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A Longitudinal Study of Brazilian Food Production Dynamics

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Abstract: Brazil is among the world's leading food producers and exporters. The opportunity arose to examine and analyse dynamics of spatiotemporal of major agricultural crop and animal commodities within Brazil. An investigation was carried out on shifts in distribution density across Brazil's different agricultural production regions between 1990 and 2015. This focused mainly on the midwest region, Brazil's main agricultural frontier in the 21st century. This process enabled an analysis of the potential areas for maintenance and expansion of food supply chains and confirmed an increase in agricultural production in country's central region. Geographical transformations were noted in the midwest region's interior and its frontier with the Amazon biome. Over the study period, geographical midpoints of some key agricultural commodities (e.g., soybean, maize) and beef cattle production shifted towards the midwest's interior, whereas milk, poultry, and pork production shifted southward. A vital issue in discussing contemporary rural areas, agricultural food production is tied to the quality of life, food supply, distribution, and consumption, as well as social, economic, and spatial inequalities. The development of science and technology applied to agriculture has implications regarding production growth and innovation targeted toward guaranteeing sustainable long-term production.

Keywords: agribusiness; agriculture; food supply chains; Brazilian biomes

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1. Introduction

The evolution of agricultural production leads to changes in land use. The quantity, quality and speed of this change, however, is variable. These factors can have positive or negative consequences, depending on the socioeconomic situation of the region and its orientation towards sustainable development.

Playing an essential role in the current sustainability debate, food connects consumers to the agricultural, logistical, commercial, and financial sectors on a daily basis. A scientific approach has been applied to the study of the impacts of technology [1–3], and it plays an important role in the current sustainability debate. Scientific efforts are made toward technology studies [1–3], territorial heritage and the development of tools [4], and agricultural productivity [5] in these sectors. Economic geography helps establish the characteristics of

the globalized food trade [6]. The economic scenario influences global climate discussions, through local resistance and political and legal agendas [7].

Increases in population income, agricultural productivity, and the diversification and development of the food trade engender changes in the sites of food procuration and consumption [8–10]. These factors contribute to an increase in the presence of foods with specific local and regional characteristics. Food production and consumption are parts of the larger global economic system. This interdependence emphasizes the complexity and importance of defining the spatial dynamics of food systems [6,11–13].

Over the coming decades, Brazil will be among the world's leading food producers and exporters. Indeed, portions of Brazilian territory have already been designed an agricultural vocation. In this context, the opportunity arose to identify and analyse spatiotemporal changes in the production of the major Brazilian agricultural. This growth encourages the diffusion of innovation and technology [14,15].

The Brazilian agricultural sector has achieved technological changes through complex innovation paths along the production chain. The revolutionary dynamics observed in tropical agriculture have been tied to institutional building focused on science and technology [15–19]. Given this backdrop, an analysis of Brazil's major agricultural and animal production dynamics and their geographical and temporal changes was undertaken. Understanding of the geography of food procurement and the evolution of food systems can inform and guide a relevant debate between public and private organizations.

2. Materials and Method

Brazil is the largest country in South America, extending more than 4000 km both from north to south and east to west. Its extent confers upon the country a wide range of geomorphological and climatic diversity (mainly in the tropical zone), and with this, great productive potential [14,16]. It has five macroregions: the north, northeast, southeast, south, and midwest regions (N, NE, SE, S, and MW, respectively). Each region has its own cultural, gastronomic, geographical, climatic, and historical peculiarities. These have direct impacts on the nation's economic and sectorial issues.

2.1. Study Area and Datasets

The value of agricultural production in the nation's 26 federative states and 1 federal district has changed over recent decades. A comparison between 1995 and 2017 shows a change in representativeness in the quantiles (Figure 1).

