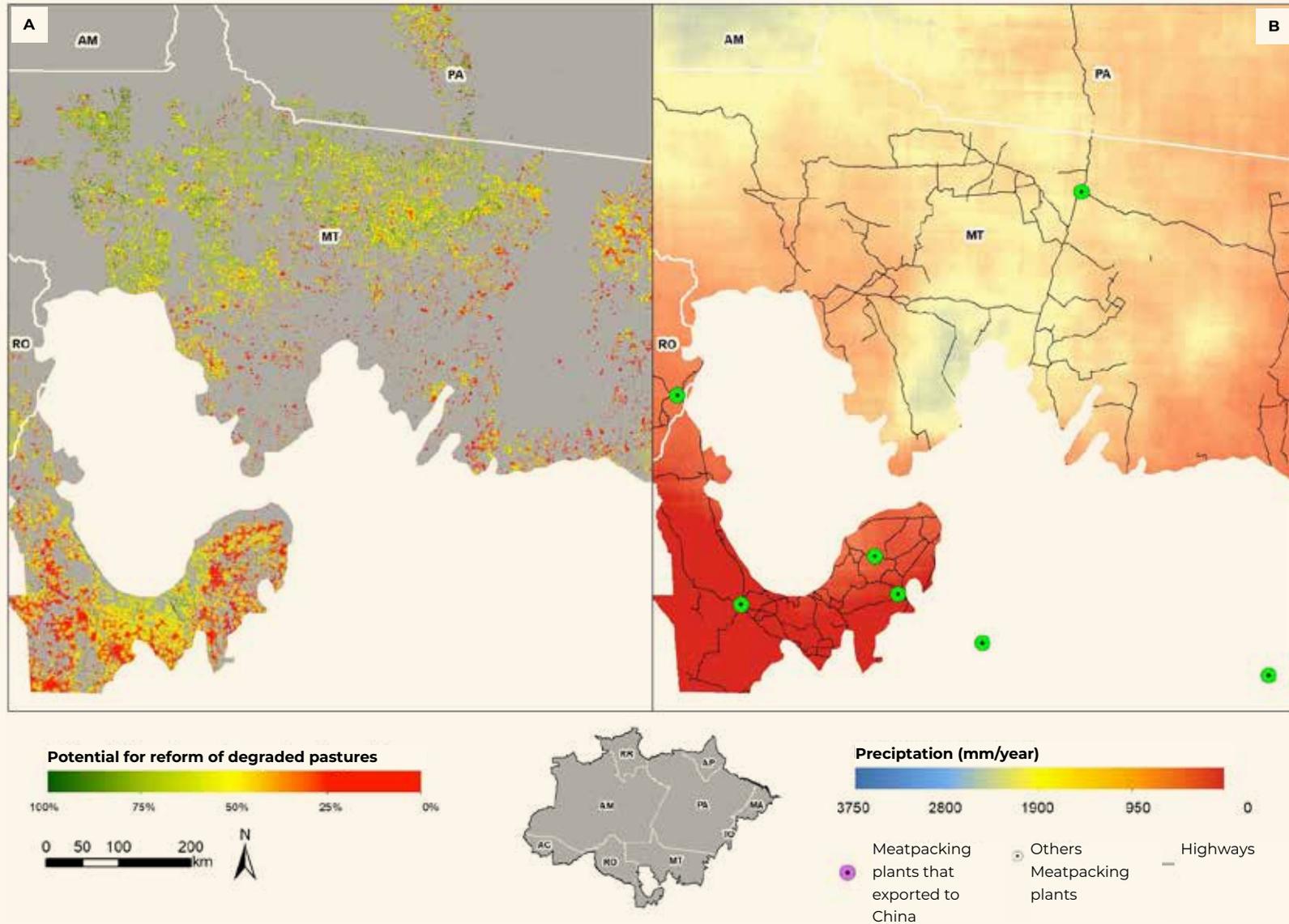
Data source: precipitation (University of California, n.d.).

**Figure 21.** Probability distribution of low- and medium-vigor pastures being converted to high vigor through pasture reform (A) and regional explanatory factors (rainfall, location of meatpacking plants and roads) in central-eastern Pará (B).



Data source: precipitation (University of California, n.d.).

**Figure 22.** Probability distribution of low- and medium-vigor pastures being converted to high vigor through pasture reform (A) and regional explanatory factors (rainfall, location of meatpacking plants and highways) in Mato Grosso (B).



Data source: precipitation (University of California, n.d.).

### 2.3.1 The low likelihood of pasture renovation under prevailing conditions

Our analysis reveals that the probability of farmers improving their degraded pastures between 2018 and 2022 was extremely low. Only 0.2% of degraded pastures during this period had a likelihood of reform equal to or greater than 75% (Figure 23). Nearly 60% of low- and medium-vigor pastures — around 19 million hectares — had a 25%–50% chance of recovery. In Pará, Mato Grosso, and Rondônia, nearly 80% of pastures fell within this likelihood range (Figure 24).

The low probability of progress reflected the region’s structural conditions and recent public and private policies, as exemplified below.

- Some factors that induce technology adoption, such as education, technical assistance and road quality, are scarce in the region (Barreto, 2021).
- Policies favorable to deforestation discourage the adoption of technologies to increase productivity. In 2012, Congress and the Executive Branch granted amnesty to farmers who had illegally deforested tens of millions of hectares, resulting in an additional deforestation of around one million hectares between 2012 and 2017 (Sant’Anna & Costa, 2021). Between 2018 and 2022, deforestation increased due to the loosening of enforcement and promises to open indigenous lands to commercial farming and regularize new occupations (Barreto & Brito, 2023; Observatório do Clima, 2021, 2022).

- Several states in the Brazilian Amazon, which hold most unallocated public lands, resist creating protected areas and have land policies that favor the regularization of land invasions (Barreto and Brito, 2023; Brito et al., 2021). Land regularization projects for illegal occupations of 19.6 million hectares would result in unaccounted subsidies estimated at R\$62 billion and R\$88 billion in 2018 (Brito et al., 2019). In this estimate, the subsidy was calculated as the difference between the sale price stipulated by the government and the market value of the land<sup>10</sup> (Brito et al., 2019). Thus, the continued regularization of invaded lands perpetuates perverse incentives for speculative deforestation, discouraging the productive use of deforested areas.
- The market and financing for farmers and the meat industry, which are still associated with deforestation, remain large (Barreto et al., 2023; Greenpeace 2024).
- Pasture renovation costs are higher in the Brazilian Amazon. For example, in 2022 the renovation of low vigor pastures cost 10% and 22% more than in the Cerrado and Atlantic Forest biomes, respectively. The cost of recovering and maintaining pastures in the Amazon, Caatinga, and Cerrado regions is mainly due to the prices of fertilizers and soil treatments needed. In the Amazon, these costs are particularly high due to the expensive transportation of these materials. Potassium chloride and urea fertilizers have high costs (de Matos et al., 2022).
- Worsening climatic extremes, such as less rainfall (Mapbiomas Project, 2024 and Appendix 4) and high temperatures, increasing production costs, reducing farmers' potential profits, and demanding greater knowledge for adaptation, such as using food supplementation and irrigation. A study in Rondônia revealed that most farmers were unprepared for these adaptations (Skidmore, 2023).

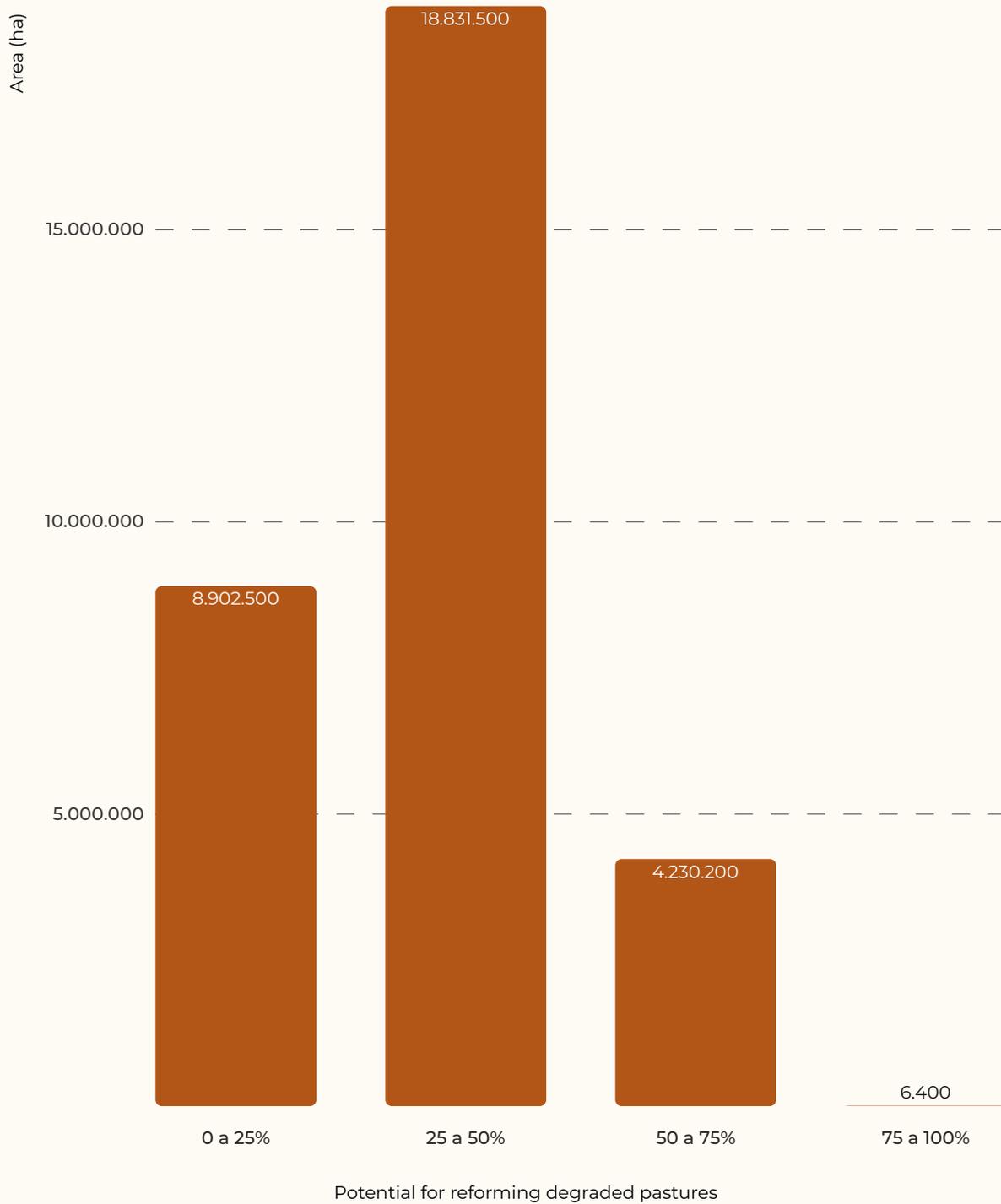
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<sup>10</sup> Essa estimativa foi conservadora, pois desconsidera os lucros que os ocupantes ilegais ganham com a exploração ilegal de madeira e o aproveitamento agropecuário das áreas desmatadas. Portanto, os incentivos à grilagem são ainda maiores.

There is a risk that unfavorable conditions will persist for improving productivity due to a lack of ambition and commitment in livestock and conservation initiatives and efforts to weaken environmental policies, as exemplified below.

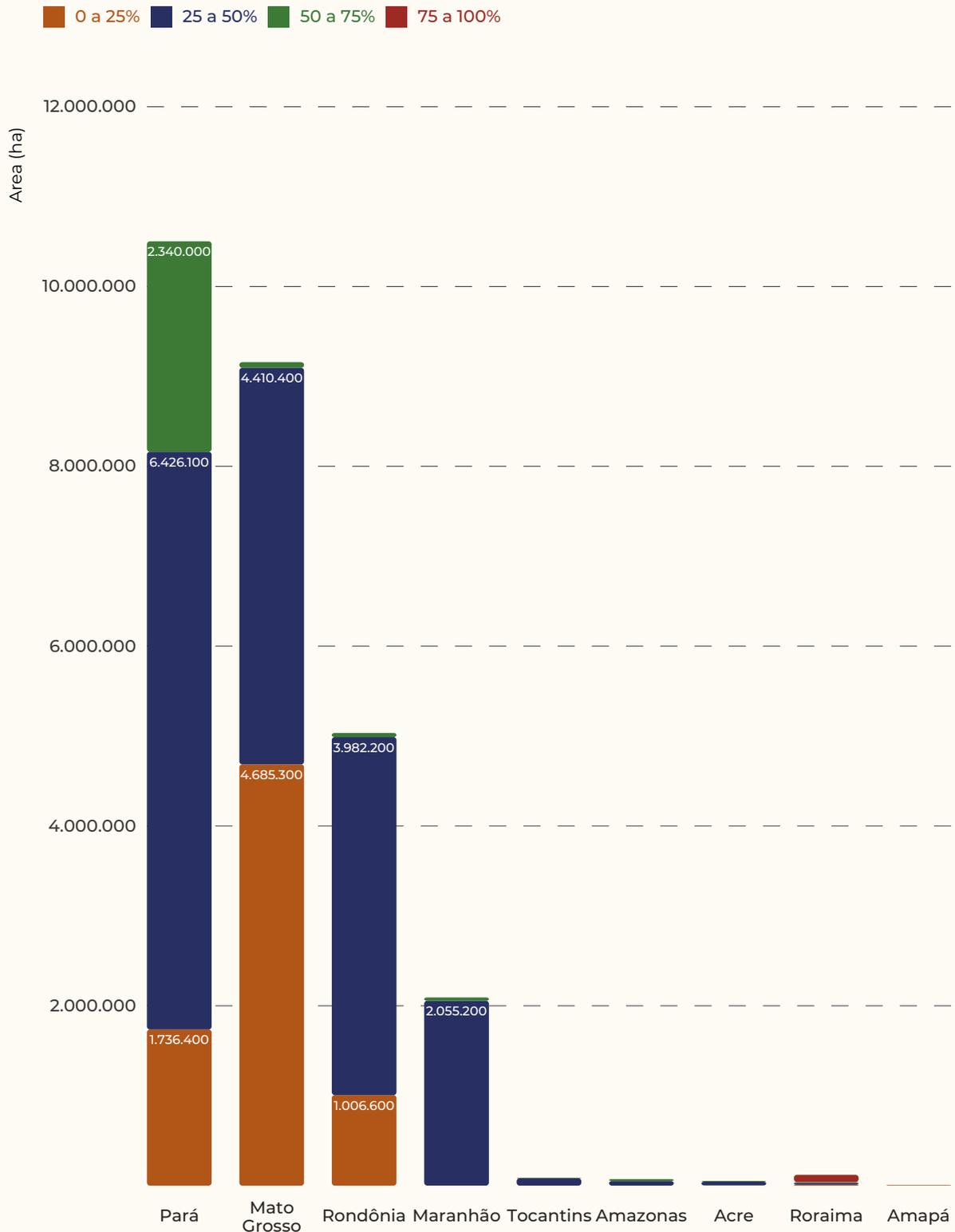
- Politicians and landowners in Mato Grosso have adopted policies that favor deforestation. For example, in October 2024, the government and the Legislative Assembly approved Law No. 12.706/2024 (Cordeiro, 2024), eliminating tax incentives and public land concessions for companies that adhere to the soy moratorium. In November 2024, a bill proposed reclassifying areas of the Amazon rainforest as Cerrado. The change would allow for an increase in permitted deforestation, reducing the legal reserve from 80% to 35%. More than forty professors warn that this could lead to an additional 5.2 million hectares of deforestation (Prizibiszki, 2024).
- The Ministry of Agriculture and Livestock (MAPA) has launched the National Livestock Traceability Plan, which provides for the mandatory individual identification of all cattle and buffalo in Brazil, with full implementation by 2032. However, the plan focuses exclusively on health and safety and does not address environmental issues. Experts say the new deadline is too late and doesn't match the urgent need to address today's environmental and climate problems. Moreover, the lack of a link to environmental control limits the system's effectiveness in responding to the demands of importing markets looking for sustainability guarantees (Prizibiszki, 2024). The lack of a national plan could weaken the implementation of the traceability plan announced by the government of Pará, which has committed to a mandatory cattle traceability system by 2026 (Governo do Pará, 2023), prompted by the risk of boycotts (Mendonça, 2022).

**Figure 23.** Distribution of pasture areas by probability of renovation, given conditions from 2018 to 2022



Data source: Data compiled from Boletim do Agro - Finance - November 2024 (Brazil, 2024a).

**Figure 24.** Degraded pasture area by probability of reform (2018–2022), by state in the Brazilian Amazon



Data source: Data compiled from Boletim do Agro - Finance - November 2024 (Brazil, 2024a).

### 3 Lessons for inducing more productive livestock farming

Our analysis reveals that productivity improvements occurred significantly and accelerated with the combination of charging and rewarding, highlighting the effectiveness of this integrated strategy. In addition, we reveal limitations to increasing productivity, including environmental factors, public policies and the market.

Below, we highlight the lessons and recommendations for increasing livestock productivity in Brazil, emphasizing the Amazon.

#### **Lessons from the expansion of cattle ranching between 2000 and 2023**

- **Pressure and support from public and private policies have conditioned productivity improvements.**
  - The growth in livestock production and productivity has been driven by premiums and specific demands from the market and public policies, including the demand for young beef (China) accompanied by price increases, the demand for hybrid calves for live animal exports (Peru) and forest protection policies (restricted credit for environmental compliance, enforcement against deforestation, creation of protected areas). Pasture reform was more significant in the years with less deforestation (See Table 1).
  - The adoption of technologies, facilitated by rural credit, promoted improvements in pastures, investments in infrastructure for practices such as rotational grazing, irrigation and artificial insemination to improve herd quality and speed up reproduction. The importers' demands coincided with a relative increase in rural credit for products associated with increased productivity.

- **The persistence of deforestation and degraded pastures**
  - In addition to productivity improvements in some areas, the expansion of cattle ranching has contributed to deforestation on new frontiers. Notably, pasture improvement was lower in the years with the highest deforestation rates. Deforestation rates varied according to fluctuations in the application or weakening of public and private environmental control policies.
  - Although the government requires rural credit borrowers to comply with environmental rules, credit can stimulate deforestation directly or indirectly; for example, when a fattening farm without deforestation that uses rural credit buys calves from breeding farms with illegal deforestation.
  - The use of rural credit for productive improvements, such as pastures and insemination, has shown significant growth. However, most of this credit is still contracted mainly for the purchase of cattle. This finding reveals an underutilization of rural credit for improving productivity, especially when related to improving productivity in areas such as pasture renovation. A study in the Cerrado showed that rural credit earmarked for pasture reform does not necessarily increase productivity, especially when the farmer does not receive proper technical assistance (Oliveira et al., 2024). In addition, the subsidized private debt instruments contracted amount to R\$1 trillion without being conditioned to environmental performance and productivity. Thus, there is significant potential to optimize the use of rural credit, directing it more efficiently to boost productivity and promote sustainable practices.
- **Factors that facilitate the improvement of degraded pastures**
  - **Infrastructure and proximity to markets.** Pasture improvement was more likely in areas close to meatpacking plants that export to China, of roads that facilitate access to inputs, technologies and the flow of production.
  - **Natural conditions.** Regions with greater water availability, flat terrain

and regular rainfall are more likely to reform due to economic and environmental viability.

### Challenges for improving degraded pastures

- **High costs and local limitations.** Pasture recovery in the Brazilian Amazon is more expensive due to the high costs of fertilizers, transport and management in remote areas.
- **The persistence of deforestation.** The increase in deforestation in the Brazilian Amazon has been inversely proportional to the reform of degraded pastures. Therefore, to stimulate the adoption of technologies that increase the productivity of cattle ranching, it is crucial to implement credible and sustained public and private policies against deforestation. However, these policies have been insufficient and inconsistent. An example of this is the national policy for tracing animal origin, published in 2024 and to be completed in 2032.
- **Aggravation of climatic extremes.** The likelihood of pasture recovery has been lower in regions with less water availability. The reduction in rainfall in the country and the region, therefore, reduces the potential for pasture reform and can increase the cost of production due to the need for adaptation, such as irrigation and feed supplementation.

## 3.2 Initiatives to encourage more productive cattle ranching

- **Strengthening and accelerating the fight against deforestation**
  - Reducing deforestation has been necessary to encourage more productive use of deforested areas. Despite the progress in combating deforestation since 2022, 6,100 square kilometers have been cleared by 2024 (INPE, 2024); that is, 37% more than the lowest level reached in 2012 and far beyond the target of zeroing illegal deforestation by 2030. We have listed the following priority measures to accelerate and consolidate progress, detailed in Appendix 5.
    - Allocate public lands following the Constitution to promote sustainability and prevent land grabbing. In addition to the executive branch's actions, judicial intervention is crucial, given that some executive and legislative policymakers have delayed or violated the Constitution's application.
    - Strengthen and expand environmental control of credit for the rural sector, especially private credit, which totaled R\$1.1 trillion in 2024 (Figure 19).
    - Make data on livestock origin accessible while making progress on establishing mandatory individual animal tracking. In 2024, the Federal Supreme Court (STF) ruled that the transparency of this data for environmental inspection is legitimate and demanded that the federal government present, within sixty days, a plan to disclose the data to the supervisory bodies (Allegation of non-compliance of fundamental precept 760, 2025). Since knowing where cattle come from also helps those focused on health and environmental management, the government should make data on farms and cattle transport widely accessible.
    - Electoral cycles have undermined the continuity and effectiveness of public policies essential to the region's sustainability (Morpurgo et al., 2021; Observatório do Clima, 2022; Pailler, 2018; Rodrigues-Filho et al., 2015; Sant'Anna & Costa, 2021). With the acceleration

of climate change, an undeniable reality of the laws of physics, this situation is unsustainable. Therefore, institutions such as the Central Bank, the Judiciary, the Public Prosecutor's Office and the Federal Court of Auditors must expand and intensify their actions to encourage environmental protection and more productive and sustainable land use in the country. The recent actions of these institutions involve, for example, the control of fires, the transparency of data on the transportation of cattle, the eviction of indigenous lands, and the environmental control of rural credit<sup>11</sup>.

- **Focus on improving productivity.**
  - Rural credit can be one of the main drivers of improvements if it is linked to productivity and environmental performance targets and monitoring. The fact that farmers have invested in meeting Chinese demand for beef from younger cattle illustrates the importance of performance targets. In addition, the need for improvements in the rural credit system is reinforced by a study that revealed a limited impact of the Low Carbon Agriculture loans for pasture restoration program (ABC Recuperação) in the Cerrado on increasing productivity (Oliveira et al., 2024). Suggestions for improving the effect of rural credit include:
    - The hiring of technical assistance, in the case of the ABC Recuperação Cerrado program, reduced the area of degraded pasture by an average of six percentage points. In contrast, farmers without assistance did not show significant improvements (Oliveira et al., 2024).
    - All financial institutions and credit providers should assess farms' land cover history before approving agricultural loans or subsidies to ensure that no financing is allocated to recently deforested land (Oliveira et al., 2024).

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<sup>11</sup> (Arguição de descumprimento de preceito fundamental 743, 2025; Arguição de descumprimento de preceito fundamental 847, 2024; Conselho Nacional de Justiça, [s.d.]; Cordeiro, 2024; Observatório do Clima, 2023b; Procuradoria da República no Pará, 2025; STF, 22DC, 2024; Tribunal de Contas da União, [s.d.]; Velloso, 2025).

- Investing in measures against preventable diseases and parasitosis could increase farmers' revenue by tens of billions of Reals (Jornal da USP, 2023).
- **Focus on the concession of credit, infrastructure, and services in priority areas**
  - Governments should focus on granting public credit, infrastructure, and services such as education and technical assistance in the areas with the highest potential for adopting technologies. Our analysis reveals regions with the most significant potential and others with a low probability of improvement (Figure 20).
  - At the same time, it is crucial to abandon infrastructure projects that offer low socio-economic returns and induce deforestation, such as the paving of the BR-319 highway (Fleck, 2009) and the construction of the Ferrogrão railroad (Assunção, Bragança, et al., 2020; Frischtak, 2024). The ease of occupying new forest frontiers discourages renovating degraded pastures, contrary to sustainable development efforts.
- **Combining production and environmental demands with performance and premium clauses**
  - Buyers and investors must fulfill commitments, encouraging more productive and sustainable land use to ensure a sustainable meat supply. In this sense, it will be crucial that the three large-scale initiatives that call for tracing the origin of cattle are met:
    - The Brazilian Federation of Banks (Febraban) has committed to only granting credit to meatpackers that achieve complete traceability of cattle by 2025.
    - The European regulation banning the import of products associated with deforestation after 2020 and requiring traceability of origin, and the Chinese Meat Association's specifications for meat decoupled from deforestation, whose implementation date is still undefined.

Given the urgency of preventing new deforestation and accelerating more sustainable practices, supply chain players must act on these commitments even without a national public system for tracking individual cattle. For example, investors, retail chains and meatpackers could establish an independent private certificate of cattle origin system. They would require direct and indirect supplier farmers to share information on animal transportation. An independent entity would use this data to identify farms without deforestation.

The companies in the beef supply chain could adopt coordinated pre-competitive incentives to implement existing best practices. For example, some meatpacking companies have set up offices and systems to support environmental regularization and production assistance for farmers (O Mundo Que Queremos & Imazon, 2025). The impact of these initiatives could be amplified by joint actions with the potential to reduce costs and expand the entry of other companies. This model of sharing sectoral resources has already proved advantageous in different agricultural and forestry sectors (Coslovsky, 2021), indicating a promising path to sustainability.

- **The urgency of the climate crisis**

- Climate change is accelerating and affecting weather patterns, soil conditions, and water availability, making livestock farming difficult and agriculture (Marengo et al. 2017; Rattis et al., 2021). In case of livestock, the acceleration of pasture degradation increases the costs of maintenance and supplementary feed (such as grains) and irrigation (Marengo et al., 2017; Skidmore, 2023). Given the projected greater impact of rising global temperatures (Rodell and Li, 2023), there is an urgent need to implement public and private policies that promote forest conservation and the sustainable use of deforested areas to mitigate climate risks.

# Appendix 1.

## **Methodology for estimating the potential for pasture reform in the Amazon biome**

To assess the potential for improving pastures in the Amazon biome, we used a program (Land Use Change Modeler in the TerrSet program) that analyzes maps from the past and uses different factors (such as the slope of the terrain or the proximity of roads) to predict how land use might change over time. Based on this analysis, the program can project what future land cover might look like. By configuring these factors, the tool uses a neural network (a technology that learns similarly to the human brain) to understand how these elements influence changes in the land. Specifically, we first analyzed maps of pastures and other factors between 2000 and 2019, a period marked by significant changes in environmental policies and agricultural practices. Based on the results of this model, we estimated the likely pasture changes between 2018 and 2022. Then, to assess the validity of this model, we compared its predictions with actual reforms observed in the pasture maps between 2022 and 2023.