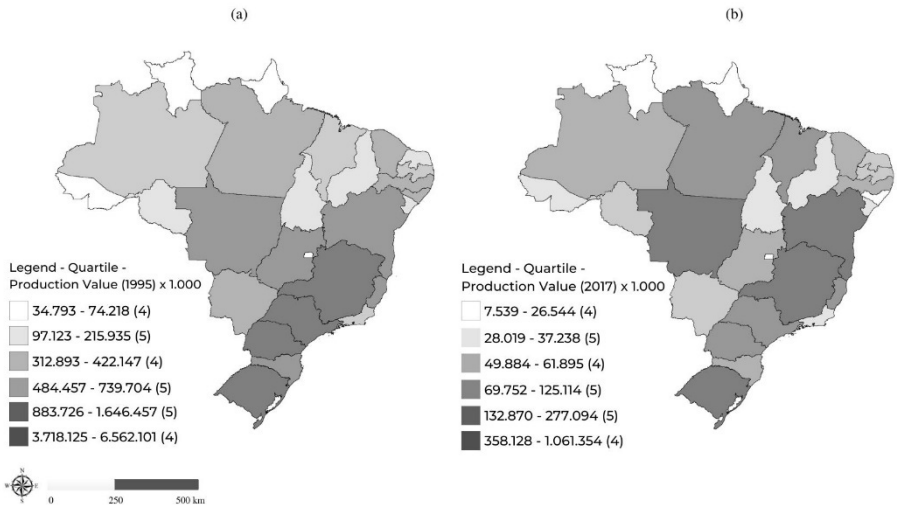

Figure 1. Value of Brazilian agricultural production in 1995 (**a**) and 2017 (**b**), in current USD. Source: Elaborated by authors based on [20,21].

To deepen the analysis of Brazilian agricultural dynamics, further analyses were performed for the Brazilian midwest region, an important agricultural frontier that has shown significant changes in the value of agricultural production. The Brazilian midwest region (main study area) includes four federative states: Mato Grosso (MT, 22 microregions), Mato Grosso do Sul (MS, 11 microregions), Goiás (GO, 18 microregions), and Distrito Federal (DF, one microregion).

The study analysed the period 1990–2015. The selected products were soybeans (Mg), maize (Mg), beef cattle (number of heads), milk (thousand litres), pork (number of heads), and poultry (number of heads). Data (quantity produced and expanse of planting) for soybeans (*Glycine max* (L.) Merr.), and maize (*Zea mays* L.) were collected from the Municipal Agricultural Production (PAM) survey [22] for non-perennial temporary crops. The number of animal products produced was drawn from the Municipal Livestock Research survey (PPM) [23]. Both surveys are available annually through the Brazilian Institute of Geography and Statistics (IBGE).

The period analysed here (1990–2015) is justified by data availability, offering complete 5-year intervals (2019 being the last year for which data is available). In 1990, Brazil had 5570 counties. During the period under analysis, 1079 new counties were formed (IBGE, 2020c), restricting analysis on a municipal scale. To address this and reduce the data variability, we chose to work with data discriminated based on Brazil's geographical microregions, available for each product in the IBGE's database.

2.2. Data Search Techniques

Descriptive statistics (i.e., absolute and relative frequencies, percentage variations, quantiles) and spatial statistics (i.e., midpoints) were employed in data analysis. Using Arcgis® software, the spatial distribution of soybean, maize, beef cattle, milk, pork, and poultry within Brazil was digitized early from 1990 to 2015. The spatial midpoint (a measure of central tendency and spatial dispersion) of the six production streams' output was geographically situated to identify trends in the spatial concentrations of Brazil's agriculture and animal production. Some studies served as methodological inspiration for this research [24–27].

In analysing the Brazilian midwest region, based on quantiles (frequency distribution into equal groups), soybean, maize, beef cattle, milk, pork, and poultry productions were georeferenced in individual 5-year interval cartograms spanning the period of 1990 to 2015. Thus, 36 midwest region maps were generated for the number of agricultural outputs produced. The EstatGeo from IBGE assisted in this step.