### **Hypotheses and explanatory variables**

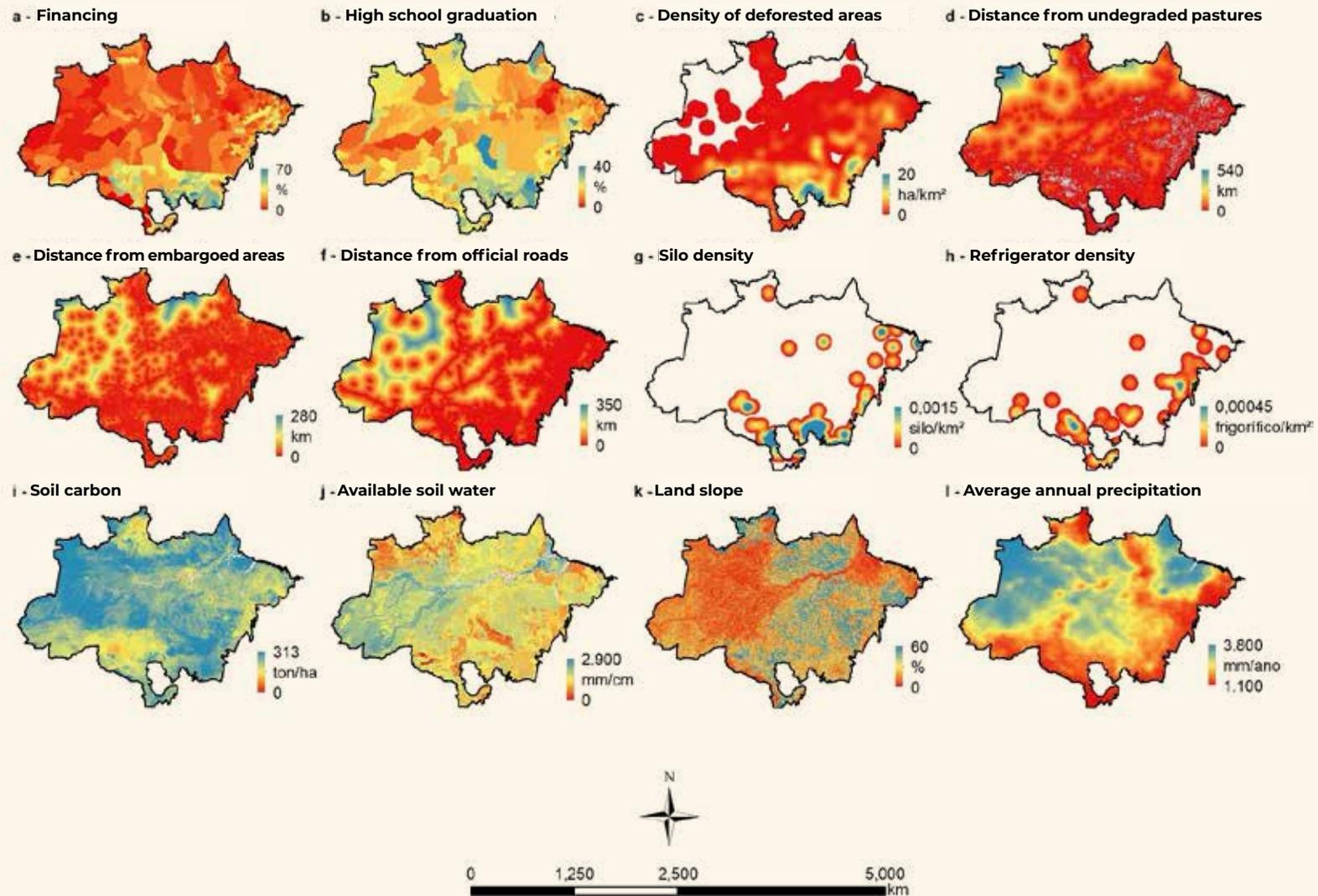
We start from the hypothesis that livestock farmers tend to reform their pastures when a combination of favorable factors is present. The main elements include environmental conditions, such as regular rainfall and soil characteristics, which are essential for pasture growth and cattle hydration (Escarcha, Lassa and Zander, 2018), as well as socioeconomic factors and public policies. Policies to combat deforestation, which restricted ranches from expanding new agricultural areas, encouraged more efficient use of available underutilized cleared lands (Garrett et al. 2018; Veríssimo et al., 2022).

The proximity to markets also favors pasture reform, facilitating access to inputs and technologies and reducing transportation costs (Tirkaso and Hailu 2022; Geldes et al., 2017). Factors such as education, income, and access to credit are crucial for adopting technologies that increase productivity (Rada, Helfand and Magalhães, 2019; Maia, Eusébio and Silveira, 2020). Based on these hypotheses, we identified the potentially explanatory variables summarized in Table 3 and Figure 25.

**Table 3.** Variáveis usadas no modelo para estimar a probabilidade de reforma de pastos

Variable	Year	Source
Municipal proportion of rural establishments that received financing (%)	2017	(IBGE, 2017)
Municipal proportion of rural establishments receiving technical assistance (%)	2017	(IBGE, 2017 <sup>a</sup> )
Municipal proportion of rural producers who have completed secondary school (%)	2017	(IBGE, 2017b)
Municipal proportion of rural producers who have completed elementary school (%)	2017	(IBGE, 2017c)
Euclidean distance of pastures without degradation (km)	2022	(MapBiomas, 2024b)
Kernel of the deforested area in a 100 km region (hectare/km <sup>2</sup> ).	2018 a 2022	(MapBiomas, 2024 <sup>a</sup> )
Euclidean distance of roads registered by IBGE (km)	2021	(IBGE, 2021)
Euclidean distance of navigable rivers (km)	2010	(ANA, 2010)
Kernel of the total number of silos in a 100 km region (silos/km <sup>2</sup> )	2021	(LAPIG, 2021)
Euclidean distance of institutions offering technical/higher education in agronomy (km)	2014	(Globo Rural, 2015)
Kernel of total slaughterhouses in a 100 km region (slaughterhouse/km <sup>2</sup> )	2022	(Imazon)
Municipal proportion of rural establishments with electricity (%)	2017	(IBGE, 2017d)
Euclidean distance of areas embargoed by IBAMA and ICMBio	2000 a 2019	(IBAMA, 2023) e (ICMBio, 2023)
Land slope rate (%)	2000	(Farr et al., 2007)
Average annual rainfall (mm/year)	2018 a 2022	(University of California, [s.d.]
Average amount of organic carbon in up to 30 cm of soil (ton/ha)	2018 a 2022	(MapBiomas, 2023)
Amount of water available in 100 to 200 cm of soil (mm/cm)	2021	(Embrapa, 2022)

**Figure 25.** Distribution of variables hypothetically linked to the potential for improving degraded pastures



Source of precipitation data: (University of California, s.d.)

## 1.2 The calibration and validation of estimates for pasture reform potential

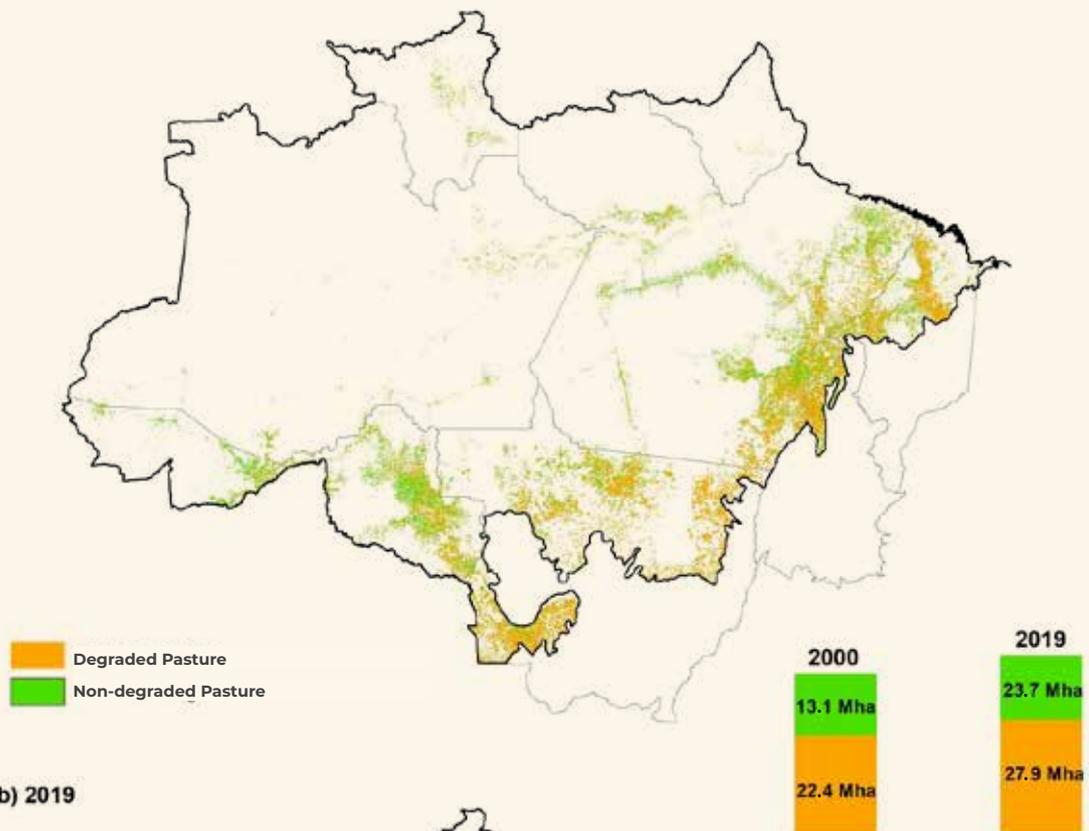
**Model calibration.** Calibrating a model is like adjusting a scale to show the right weight. When we calibrate a model, we adjust it to make more accurate predictions. Think of predicting plant growth. First, you measure how factors such as water, sunlight and fertilizer affect plant growth in various situations. Then, you adjust the model to use these factors correctly, ensuring accurate predictions about plant growth. Calibrating a model is the process of adjusting and checking to ensure that it works well and gives reliable results.

Our study estimated the importance of the variables representing the determining factors in pasture reform between 2000 and 2019. To do this, we used the Land Use Change Modeler (LCM) in TerrSet (Clark Labs 2020), which is a program that uses maps of land cover and various factors (such as slope or proximity to roads) to explain the influence of these factors on land cover change. Based on these factors, the program can predict what the soil might look like in the future according to the situation of the variables used (e.g., road changes). You configure these factors, and the tool uses a special type of learning (similar to how the human brain works) to see how these elements affect changes in the land. The result is a series of maps showing where changes might occur.

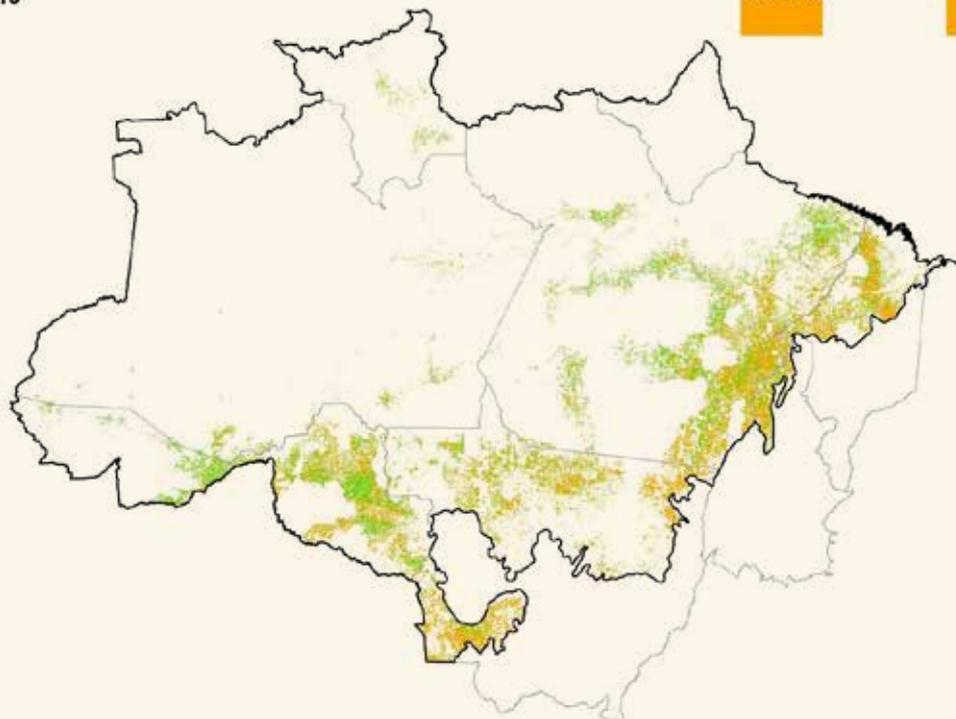
**Gather pasture data.** We collected data from the vegetation cover maps from MapBiomas between 2000 and 2023 (Collection 8, 2023). In the condition of degraded pastures, we included pastures of low and medium vigor and the area of pasture that has become secondary vegetation (an indication that the pasture has been abandoned after degradation). We adjusted the pixel size to one kilometer to optimize the processing, as shown in Figure 26.

**Figure 26.** Pasture area by vigor class in 2000 and 2019: degraded vs. non-degraded

a) 2000



b) 2019



Data source: Calculated by the authors based on data from MapBiomass Brasil (2023).

To estimate the relevance of the factors explaining pasture reform. We estimated the main factors influencing pasture renovation using the Multilayer Perceptron (MLP) neural network (Eastman, [n.d.]). This technique was applied to associate the recovery of degraded pastures between 2000 and 2019 with all the variables that could explain it. The process assessed the learning capacity of the model with all the variables and estimated the impact on the model's performance of excluding each of them (Dominguez et al. 2022). The program repeated the procedure tens of thousands of times for each test. Based on these results, it was possible to rank the variables with the most significant association with pasture improvement and eliminate the factors with low or no association with the transition from degraded pasture to high vigor pasture. We tested various combinations of the explanatory variables to find the set that resulted in the highest accuracy of the model. Table 4 shows an example of the combinations tested with the highest accuracy and the model chosen, where the zeros represent the removal of the variable from the model.

**Table 4.** Exemplo de conjunto de variáveis testadas que resultaram em maiores indicadores de qualidade do modelo: acurácia (%) e validação (% ROC)

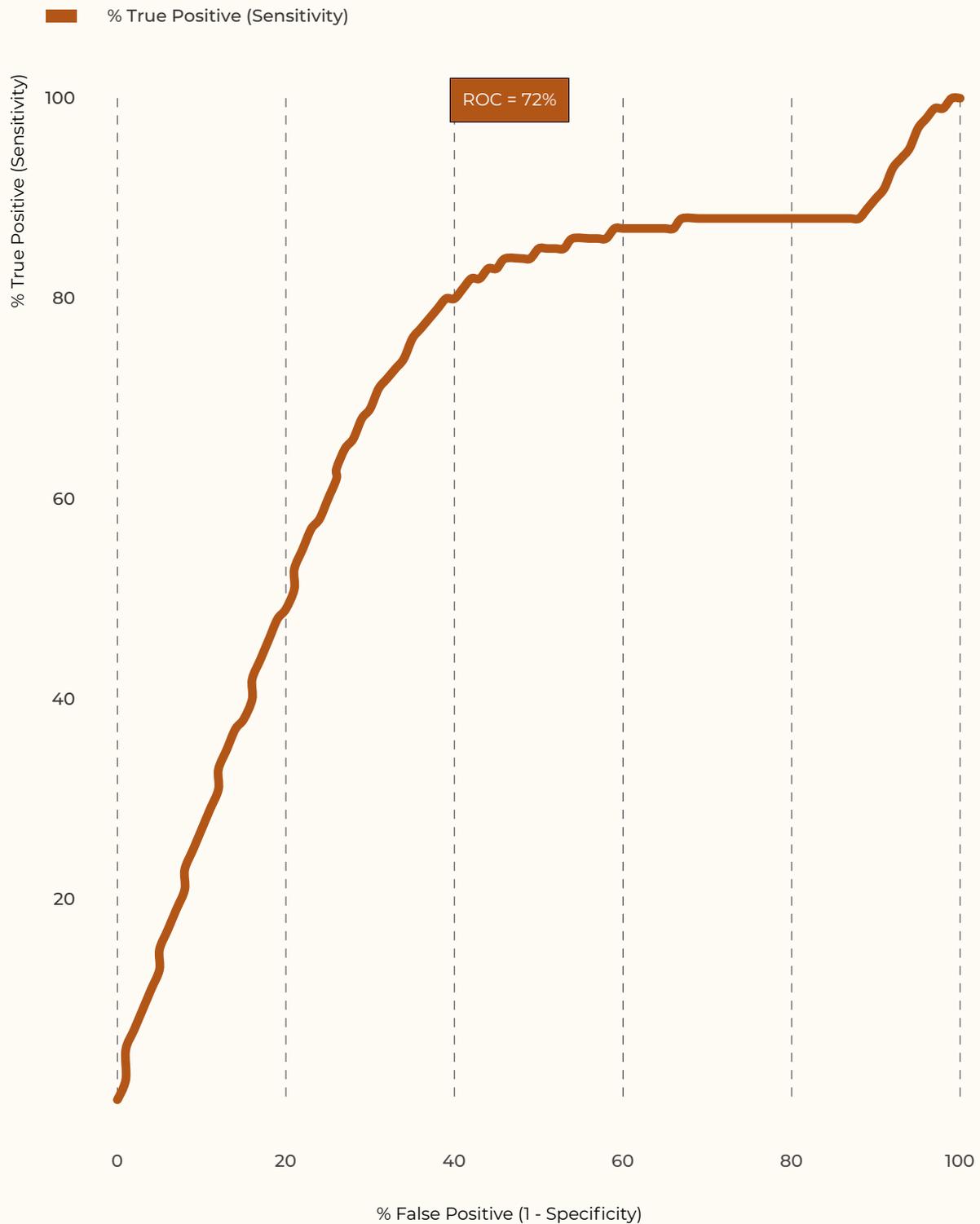
Independent variables	Model 4	Model 5	Model 8	Model 9
Density of deforestation	1	1	1	1
Density of meatpackers exporting to China	1	1	1	1
Density of meatpacking plants	1	1	1	1
Density of silos	1	1	1	1
Distance from embargoed areas	1	1	1	1
Distance from non-degraded pastures	1	1	1	1
Distance from navigable rivers	1	1	1	1
Distance from roads	1	1	1	1
Available water in the soil	1	1	1	1
Average annual rainfall	1	1	1	1
Terrain slope	1	1	1	1
Carbon in the soil	1	1	1	0
Technical assistance	1	1	0	0
Electricity	0	0	0	1
Elementary School	0	0	0	0
High School	0	0	0	0
Financing	0	0	0	0
Credit (R\$) / Area of degraded pasture (Ha)	0	0	0	0
<b>Number of samples (Thousand)</b>	<b>30</b>	<b>10</b>	<b>30</b>	<b>30</b>
<b>Model accuracy percentage</b>	<b>88.56%</b>	<b>83.00%</b>	<b>87.00%</b>	<b>81.00%</b>
<b>Model validation</b>	<b>72.00%</b>	<b>70.00%</b>	<b>72.00%</b>	<b>72.00%</b>

**Model validation.** Validating a model is the process of verifying that it makes correct predictions. The verification is done by comparing the results predicted by the model with real data. The model is considered accurate and reliable if the predictions are close to real data. If not, adjustments are made to improve its accuracy. For example, if you created a model to predict plant growth based on factors such as water, light, and fertilizer, you would check that the model's predictions align with actual plant growth. Validation indicates that the model works well and makes reliable predictions for the future.

We evaluated the performance of our model by estimating errors and successes in predicting the transition from degraded pastures to high vigor pastures. To do this, we compared the map showing where pasture changes are likely to occur with the areas that changed between 2022 and 2023. We used a technique called Receiver Operating Characteristic (ROC) (Mandrekar, 2010), which calculates the chance of our model correctly identifying the areas that have changed in the pastures. The model chosen resulted in an ROC curve of 72%, demonstrating a satisfactory accuracy level (Figure 27).

ROC = 72%

**Figure 27.** Validation of the degraded pasture renovation potential model using the ROC Curve shows the model's accuracy rates through the area under the curve (AUC).



Data source: Calculated by the authors based on data from MapBiomass Brasil (2023).

## Appendix 2.

# Public and private policies that contributed to reducing deforestation

Between 2005 and 2012, the rate of deforestation in the Amazon biome fell by around 83% (from 27,800 square kilometers to 4,600 square kilometers) according to data from Prodes (INPE, 2024). Several studies have attributed part of this drop to public and private policies. Public policies include the implementation of the Brazilian Forest Code and the Action Plan for the Prevention and Control of Deforestation in the Brazilian Amazon (PPCDAm) (Arima et al., 2014; Assunção et al., 2023; Gandour, 2021; Garrett et al., 2018; Soares-Filho et al., 2023). The PPCDAm (Brazil, 2013, 2016) included:

- More accurate and frequent monitoring of deforestation and focusing enforcement on critical municipalities (those with the highest deforestation rates) (Arima et al., 2014; Gandour, 2021).
- The application of penalties against offenders, such as fines, publication of a list of offenders and the potential penalization of those who bought from these areas, confiscation of property (such as cattle) and destruction of equipment such as tractors (Gandour 2021; IPEA et al., 2011).
- The creation of protected areas and the recognition of indigenous lands, especially those in illegally occupied areas. Protected areas in the Amazon reduced deforestation by 21% between 2008 and 2020 (Soares-Filho et al., 2023). Deforestation was 9% to 39% lower in conservation units supported by the Amazon Protected Areas Program (ARPA) (Soares-Filho et al., 2023; Filho et al., 2023), indicating the importance of funding and means for effectively implementing conservation units. Created in 2002, the Arpa Program was established to strengthen the protection and use of 60 million hectares of conservation units in the Amazon.

- The conditioning of rural credit on compliance with environmental rules, such as the registration of farms in the Rural Environmental Registry. As of 2008, the National Monetary Council ordered all banks to grant rural credit only to landowners who comply with environmental rules. The reduction in rural credit, especially for medium and large landowners, was associated with a 60% drop in deforestation from 2009 to 2011 compared to what it would have been without credit restrictions (Assunção, Gandour, et al. 2020).
- The Bolsa Verde program paid low-income families to carry out sustainable activities and maintain forest cover in their communities. The researchers found that the program reduces deforestation by 22% in the treated areas, compared to similar areas that do not participate in the program. The program's reduced carbon emissions benefits were about four times greater than the program's costs. Varied effects in different properties suggest that the program protects against deforestation pressure from groups that don't participate. Data on fines and satellite alarms indicate that beneficiaries' inspections and reports help reduce illegal deforestation. The Bolsa Verde Program, created in 2011, paid R\$300 a quarter to around 100,000 families living in extreme poverty, mainly in the Amazon, to support environmental conservation. A new government deactivated the program in 2016, alleging a lack of funding (Brasil [n.d.]-b).

In 2008, the Federal Public Prosecutor's Office and Ibama used the embargo list of illegally deforested areas to inspect meatpacking plants that bought cattle from these areas. To stop the lawsuits, several meatpackers that bought from irregular areas signed commitments (terms of conduct adjustment - TAC) not to purchase cattle from ranches with deforestation after 2008. The cattle TAC partially helped to reduce deforestation. Still, it did not achieve its full potential effect due to several flaws, such as the lack of disclosure of data from the ranches that sell calves and steers to the fattening ranches that sell cattle to the meatpackers (Alix-Garcia and Gibbs, 2017; Barreto et al., 2023; Gibbs et al., 2015; Levy et al., 2023; Moffette et al., 2021; Pereira et al., 2020; Skidmore et al., 2021).

Starting in 2006, environmental campaigns led companies to boycott soy from new deforestation in the Amazon, known as the soy moratorium. This measure reduced deforestation for soy plantations, which grew on degraded pastures (Gibbs et al., 2015). However, part of the cattle ranching industry moved from the regions occupied by soy to new forest frontiers (Arima et al., 2011).

## Appendix 3.

# Trends in rural credit for productivity gains in cattle farming: by purpose and product type in the Brazilian Amazon states

In the five states with the largest cattle herds in the Brazilian Amazon (Mato Grosso, Pará, Rondônia, Tocantins and Maranhão), which concentrate 92% of the region's herd, there was a 174% increase in rural credit contracting, from R\$9.7 billion (average 2013-2020) to R\$26.6 billion (2020-2023). The proportion of credit earmarked for livestock productivity increased from 14% in 2013 to 25% in 2023, with a significant increase in 2017 (12% to 17%).

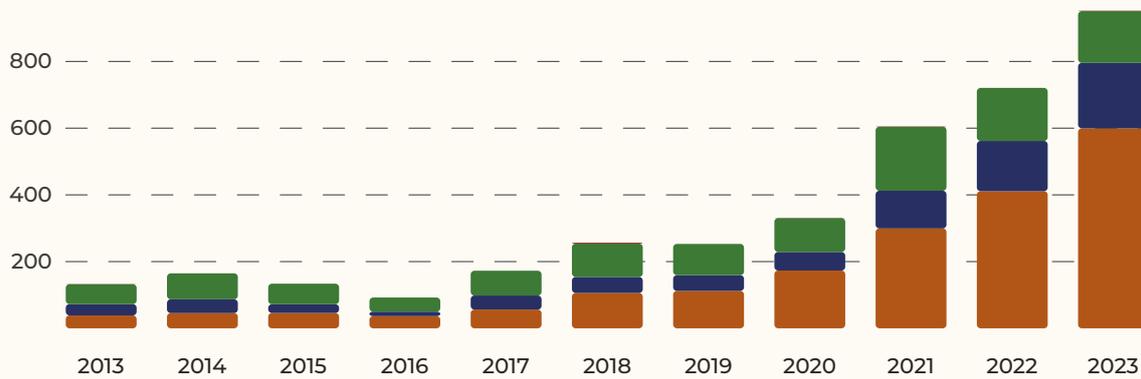
In states with smaller cattle herds — Amazonas, Amapá, and Roraima — a larger share of credit (11%–40%) goes to productivity. However, this share fluctuates more, especially in Amazonas and Amapá.

Figures 28 to 36 show the results by state in the region with data from the Central Bank of Brazil (n.d.).