3. Results

3.1. Quantitative Changes in Agricultural and Animal Production in Brazil

Changes in the quantities of soybeans, maize, beef cattle, milk, pork, and poultry produced across all Brazilian regions from 1990 to 2015 (Table 1) shows an expansion in agricultural and animal production, except the north and the northeast regions, which showed dwindling pork production [22].

Table 1. Percent change in the production of selected agricultural and animal products, Brazil and regions, 2015/1990 (Δ%).

Region	Soybean	Maize	Beef Cattle	Milk	Pork	Poultry
North (N)	9529.3	328.9	254.1	230.1	−63.6	83.9
Northeast (NE)	3619.0	804.4	11.1	102.6	−39.9	55.2
Southeast (SE)	251.7	119.9	6.8	71.9	14.3	115.3
South (S)	203.7	107.0	8.3	277.6	86.8	177.1
Midwest (MW)	582.2	1222.9	58.3	182.8	82.7	438.7
Brazil (BR)	389.8	299.5	46.3	141.6	19.9	143.9

Source: Elaborated by authors based on [22,23].

Regarding annual crops, soybean is the main commodity in Brazilian agricultural production. From 1990 to 2015, soybean production increased by 389.83%, with the midwest and south regions accounting for 80.93% of the overall production. The south region represented 57.80% of the country's soybean production in 1990, decreasing to 35.84% in 2015 when the midwest region accounted for 45.09% of Brazil's soybean production [22]. The years from 2000 to 2015 were essential for the growth of soybean production in the north and northeast regions; however, these regions' total relative contribution remained below 10%. As with other crops, soybean production comprises a ride range of large- to small-scale production systems and social relations [28].

With a 299.50% increase over the period analysed, maize production in the midwest region in 2015 represented 48.22% of national production, a value rising from 14.56% in 1990. The south and southeast regions combined showed a relative decline in production, falling from 79.87% (in 1990) to 42.19% (in 2015). In 2015, the midwest and south regions accounted for 78.85% of Brazil's maize production [22]. The two crops declined in the southern region due to a reduction in their corresponding land use [25]. Agriculture had expanded to the southern territory long before it came to the midwest region.

Maize and soybeans, as grains, are of little use for direct human consumption. However, their derivatives enter the food chain in many forms. The main products derived from maize are flour, oil, starch, margarine, glucose syrup, and flakes. The main soybean derivatives are oil and bran, products with relatively high protein values.

As many countries (e.g., China) have a growing need for grain imports, changes in land use have occurred in agricultural product-exporting countries such as Brazil [29,30]. The agro-industry invests heavily in the development of new products derived from soybeans. The increased demand for cereal crops requires high yields, varieties adapted to the climate, technological alternatives, and public and private investments [31]. Before the 1990s, crop adaptation changes led to greater agricultural productivity. Changes have also occurred in market efficiency (economic aspects, food prices), e.g., Chinese trade liberalization increased world soybean demand in the 1990s.

Aside from vegetal products, Brazil stands out globally in animal protein production. These products are destined for domestic markets. Official practices in food quality control for improving animal health have promoted gains in the food supply chains' performance. The worldwide rise in consumption of animal protein is associated with Brazilian agriculture's economic performance in the first decade of the 2000s.

With one of the largest herds in the world, the Brazilian beef industry has productive chains for beef cattle and milk. The percentage variation of beef cattle production over the period under analysis was 46.29%. The north region's share of beef cattle production rose from 9.05% in 1990 to 21.91% in 2015. Comparatively, in the midwest region, there was slight relative rise (31.23% to 33.79%) in production [23]. The two regions accounted for 55.70% of the country's cattle production in 2015. In some regions, beef cattle production has moved from the extensive to the intensive model due to farming modernization and productivity gains [32].