**Figure 28.** Trends in rural credit for productivity-boosting cattle farming in Acre state (2013–2023), by purpose and product type (R\$ Millions)

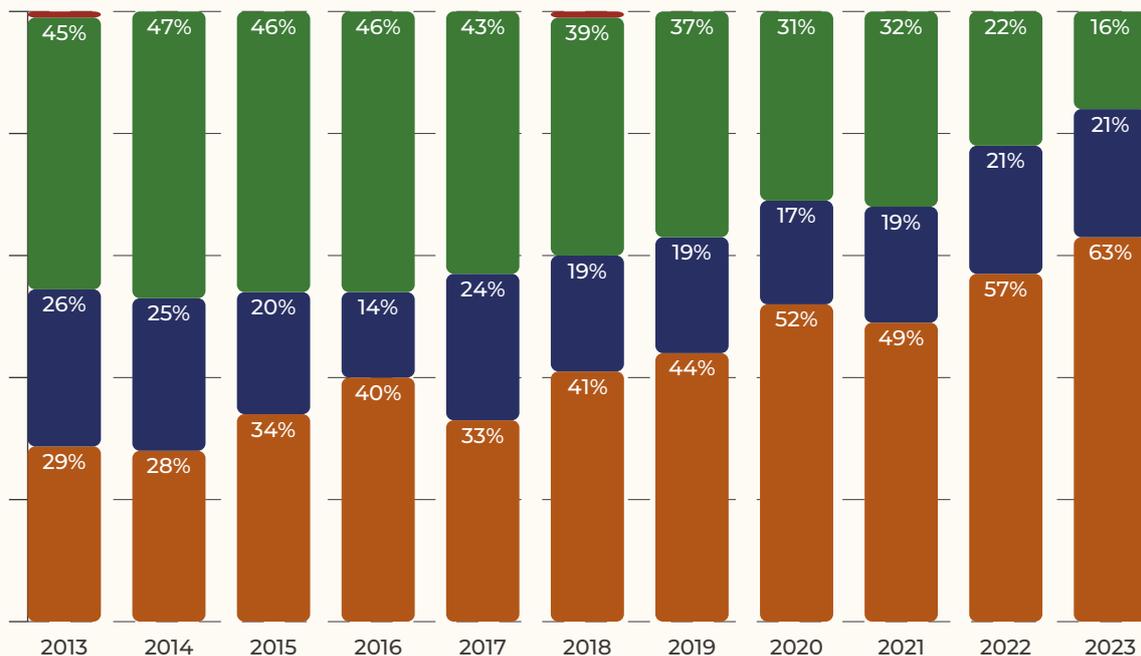
**A. In nominal Reals**

■ COSTING - CATTLE 
 ■ INVESTMENT - INCREASING PRODUCTIVITY  
■ INVESTMENT - CATTLE 
 ■ OTHER



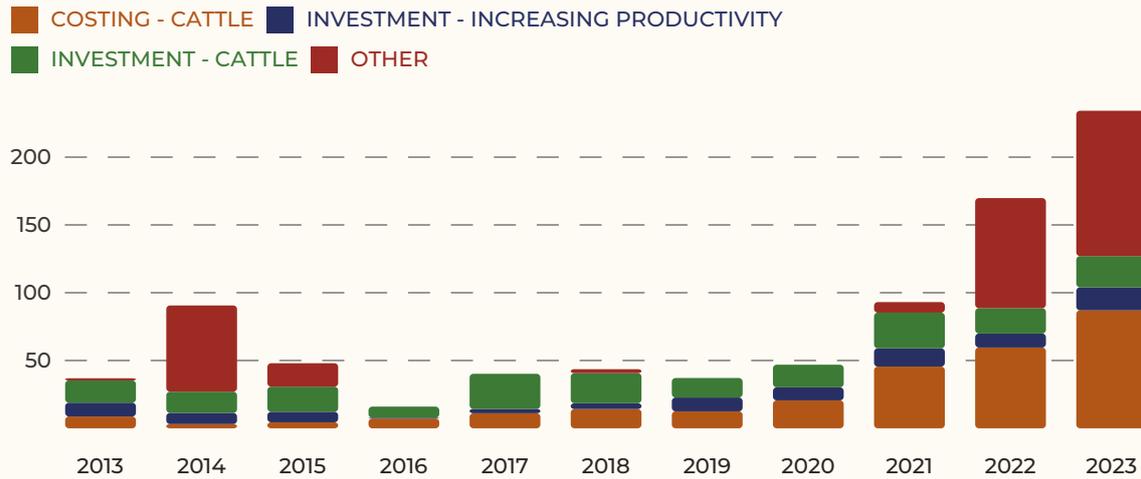
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
<span style="color: #8B4513;">●</span> COSTING - CATTLE	R\$ 38.7	R\$ 45.6	R\$ 45.9	R\$ 36.5	R\$ 56.2	R\$ 105.9	R\$ 112.1	R\$ 173.2	R\$ 299.4	R\$ 411.0	R\$ 599.4
<span style="color: #191970;">●</span> INVESTMENT - INCREASE PRODUCTIVITY	R\$ 34.0	R\$ 41.4	R\$ 26.3	R\$ 13.4	R\$ 42.1	R\$ 48.1	R\$ 47.2	R\$ 55.7	R\$ 113.0	R\$ 150.7	R\$ 196.3
<span style="color: #228B22;">●</span> INVESTMENT - CATTLE	R\$ 59.5	R\$ 77.8	R\$ 61.6	R\$ 42.4	R\$ 74.3	R\$ 100.1	R\$ 93.6	R\$ 101.5	R\$ 192.0	R\$ 158.9	R\$ 154.9
<span style="color: #8B0000;">●</span> OTHER	R\$ 0.7	R\$ 0.0	R\$ 0.0		R\$ 0.0	R\$ 2.7	R\$ 0.2	R\$ 0.7	R\$ 1.0	R\$ 0.1	R\$ 1.3

**B. In percent**



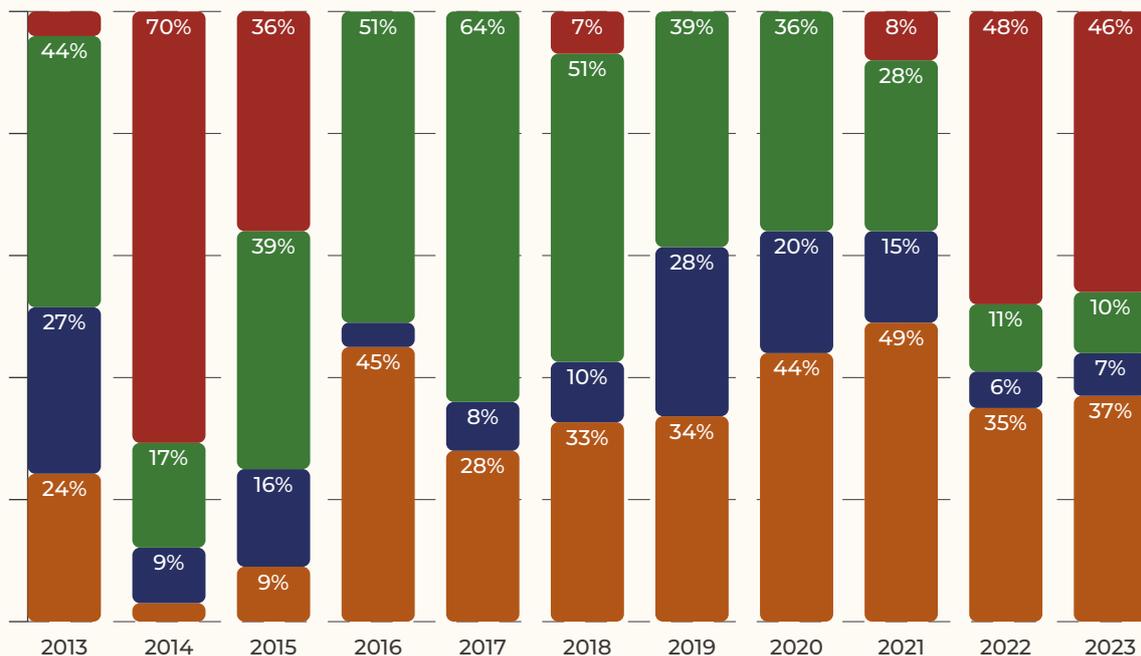
**Figure 29.** Trends in rural credit for productivity-boosting cattle farming in Amazonas state (2013–2023), by purpose and product type (R\$ Millions)

**A. In nominal Reals**



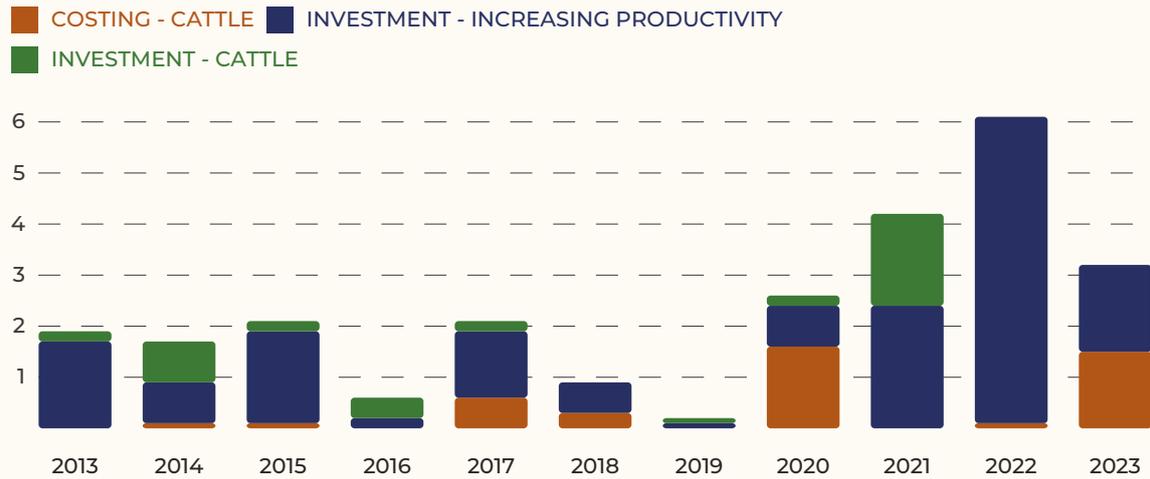
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
● COSTING - CATTLE	R\$ 8.7	R\$ 3.1	R\$ 4.4	R\$ 7.2	R\$ 11.1	R\$ 14.2	R\$ 12.5	R\$ 20.6	R\$ 45.5	R\$ 59.6	R\$ 87.0
● INVESTMENT - INCREASE PRODUCTIVITY	R\$ 10.2	R\$ 8.3	R\$ 7.8	R\$ 0.6	R\$ 3.2	R\$ 4.3	R\$ 10.2	R\$ 9.6	R\$ 13.5	R\$ 10.3	R\$ 17.0
● INVESTMENT - CATTLE	R\$ 16.4	R\$ 15.6	R\$ 18.5	R\$ 8.2	R\$ 25.9	R\$ 22.2	R\$ 14.4	R\$ 16.7	R\$ 26.3	R\$ 18.7	R\$ 23.0
● OTHER	R\$ 1.6	R\$ 63.6	R\$ 17.3			R\$ 2.9			R\$ 7.8	R\$ 81.2	R\$ 107.2

**B. In percent**



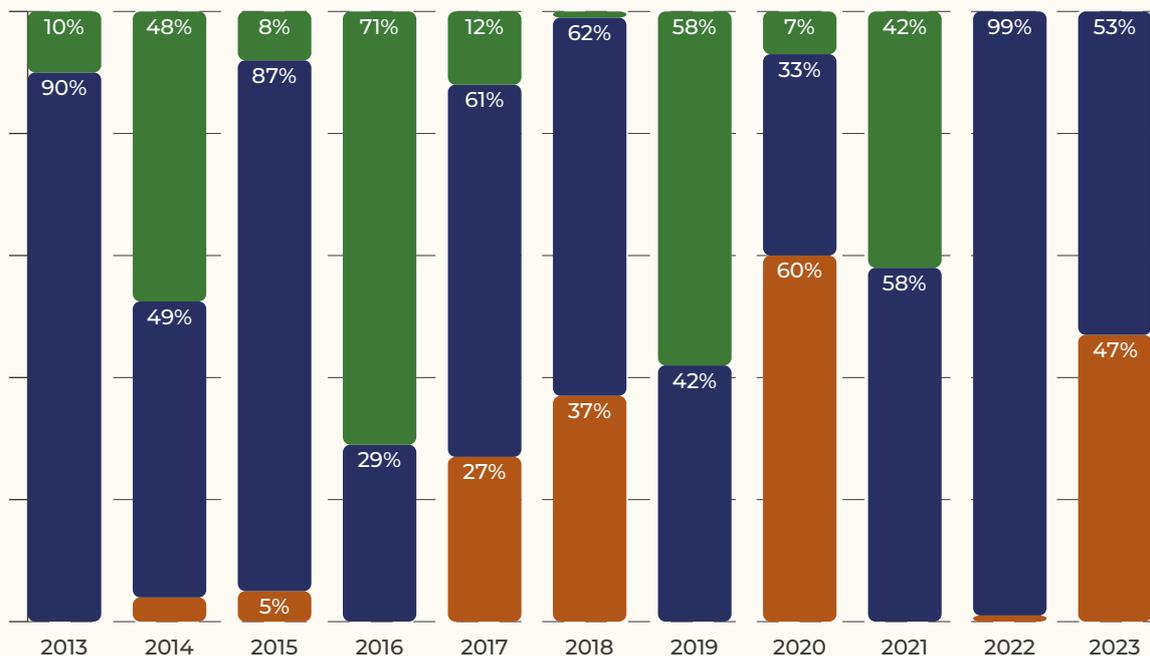
**Figure 30.** Trends in rural credit for productivity-boosting cattle farming in Amapá state (2013–2023), by purpose and product type (R\$ Millions)

**A. In nominal Reals**



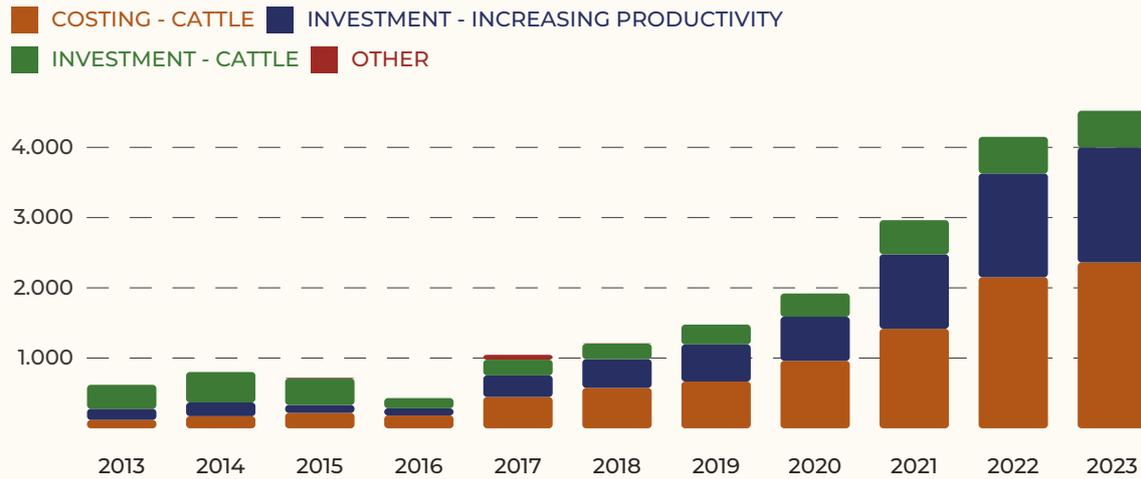
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
<span style="color: orange;">●</span> COSTING - CATTLE		R\$ 0.1	R\$ 0.1		R\$ 0.6	R\$ 0.3		R\$ 1.6		R\$ 0.1	R\$ 1.5
<span style="color: blue;">●</span> INVESTMENT - INCREASE PRODUCTIVITY	R\$ 1.7	R\$ 0.8	R\$ 1.8	R\$ 0.2	R\$ 1.3	R\$ 0.6	R\$ 0.1	R\$ 0.8	R\$ 2.4	R\$ 6.0	R\$ 1.7
<span style="color: green;">●</span> INVESTMENT - CATTLE	R\$ 0.2	R\$ 0.8	R\$ 0.2	R\$ 0.4	R\$ 0.2	R\$ 0.0	R\$ 0.1	R\$ 0.2	R\$ 1.8		
<span style="color: red;">●</span> OTHER	R\$ 2.846	R\$ 3.279	R\$ 2.863	R\$ 3.120	R\$ 4.974	R\$ 5.203	R\$ 5.480	R\$ 3.909	R\$ 4.626	R\$ 3.481	R\$ 3.706

**B. In percent**



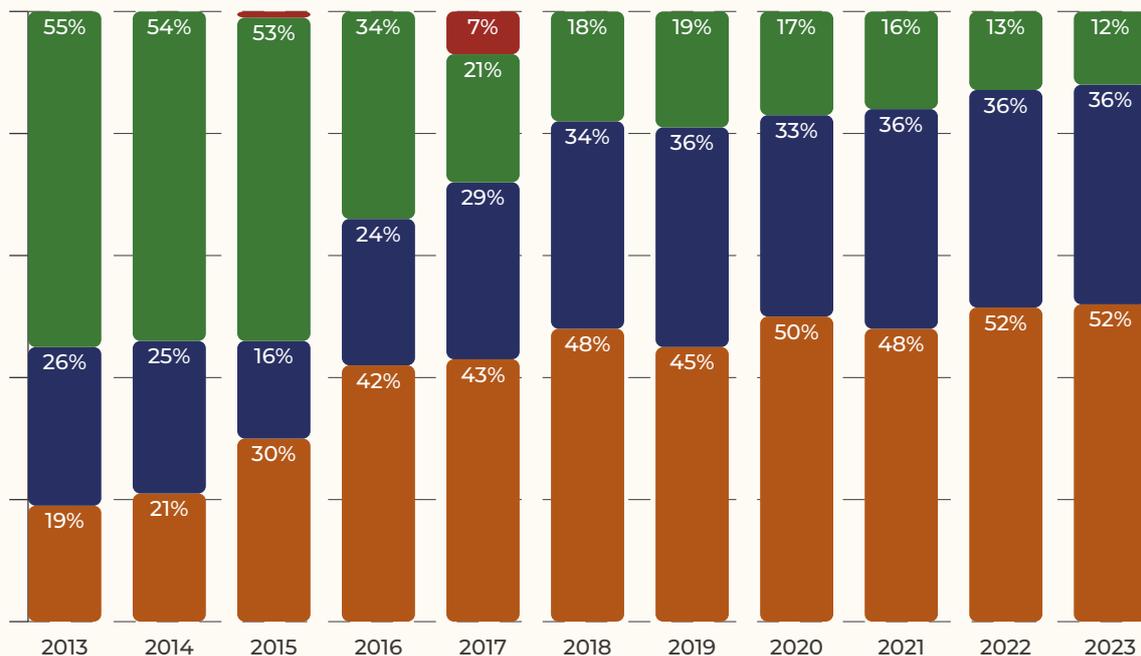
**Figure 31.** Trends in rural credit for productivity-boosting cattle farming in Maranhão state (2013–2023), by purpose and product type (R\$ Millions)

**A. In nominal Reals**



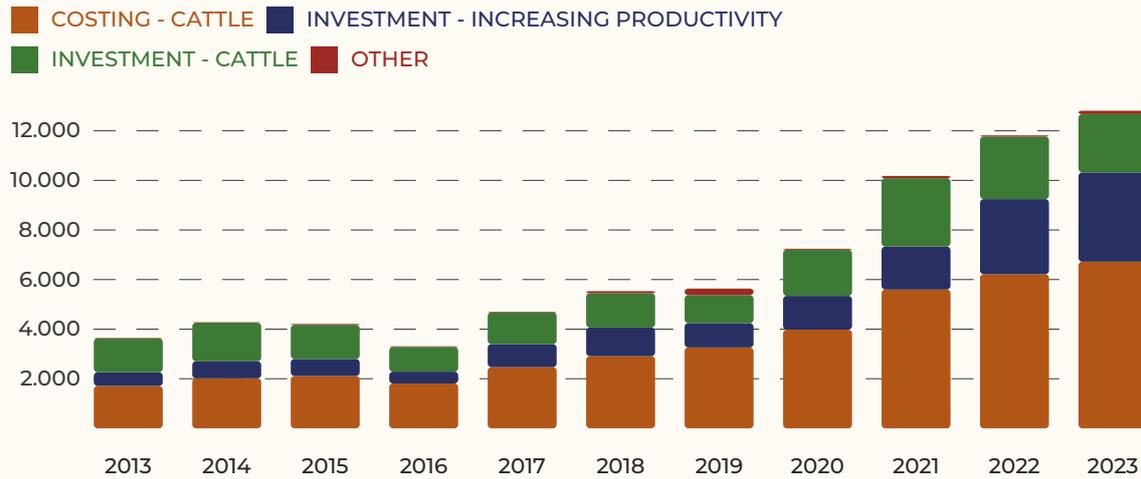
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
COSTING - CATTLE	R\$ 119.5	R\$ 172.2	R\$ 218.7	R\$ 183.0	R\$ 445.7	R\$ 575.9	R\$ 666.3	R\$ 961.6	R\$ 1,417.4	R\$ 2,151.4	R\$ 2,361.8
INVESTMENT - INCREASE PRODUCTIVITY	R\$ 158.6	R\$ 196.4	R\$ 113.8	R\$ 101.7	R\$ 307.3	R\$ 408.8	R\$ 528.1	R\$ 627.4	R\$ 1,059.8	R\$ 1,477.3	R\$ 1,636.9
INVESTMENT - CATTLE	R\$ 341.2	R\$ 432.8	R\$ 379.4	R\$ 145.3	R\$ 224.5	R\$ 221.1	R\$ 282.3	R\$ 330.6	R\$ 486.3	R\$ 520.7	R\$ 522.4
OTHER	R\$ 0.1	R\$ 0.1	R\$ 9.0	R\$ 0.9	R\$ 69.0	R\$ 4.3		R\$ 0.0		R\$ 0.0	

**B. In percent**



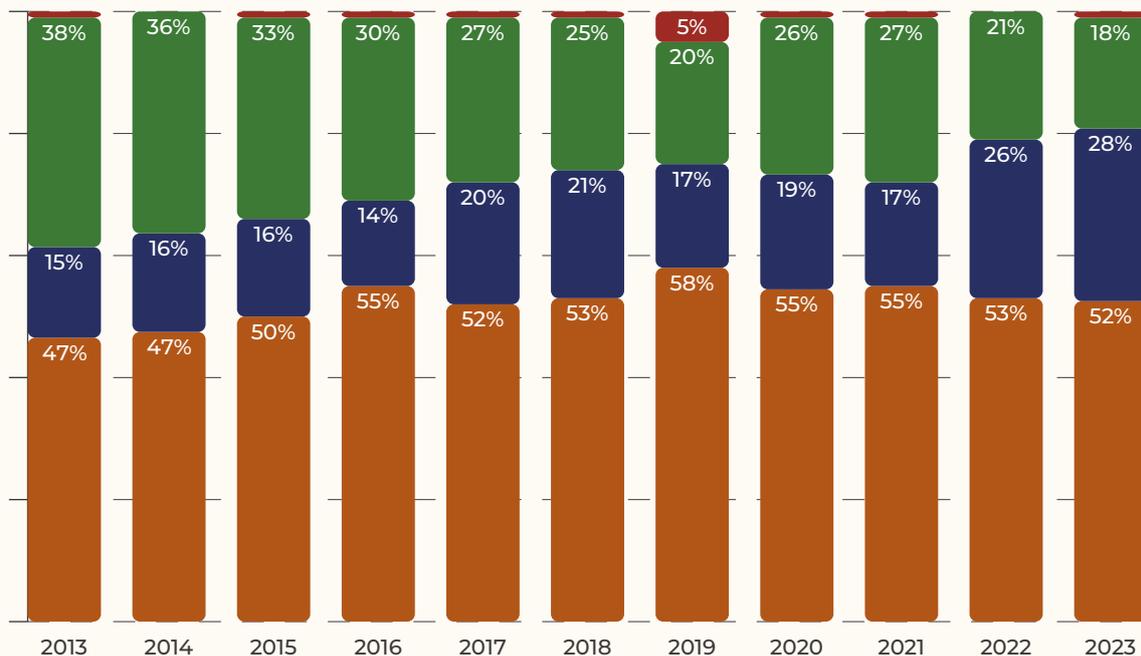
**Figure 32.** Trends in rural credit for productivity-boosting cattle farming in Mato Grosso state (2013–2023), by purpose and product type (R\$ Millions)

**A. In nominal Reals**



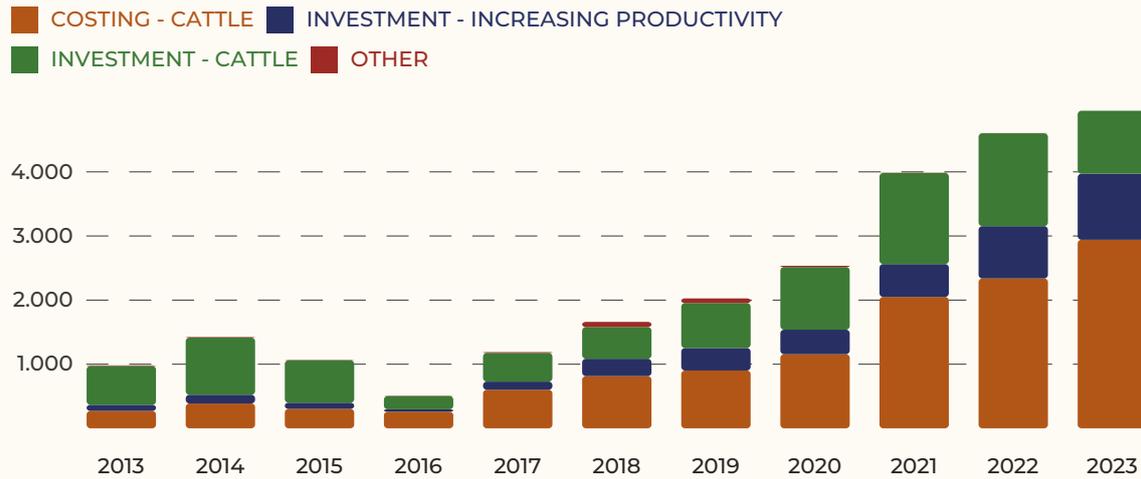
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
<span style="color: orange;">●</span> COSTING - CATTLE	R\$ 1.709,3	R\$ 2.015,4	R\$ 2.110,0	R\$ 1.807,7	R\$ 2.466,3	R\$ 2.910,1	R\$ 3.261,0	R\$ 3.979,8	R\$ 5.598,6	R\$ 6.216,6	R\$ 6.721,3
<span style="color: blue;">●</span> INVESTMENT - INCREASE PRODUCTIVITY	R\$ 550,6	R\$ 687,3	R\$ 686,8	R\$ 477,7	R\$ 931,6	R\$ 1.155,2	R\$ 980,9	R\$ 1.362,6	R\$ 1.733,9	R\$ 3.028,6	R\$ 3.599,9
<span style="color: green;">●</span> INVESTMENT - CATTLE	R\$ 1.369,3	R\$ 1.556,7	R\$ 1.376,3	R\$ 995,8	R\$ 1.280,0	R\$ 1.389,7	R\$ 1.133,0	R\$ 1.864,0	R\$ 2.755,5	R\$ 2.520,6	R\$ 2.353,1
<span style="color: red;">●</span> OTHER	R\$ 18,5	R\$ 17,1	R\$ 34,7	R\$ 26,7	R\$ 25,2	R\$ 77,8	R\$ 261,9	R\$ 37,7	R\$ 91,4	R\$ 49,5	R\$ 134,7