Brazilian milk production showed a 141.64% rise from 1990 to 2015 [23]. The south and southeast regions accounted for 69.21% of the country's milk production in 2015. The southern region's relative contribution declined from 47.80% in 1990 to 34.01% in 2015, while the southeast region's contribution rose from 22.52% to 35.20% over the same period [23]. Available land and a tropical climate enable cattle production in free pastures. Investments in technology, research and development, and human capital, as well as public policies aimed at tracking the herd and controlling diseases, are all factors that have contributed to growth in beef and dairy cattle production.

These factors have fostered the expansion of pork production in Brazil for domestic consumption and export. Over the study period, pork production showed the lowest increase (19.95%) among all agricultural production outputs. The south region accounted for 49.28% of Brazil's overall pork production in 2015, up from 31.64% in 1990 [23]. This indus-

try's development factors include research involving nutrition (a decrease in the percentage of meat fat, cholesterol, and calories), adequate management, and integrated production.

Production of poultry meat, particularly chicken, rose by 143.87% over the period. The south and southeast regions accounted for 71.28% of poultry production in 1990, rising to 73.05% in 2015, associated with the land structure and the availability of labour within the region. In the period under review, the midwest recorded a 438.71% rise in poultry production, from 5.14% of national production in 1990 to 11.36% in 2015 [23].

The Brazilian industry's competitiveness for these products achieves through productivity growth, quality improvement, industrial modernization, and good animal nutrition and health. This success occurs due to chicken production without hormones or other banned veterinary products and reduced production costs because of better coordination among the poultry production chains.

3.2. Geographical Changes in Agricultural and Animal Production in Brazil

Agricultural and animal production occupies a significant portion of the Brazilian territory. An analysis was made of spatiotemporal changes in the production of the major Brazilian agricultural commodities, focusing on Brazil's second largest (approx. 20% of the nation's territory). This region, coinciding with Brazil's geographical centre, extends over three large and diverse biomes: Amazon, Pantanal, and Cerrado.

Given that, over the period of interest, unusual and intense human geographic dynamics were at work, we assessed its participation in changing the geographical distribution of specific Brazilian agricultural production densities.

The analysis of spatial movement in the production chains of selected Brazilian agricultural commodities between 1990 and 2015. These productions have gravitated toward the midwest region (Figure 2). Over most of the period analysed, the respective midpoints of Brazilian soybean and maize production shifted from the midwest toward the northern regions. Beef cattle production showed a similar movement. This change is noted in [3,15,25,33,34] and is generally attributed to the availability of lower-priced lands in the north and technical changes.

In contrast, pork, poultry, and milk production moved toward the south. While these productions do not necessarily require extensive tracts of farmland, soybean, maize, and beef cattle production usually require large-scale farming, linked to the availability of agricultural land and innovation centres. The blocks of innovation essential to this spread were soil-liming techniques, "tropicalization" of plant varieties, biological nitrogen fixation, no-till systems, pasture breeding, diffusion of biotechnology, mechanization improvement, and business economics management.

Maize's geographical midpoint of production varied the most among the systems considered (Figure 2). Maize production is at the centre of local cultural changes, suggesting the existence of a spatial association between the crop and animal supply chains. The midpoint migration of soybean and beef cattle production followed a linear pattern. Milk, pork, and poultry production showed greater stability in localization.

The determinants of the production transitions comprehend biophysical, institutional, and technological aspects. The agricultural frontier expanded towards the Cerrado biome, and agricultural production had spread from the south to the midwest region. Since 2000, this expansion reached the northeast region. Regarding biophysical determinants, specific crop or animal production systems are more adapted to certain soils and climatic conditions. For this reason, the Pantanal biome territory presents cattle production. As the midwest region shows relatively stable weather throughout the year, it is possible to obtain two or three annual crop harvests there. Accordingly, Brazil's midwest region is where most agricultural transitions occurred in Brazil since the 1950s.

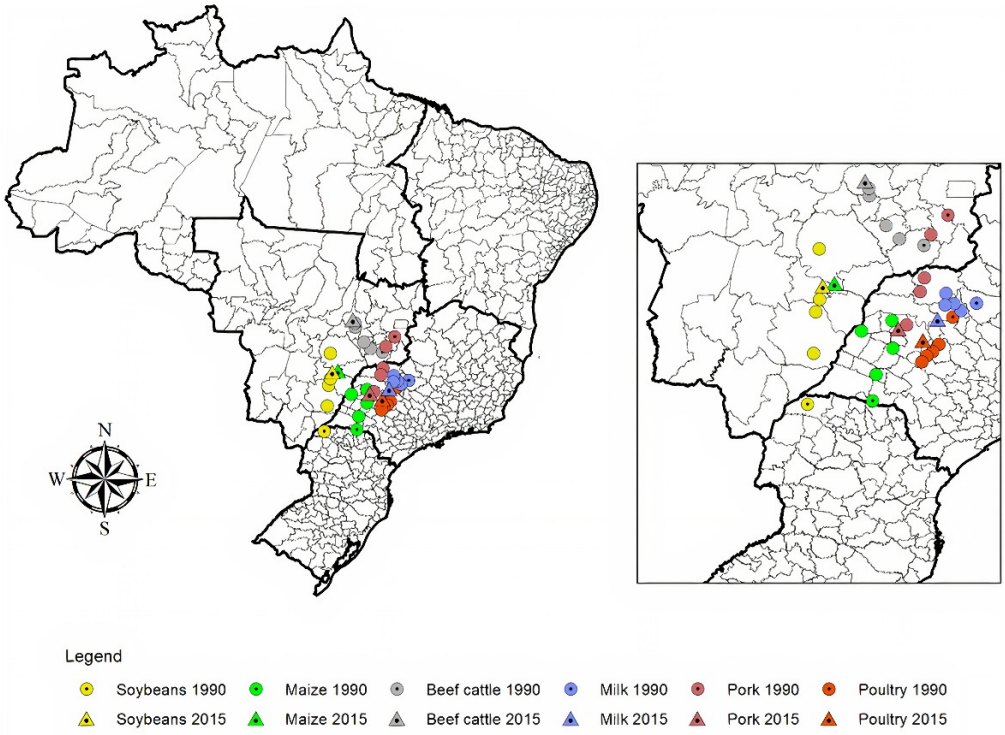

Figure 2. Annual midpoints of the production of soybeans, maize, beef cattle, milk, pork, and poultry in Brazil from 1990 to 2015. Source: Elaborated by authors based on [22,23]. Notes: each microregion as represented by the gray lines has different territorial dimensions.

3.3. Spatial Movement of Agricultural and Animal Production in the Microregions of the Midwest

The present study suggests that changes in agricultural production and land use in the Brazilian midwest affected the geographical distribution of agricultural production throughout Brazil. The movements which occurred in the geographical midpoints of the major Brazilian agricultural commodities between 1990 and 2015 (Figure 2) seem to the geographical changes in agricultural production occurred in the Brazilian midwest region during the period (Figure 3).

As the similarities in soybean and maize production indicate, the expansion in production during the 1990–2015 period in the Brazilian midwest region was linked to changes in land use. During this period, there was a marked change in Brazilian land use due to agricultural expansion into previously unoccupied territories. This followed a pattern of successive cultures, starting with cattle with alternating crops; thus, the major axes of Brazilian agricultural production reconfigured (north–south, east–west).

The respective production systems adopted for each culture can explain these transitions. Soybeans, maize, and beef cattle are major commodities based chiefly on independent production units. Therefore, the individual decision of the locally based stakeholders (rural entrepreneurs, often landowners) primarily determines the land use for these crop and animal production systems. Farmers usually assess market prices for crops and beef to decide the next production cycle.