**B. In percent**



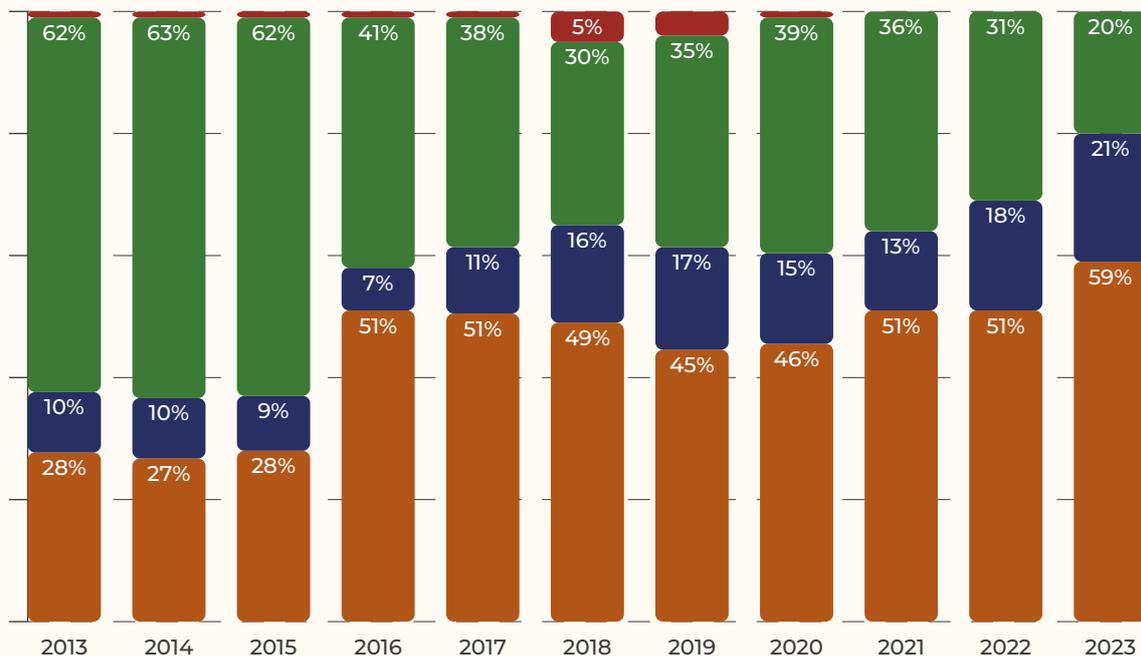
**Figure 33.** Trends in rural credit for productivity-boosting cattle farming in Pará state (2013–2023), by purpose and product type (R\$ Millions)

**A. In nominal Reals**



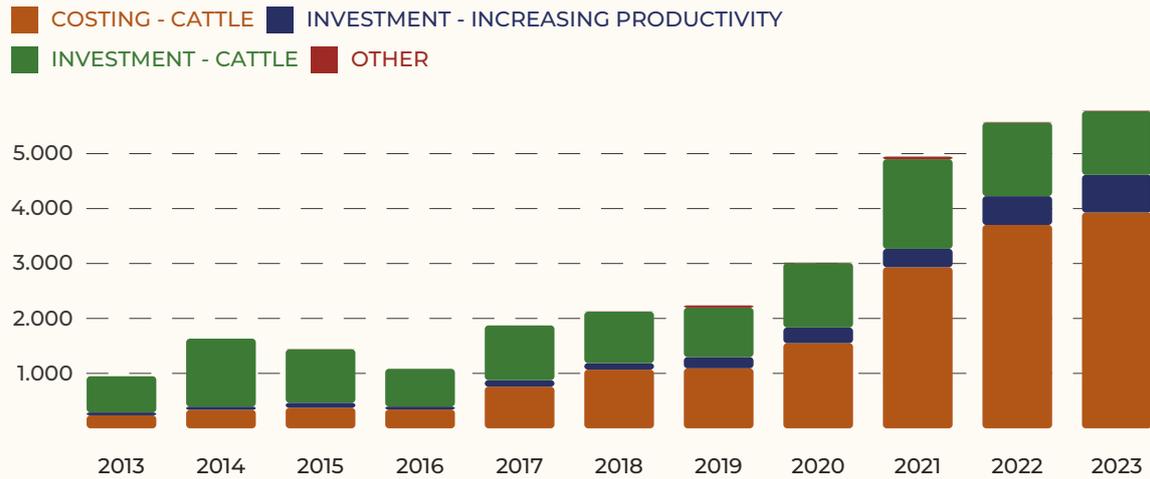
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
COSTING - CATTLE	R\$ 271.3	R\$ 387.4	R\$ 302.8	R\$ 259.0	R\$ 601.1	R\$ 814.2	R\$ 901.7	R\$ 1.155.6	R\$ 2.048.6	R\$ 2.337.5	R\$ 2.940.9
INVESTMENT - INCREASE PRODUCTIVITY	R\$ 95.3	R\$ 136.1	R\$ 96.2	R\$ 37.1	R\$ 127.5	R\$ 271.0	R\$ 350.6	R\$ 383.0	R\$ 513.2	R\$ 815.9	R\$ 1.030.4
INVESTMENT - CATTLE	R\$ 605.6	R\$ 892.4	R\$ 662.5	R\$ 208.1	R\$ 446.9	R\$ 494.6	R\$ 701.4	R\$ 977.5	R\$ 1.421.5	R\$ 1.448.8	R\$ 981.9
OTHER	R\$ 9.4	R\$ 8.5	R\$ 5.5	R\$ 4.4	R\$ 13.3	R\$ 80.3	R\$ 72.4	R\$ 19.1	R\$ 3.7	R\$ 3.0	

**B. In percent**



**Figure 34.** Trends in rural credit for productivity-boosting cattle farming in Rondônia state (2013–2023), by purpose and product type (R\$ Millions)

**A. In nominal Reals**



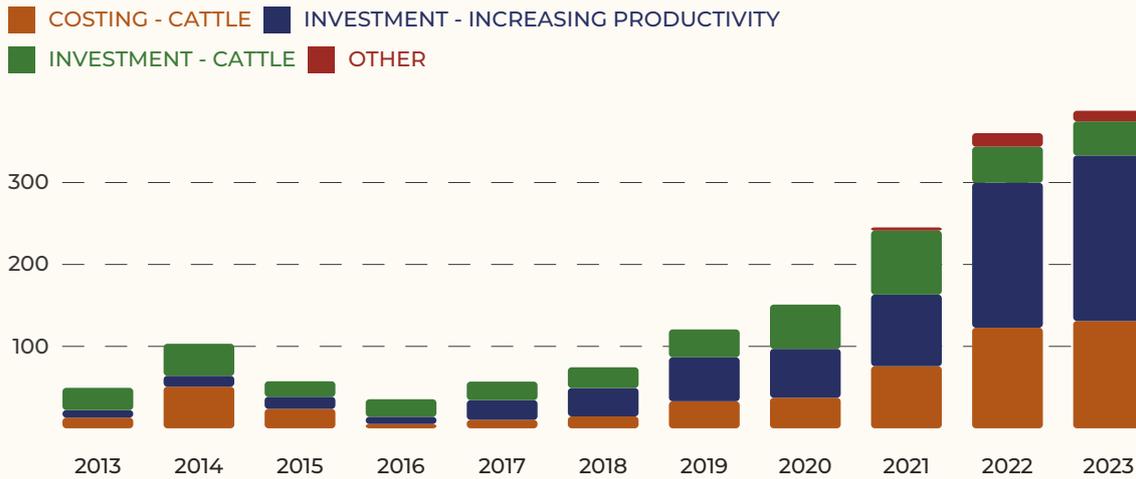
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
COSTING - CATTLE	R\$ 235.8	R\$ 336.0	R\$ 373.5	R\$ 341.7	R\$ 758.3	R\$ 1,068.1	R\$ 1,092.0	R\$ 1,549.5	R\$ 2,932.4	R\$ 3,702.0	R\$ 3,928.5
INVESTMENT - INCREASE PRODUCTIVITY	R\$ 51.9	R\$ 58.6	R\$ 91.7	R\$ 54.2	R\$ 118.4	R\$ 119.5	R\$ 205.3	R\$ 285.6	R\$ 335.9	R\$ 524.7	R\$ 685.7
INVESTMENT - CATTLE	R\$ 659.8	R\$ 1,237.5	R\$ 973.5	R\$ 687.4	R\$ 996.0	R\$ 936.3	R\$ 900.0	R\$ 1,174.9	R\$ 1,630.3	R\$ 1,339.9	R\$ 1,158.4
OTHER	R\$ 0.4	R\$ 0.0	R\$ 3.7	R\$ 0.2	R\$ 0.1	R\$ 4.0	R\$ 39.8	R\$ 7.1	R\$ 47.8	R\$ 9.0	R\$ 8.1

**B. In percent**



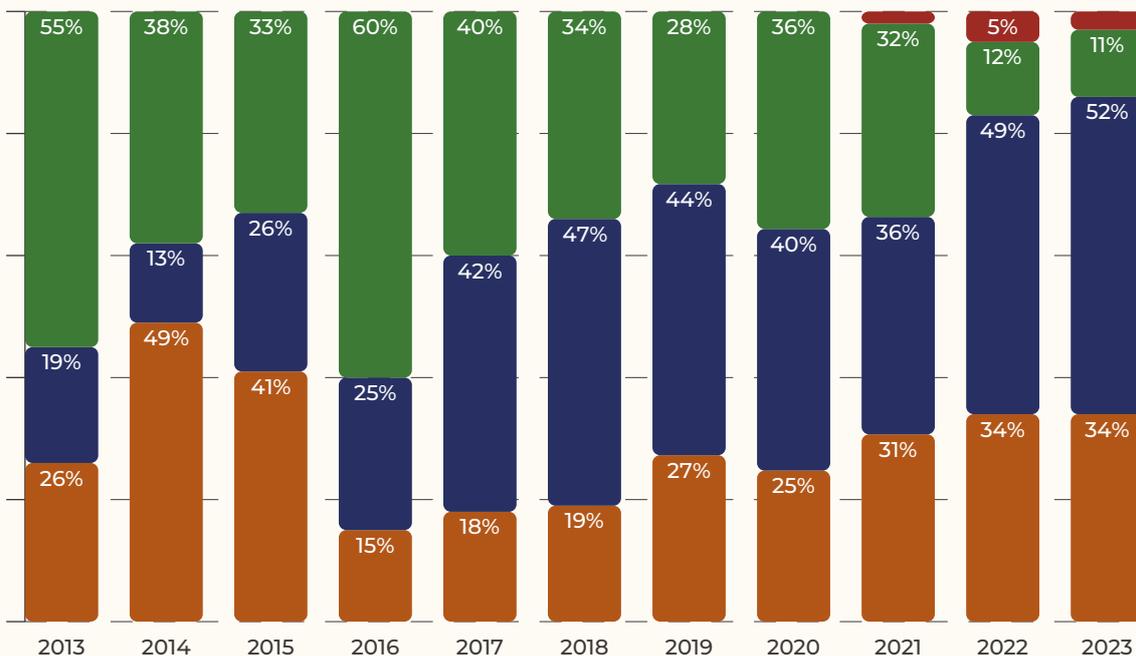
**Figure 35.** Trends in rural credit for productivity-boosting cattle farming in Roraima state (2013–2023), by purpose and product type (R\$ Millions)

**A. In nominal Reals**



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
COSTING - CATTLE	R\$ 13.0	R\$ 50.8	R\$ 23.7	R\$ 5.2	R\$ 10.3	R\$ 14.5	R\$ 33.0	R\$ 37.3	R\$ 75.8	R\$ 122.8	R\$ 131.0
INVESTMENT - INCREASE PRODUCTIVITY	R\$ 9.3	R\$ 13.3	R\$ 14.8	R\$ 8.9	R\$ 24.1	R\$ 34.7	R\$ 53.6	R\$ 59.7	R\$ 87.4	R\$ 176.9	R\$ 202.0
INVESTMENT - CATTLE	R\$ 27.1	R\$ 39.1	R\$ 18.9	R\$ 21.4	R\$ 22.6	R\$ 25.3	R\$ 34.1	R\$ 54.0	R\$ 78.1	R\$ 44.0	R\$ 41.6
OTHER									R\$ 3.9	R\$ 16.6	R\$ 13.0

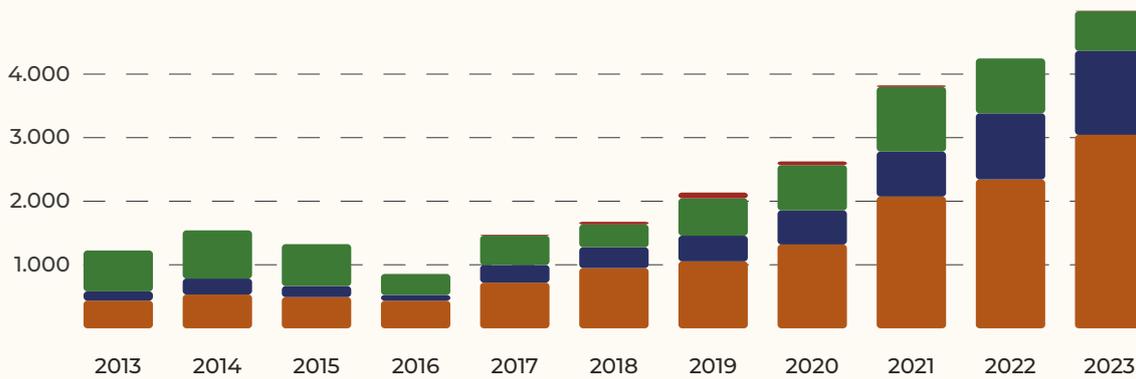
**B. In percent**



**Figure 36.** Trends in rural credit for productivity-boosting cattle farming in Tocantins state (2013–2023), by purpose and product type (R\$ Millions)