However, pork, poultry, and milk production based on integrated systems, with industrial units located at strategic points leading farmers to establish their animal production units closer to agro-industries for convenience in logistics. Because most of these industrial units belong to companies rooted in southern Brazilian states, by institutional force, the migration axis of the integrated animal production midpoints faces the south.

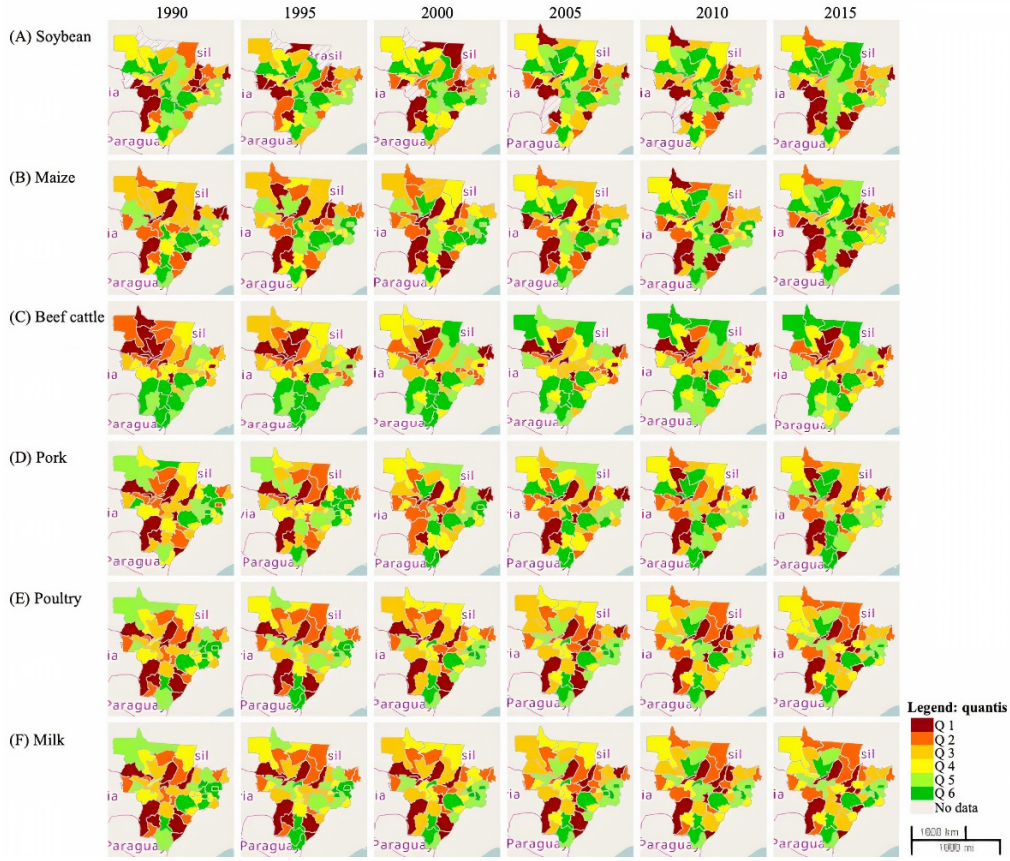

Figure 3. Six quantiles of quantity produced for soybeans (**A**), maize (**B**), beef cattle (**C**), milk (**D**), pork (**E**), and poultry (**F**) in the Brazilian midwest region for the years 1990, 1995, 2000, 2005, 2010, and 2015. Source: Elaborated by authors based on [22,23]. Notes: Each midwest microregion map is distributed in six quantiles (frequency distribution of quantity produced into equal groups) for each of the six products analysed in each year (interval of five years from 1990 to 2015). The quantiles are presented from the lowest to the highest quantity produced, that is, from Quantile 1 (Q1 or strong red in colour palette) to Quantile 6 (Q6 or strong green in colour palette).

To interpret the drive to the north for soybean, maize, and beef cattle production, our attention shifts to the agricultural development in Brazil's north and northeast regions, particularly in the regions of Matopiba (which includes the states of Maranhão, Tocantins, Piauí, and Bahia) and Sealba (which encompasses the states of Sergipe, Alagoas, and Bahia). These new agricultural frontiers have played an essential role in the Brazilian agricultural production axis changes during the period under analysis, and they will continue to do so in the coming decades.

Soybeans and maize are the primary nutritional inputs for animal production. Therefore, animal production becomes economically attractive once these cultures are established in a region. The integration of agriculture and animal production also plays a relevant role in the changes described in this work. Public policies enacted based on environmental concerns may restrict the migratory phenomenon in some places; for example, preventing deforestation in certain territories (e.g., the Amazon Legal Territory, with the allocation of conservation units and indigenous lands).

3.4. Discussion

Brazilian agricultural and animal production being a knowledge- and science-based sector, production growth has been associated with research, focused mainly in three fields: (i) improvement of degraded tropical soils, (ii) plant breeding and genetic engineering, and (iii) integrated management practices [15,27]. The cultural background of the migration of

production centres from the southern to the midwestern and northeast regions has played a vital role in the diffusion of technical changes, developed or adapted for the Cerrado biome by the national systems of innovation [14–18,26].

Innovation is vital since it increases the production output per input unit. Although the Brazilian agricultural frontier has been expanding into the Cerrado biome, encroaching upon the midwest, Matopiba, and Amazonian transition zones, this intense rise in knowledge and technology has led to increased livestock activity, with growth in feedlot numbers over recent decades. While the intensification and commodification of Brazilian agriculture have grown since 2005, deforestation practices have declined and dissociated from agricultural production growth [35].

With the development of science and technology in agriculture, substantial production growth occurred in the Cerrado biome. Given its central location, the state of Mato Grosso was critical in this regard. In this context, we can consider two main challenges: (i) infrastructure improvement (railway and waterway investments) to transport products, both for domestic and foreign markets; (ii) the establishment of regulations in the productive sector to promote sustainable management practices.

In recent decades, infrastructure investment has grown and been concentrated into two primary efforts. Firstly, the north–south railway was designed to become the backbone of rail transport in Brazil, strategically integrating the nation's territory and reducing the logistical costs of cargo transportation. The railway's length was projected to be 4787 km; however, only 2320 km has been built, connecting Barcarena, in the state of Pará (the north region), to Anápolis, in the state of Goiás (the midwest region). In 2016, an important investment partnership program was created to consolidate Brazil's new export rail corridor through Arco north–Ferrogrão. This railway has a length of 933 km, connecting the grain-producing midwest region to the state of Pará (in the north region), ending at the Port of Miritituba, and improving transport by waterways [36].

In 2004, the National Institute for Space Research (INPE) granted access to all data generated by satellite image monitoring systems, allowing the private sector to monitor deforestation rates in the Amazon region. At the time, it was the first time any country had done this. This information was considered strategic and for military use only. Accordingly, lacking this data, land cover and changes following local conflict are still not well [37].

The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) was created to improve land analysis. There has been a decline in deforestation, from approximately 18,309 km^2 yr^{-1} from 1990 through 2004, to just under 8877 km^2 yr^{-1} in 2005–2019, with the lowest rate (4571 km^2 yr^{-1}) in 2012 [38]. Recent studies in the region address other concerns: green and blue water effects on productivity and efficiency [5], political mobilization and the legal arena [7], fire and deforestation on spatial and temporal dynamics [39], and land use effects on ecosystem function [40].