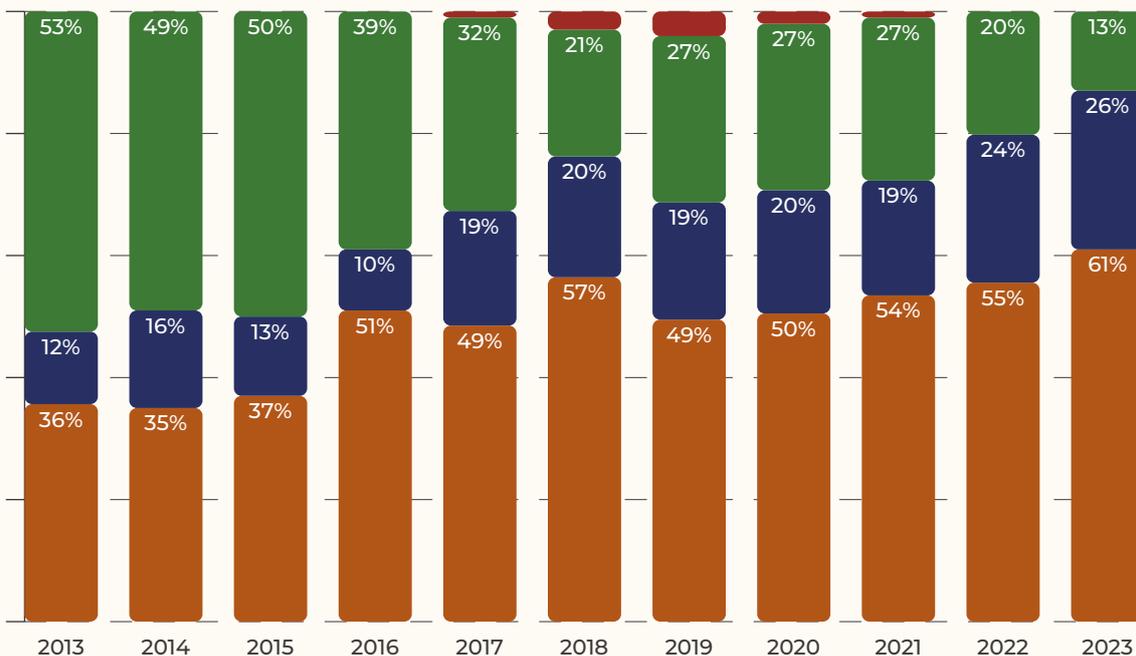
**A. In nominal Reals**

■ COSTING - CATTLE 
 ■ INVESTMENT - INCREASING PRODUCTIVITY  
■ INVESTMENT - CATTLE 
 ■ OTHER



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
<span style="color: #8B4513;">●</span> COSTING - CATTLE	R\$ 435.4	R\$ 531.9	R\$ 490.6	R\$ 434.4	R\$ 718.4	R\$ 947.7	R\$ 1.053.3	R\$ 1.318.4	R\$ 2.072.9	R\$ 2.342.9	R\$ 3.044.2
<span style="color: #000080;">●</span> INVESTMENT - INCREASE PRODUCTIVITY	R\$ 145.5	R\$ 250.8	R\$ 173.5	R\$ 89.5	R\$ 277.8	R\$ 327.5	R\$ 404.6	R\$ 536.3	R\$ 707.8	R\$ 1.039.8	R\$ 1.320.3
<span style="color: #008000;">●</span> INVESTMENT - CATTLE	R\$ 643.4	R\$ 758.4	R\$ 659.5	R\$ 331.0	R\$ 464.7	R\$ 358.5	R\$ 586.9	R\$ 713.0	R\$ 1.018.6	R\$ 863.7	R\$ 626.4
<span style="color: #8B0000;">●</span> OTHER	R\$ 0.0		R\$ 1.3	R\$ 0.8	R\$ 12.7	R\$ 42.5	R\$ 91.6	R\$ 58.3	R\$ 23.8		R\$ 5.6

**B. In percent**



## Appendix 4.

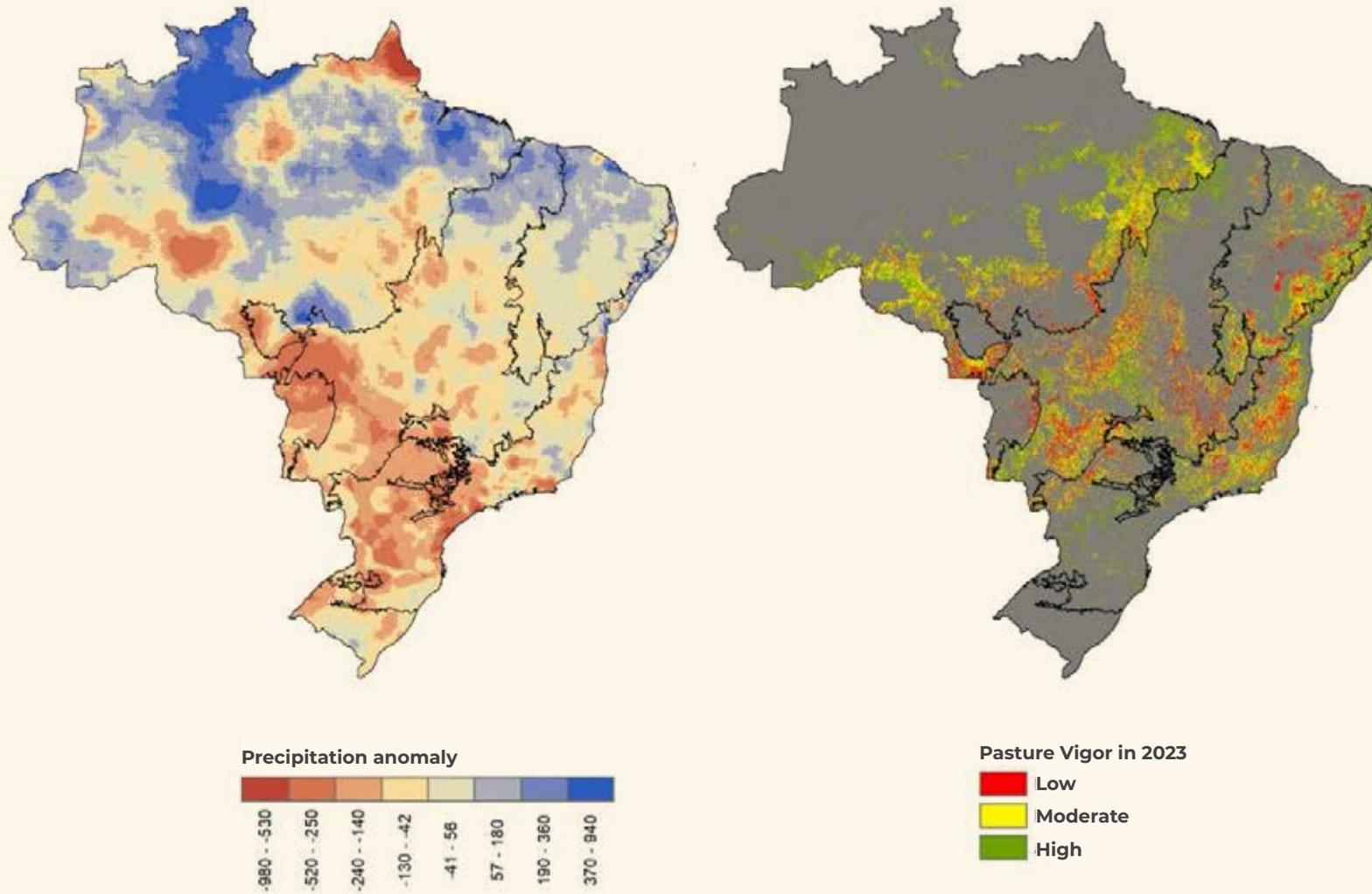
# Precipitation anomalies and pasture vigor in Brazil

Precipitation anomaly is the difference between the amount of rainfall in a region and the historical average for that area. In other words, it's how much more or less rain falls than usual.

- **Positive anomaly:** It represents areas where it rained more than the historical average (blue shades on the map - Figure 37).
- **Negative anomaly:** It rains less than the historical average (light green to brown on the map).

In most Brazil, rainfall has significantly reduced compared with the average for 2019 and 2023 and the previous 36 years (1982 to 2018). The impact of this trend is crucial, as pasture reform is less likely in areas with a soil water deficit.

**Figure 37.** Brazil's precipitation anomaly (2019–2023 compared to 1982–2018) and pasture vigor in 2023



Data source: Precipitation anomaly calculations with data from the University of California (University of California, n.d.). Vigor of pastures (Mapbiomas Brasil, 2023).

# Appendix 5.

## Strengthening policy frameworks for effective deforestation control

### Large-scale public policies

**Allocate public lands following the Brazilian Constitution and for purposes compatible with more sustainable uses.** In 2021, there were approximately 143 million hectares of unallocated public lands in the Brazilian Amazon (Brito et al., 2021), with millions of hectares that illegal occupants could regularize (Brito et al., 2019). Some state laws encourage new occupations by not setting a deadline for occupation (Brito and Gomes, 2022).

To prevent speculative and illegal deforestation of public lands, the executive branch should:

- Allocate public lands for uses compatible with forest conservation and priority constitutional rights, such as those of indigenous peoples;
- Extinguish the donation and sale of public land below market price.
- Take back possession of illegally occupied land and prohibit the titling of properties with recent deforestation.
- Granting already deforested public lands for forest restoration to generate income and reduce climate risk. Recent initiatives by the federal government (SFB, 2024) and the government of Pará (Governo do Pará, 2025; Nascimento, 2024) are relevant and can offer lessons for the expansion of this approach.

In addition to actions by the executive branch, judicial intervention is crucial, given that some executive and legislative policymakers have delayed or violated the application of the Constitution. For example, the Federal Supreme Court (STF) could:

- Ensure the application of the law, accepting the case initiated by the Public Prosecutor's Office in 2017 (ADI 5771 - Direct Action of Unconstitutionality) against a new plan to regularize illegal lands (Barreto and Brito, 2023);
- Oblige state authorities to set deadlines for the occupation of land eligible for regularization (Barreto and Brito, 2023).

**Strengthen and expand environmental control of private credit for the rural sector.** Despite the progress made in restricting rural credit for unregulated producers, there is a lack of regulation or regulatory clarity regarding the mandatory environmental control of other forms of subsidized credit for the rural sector (Greenpeace, 2024), which totaled R\$1.1 trillion in 2024 (Figure 19). It is necessary to expand environmental controls for these instruments and increase transparency about their application to facilitate the monitoring of their productivity and environmental impacts.

**Making data on the origin of cattle accessible.** Making data on the origin of livestock (Animal Transit Guide) and farms (Rural Environmental Registry) accessible is crucial to mitigating the risk of deforestation and fostering sustainable investments in the agricultural sector. Data transparency would make it easier for meatpackers and other stakeholders to trace the origin of cattle, encouraging compliance with sustainable practices (Barreto et al., 2023). This measure would represent a significant step forward until the implementation of individual cattle tracking systems, promised by the federal government by 2032. Greater transparency would not only meet the demands of companies in the sector, which face challenges due to the lack of public data (Coalizão Brasil Clima Florestas e Agricultura, 2024; Mesa Brasileira da Pecuária Sustentável & Coalizão Brasil Clima Florestas e Agropecuária, 2024; Prizibiszki, 2023), but it would also promote a more responsible and attractive business environment for investors.

The recent decision by the Federal Supreme Court (STF) represented a significant advance in transparency and control over the cattle origin in Brazil (Arguição de descumprimento de preceito fundamental 760, 2025). The STF ruled that Animal Transit Guides (GTA) data must be made available to environmental inspection bodies. The federal government must present a plan to make this data accessible within 60 days.

While this measure strengthens tracking and enforcement, expanding access to GTA data to include the private sector is critical. The individual cattle tracking program, announced by the government in December 2024, is considered inadequate because it is not linked to environmental legality and foresees the completion of tracking only in 2032 (Prizibiszki, 2024). Including the private sector in access to data is essential to ensure effective monitoring and combat illegal deforestation practices, promoting sustainability and environmental conservation in the region

## Large-scale private and multilateral policies

**European regulation against the import of products associated with deforestation.** The Deforestation Regulation, which came into force on June 29, 2023, aims to minimize the EU's contribution to global deforestation and forest degradation by ensuring that commodities such as beef, soy, palm oil, cocoa, coffee, rubber and timber are deforestation-free. The regulation requires operators and traders to conduct due diligence to trace these commodities to their origin, ensuring they have not been produced on deforested land after December 31, 2020. Implementation deadlines are set for December 30, 2025, for large and medium companies, and June 30, 2026, for micro and small companies. The EU policy-makers expect that the regulation will significantly reduce greenhouse gas emissions and biodiversity loss associated with consumption in the EU. European member state authorities and market operators will adopt simplified due diligence duties for low-risk countries and strengthened control for high-risk countries.

According to Chain Reaction Research, the EU Deforestation Regulation will significantly impact Brazilian meatpackers JBS, Marfrig, and Minerva, with possible fines and reductions in operating profits due to their supply chains being linked to deforestation. Estimates for 2022 point to a drop in EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization) of 1.8% for JBS, 2.7% for Marfrig and 5.3% for Minerva, and fines could reach up to 4% of sales to the EU (Chain Reaction Research, 2022).

However, Chain Reaction Research has estimated that supply chain players investing in proper verification can mitigate deforestation's financial risks. Small price increases would cover these costs without affecting shareholder profits. Chain Reaction Research's analysis indicates that the sheer scale of the automotive and footwear industries, compared to the value of Brazilian leather, supports this view (Chain Reaction Research, 2022).

**Voluntary commitment by the Brazilian Federation of Banks (Febraban).**

In 2023, Febraban announced that “banks participating in Self-Regulation will ask their meatpacking clients, in the Brazilian Amazon and Maranhão, to implement a traceability and monitoring system that allows them to demonstrate, by December 2025, that they have not acquired cattle associated illegal deforestation from direct and indirect suppliers” (FEBRABAN, 2023). According to Febraban (Febraban 2023), the date “is in line with commitments made by some of the large meatpackers to monitor their suppliers and with public commitments by the banks.”

**Chinese Sustainable Meat Declaration.** In 2017, the China Meat Association (CMA) and the World Wildlife Fund (WWF) published a declaration to curb deforestation linked to the demand for beef. In 2021, the CMA specified the rules of the declaration, which ask beef importers to avoid sourcing from areas at high risk of deforestation, such as the Amazon and Cerrado, and emphasizes the need for transparency and traceability in supply chains, including direct and indirect suppliers. Although the CMA has not set a deadline for the application of the rules, it is expected that full traceability of cattle will be required within a few years (Vilarino, 2024).

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