From 1990 to 2015, better-balanced livestock diets contributed to increased carcass weight, reducing the time to slaughter and lessening greenhouse gas emissions [15]. Comparing degraded pastures (low productivity) with fields recovered by improved systems, the stocking rate increased from 0.7 to 2.5 heads per hectare, the slaughter age decreased from 4.5 to 2.5 years, and the birth rate grew from 60% to 85% [15]. Very productive pasture areas (high support capacity) led to low levels of greenhouse gas emissions per unit of production. Such was the beef cattle frontier trend over the past decade (states of Pará and Mato Grosso).

In 2010, the sectorial plan known as the ABC Plan was designed to mitigate and adapt to climate change. It was composed of seven programs: (i) recovery of degraded pastures; (ii) crop-livestock-forest integration and ag-forestry systems; (iii) no-till systems; (iv) biological nitrogen fixation; (v) planted forests; (vi) treatment of animal waste; and (vii) adaptation to climate change. The ABC Plan was dedicated to financing sustainable production practices. All combined project loans from 2010 to 2019 totalled represented 4.3 billion dollars. The Conference of the Parties (COP) established that the intended Brazilian contributions were accomplished before 2020 [41].

In 2012, the "Forest Code" was established by Federal law in Brazil, determining general rules on the use and protection of native vegetation. It regulates areas of permanent preservation, restricted use, legal reserve, forest exploration, control and prevention of forest fires, and creating economic and financial instruments for sustainable production. This legal framework guides and codifies the use of land and the conservation of natural resources in Brazil.

A study [42] has compared land-use laws amongst the world's leading food exporting countries (Argentine, Brazil, Canada, China, France, Germany, and the United States) and found that Brazilian forest coverage was double that observed in the other countries. To protect biodiversity, the "Forest Code" requires all private farming producers to preserve a percentage of native vegetation (legal reserve), without financial compensation. The rate of legal reserve varies from 20 to 80 percent, depending on biomes (i.e., the Amazon biome requirement is 80 percent, whereas the Cerrado biome is 20 percent).

4. Conclusions

This research analysed the expansion of Brazil's agricultural frontier from 1990 to 2015. Growth was oriented towards the occupation of the Cerrado biome, which was considered unsuitable for food production in the past since it is a region with low rates of soil fertility. We presented a longitudinal microregional analysis of Brazil's agricultural and animal production dynamics. It verified the potential areas for maintenance and expansion of the food supply chains under study.

An increase in agricultural production occurred in Brazil's central region. Based on the average displacements of production, the leading transformation of the overall output tended to be concentrated in the interior of the midwest region, confirming not only the occupation of the Cerrado but also the fluidity of the productive frontier with the Amazon biome. The production of soybean, maize, and beef cattle moved to the midwest's interior. On the other hand, milk, poultry, and pork production moved southward.

This study highlights that a portion of food production has settled on the Amazon border, increasing concerns regarding deforestation. Nonetheless, innovations and adoption of recovered pastures in this region led to sustainable growth, climate change mitigation, and deforestation rate.

Such displacements are average movements in the productive space, where the average does not always express reality. The Brazilian midwest emerges as an important grain- and beef-producing region, as well as an essential important in the production of other crops and animal products. The southern region has become a significant poultry and pork meat producer, while the state of Minas Gerais established in milk production. Since there is increased occupation at the border with the Amazon rainforest, innovation is essential to guarantee long-term sustainable output.

With the development of science and technology applied to agriculture, remarkable growth in production occurred in the Cerrado biome. As a result, there have been successful experiences in this Brazilian area, which could be the subject of future studies, considering issues such as greenhouse gas emissions, deforestation, biodiversity, and water resources. Therefore, we recommend revisiting this manuscript while considering the point of view of the geosciences, as there is an opportunity to discuss the consequences of migration in environmental, social, and economic aspects [43].

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

PAM	Municipal Agricultural Production
PPM	Municipal Livestock Research
IBGE	Brazilian Institute of Geography and Statistics
INPE	National Institute for Space Research
PPCDAm	Prevention and Control of Deforestation in the Legal Amazon
COP	Conference of the Parties

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