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HETEROGENEITY IN AMAZONIAN AGRICULTURE: A MULTIVARIATE ANALYSIS BASED ON THE 2017 AGRICULTURAL CENSUS[1]

HETEROGENEIDADE NA AGROPECUÁRIA AMAZÔNICA: UMA ANÁLISE MULTIVARIADA A PARTIR DO CENSO AGROPECUÁRIO DE 2017

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ABSTRACT

The objective of this study is to assess agricultural heterogeneity in the Brazilian Amazon, focusing on the characteristics of agricultural facilities in the region. To this end, variables related to different dimensions were combined: agrarian, economic, production, technological, structural, and environmental. Information on the structure of the agricultural sector was extracted from IBGE's 2017 Agricultural Census database, while deforestation data were obtained from Prodes/INPE. Deforestation containment areas, mainly public lands—such as military areas, strictly protected conservation units, and indigenous lands—were sourced from CNFP/MAP. Exploratory analysis and multivariate cluster analysis were used to identify patterns, considering variables restricted to the Amazon biome and at the municipal level. The results revealed six distinct municipal profiles with varied production patterns: extensive livestock farming, low-tech livestock farming, high-tech livestock farming, technologically developed agriculture, low-tech plant production, and plant conservation. Although located in a specific biome, agricultural facilities exhibit diverse production characteristics, and reflect the heterogeneity of Brazilian agriculture.

Keywords: Multivariate analysis. Amazon; Clusters. Production heterogeneity. Agricultural structure.

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RESUMO

O objetivo deste estudo é avaliar a heterogeneidade da agropecuária na Amazônia brasileira, com foco nas características dos estabelecimentos agropecuários da região. Para isso, foram combinadas variáveis relacionadas a diferentes dimensões: agrária, econômica, produtiva, tecnológica, estrutural e ambiental. As informações sobre a configuração do setor agropecuário foram extraídas da base de dados do Censo Agropecuário de 2017 do IBGE, enquanto os dados sobre desmatamento foram obtidos do Prodes/INPE. As áreas de contenção de desmatamento, representadas principalmente por terras públicas, foram extraídas do CNFP/MAP. A análise exploratória e a técnica de agrupamento multivariado (análise de clusters) foram utilizadas para identificar padrões, considerando variáveis atribuídas em nível municipal, restritas ao bioma Amazônia. Os resultados revelaram seis perfis distintos de municípios, com padrões de produção variados: pecuária extensiva, pecuária com baixo padrão tecnológico, pecuária com alto padrão tecnológico, agricultura com desenvolvimento tecnológico, produção vegetal de baixa tecnologia e conservação vegetal. Apesar de se tratar de um bioma específico, os estabelecimentos agropecuários apresentam características produtivas diversas, refletindo a heterogeneidade da agropecuária brasileira.

Palavras-chave: Análise multivariada. Amazônia. *Clusters.* Heterogeneidade produtiva. Estrutura agrícola.

INTRODUCTION

The dynamics of Brazilian agricultural growth manifest in several territorial patterns, which reveal profound structural heterogeneity across the country's different regions (Vieira Filho, Santos and Fornazier, 2013). This perspective is consolidating itself in the literature focused on evaluating and explaining distinct performances of the agricultural sector. There is extensive theoretical and empirical contribution regarding the multiple forms of manifestation of this heterogeneity, encompassing from regional divisions and farmer profiles (Guanziroli, Buainain and Sabbato, 2013; Kageyama, Bergamasco and Oliveira, 2013; Schneider and Cassol, 2014) to technological patterns (Souza et al., 2018, 2019).

Brazilian agricultural expansion, driven by a modernization process, had its initial landmark in its Central-Western region, which is predominantly covered by the Cerrado biome. The conversion of previously unproductive lands into arable areas, enabled by technological advancement, was determinant for the economic growth of the region, which has consolidated itself as one of the country's main agricultural hubs (Vieira Filho, 2016). In this context, Vieira, Buainain, and Contini (2014) highlight that the state of Goiás transitioned "from empty to heterogeneous".

Despite its consolidation in Brazilian Southern and Central-Western regions, agricultural activities expanded advancing towards the North of the country, where the Amazon biome predominates. This region concentrates significant attention due to the need for biodiversity conservation and the environmental services it provides. Furthermore, Brazilian Amazon is home to over 20 million people (nearly 10% of the national population), contributes 7% to Brazil's gross domestic product (GDP) (IBGE, 2022), and features some of the lowest development indices in the country (Benevides and Almeida, 2015; PNUD, 2013). These factors foster extensive debates on economic growth models which reconcile productive inclusion, sustainability, and environmental preservation (Souza and Ferrera de Lima, 2023)

The region's economic evolution rendered complex and heterogeneous production structures (Becker, 2005). Lira, Silva, and Pinto (2009) identified the coexistence of Amazonian municipalities with modernized and strengthened local economies alongside others characterized by low economic dynamism and strong dependence on the public sector. At least two development approaches have been outlined in the region: one focused on promoting agriculture, and another based on practices for the conservation of natural resources (Mello, 2015). This dichotomy transcended the academic environment and became part of the political agendas in the Amazonian states.

The biome's inherent complexity is intensified when facing the challenge of reconciling environmental preservation and ecosystem services' maintenance along with agricultural growth, especially by means of containing deforestation. Homma (2013) identified the existence of at least 84 agricultural macro-systems in the Amazon which require improvement. These systems range from traditional and subsistence forms of production (extractivism, artisanal fishing, and family farming) to more technified models, such as beef and dairy cattle ranching, perennial and temporary crops, agroforestry systems, and reforestation, in addition to non-agricultural activities.

As pointed out by Cavalcante Filho et al. (2023), based on the Brazilian Agricultural Censuses of 2006 and 2017, the area occupied by agricultural establishments in Brazil increased from 333.7 million to 351.3 million hectares, an expansion of 17 million hectares. Of this total, 66% of the expansion occurred within the Amazon biome, which highlights the advancement of agriculture in the region. In this context, this study aims to characterize agriculture in the municipalities of the Amazon biome by means of the formation of clusters. We specifically seek to combine representative variables of agrarian, production, social, technological, structural, and environmental dimensions to identify spatial patterns in the Amazonian territory.

The agricultural variables were determined based on data of the 2017 Agricultural Census. The environmental variables consider deforestation level and the area designated for conservation in the municipalities, based on information extracted from the Project for Deforestation Monitoring of the Legal Amazon by Satellite (Prodes), coordinated by the Brazilian National Institute for Space Research (INPE, 2024), and the Brazilian National Registry of Public Forests (CNFP), systematized by the Ministry of Agriculture and Livestock (MAP, 2024). Thus, this study contributes empirically to understanding the configuration of the agricultural sector in the Amazon and its relationship with environmental aspects, highlighting municipalities that demand greater attention regarding deforestation, considering their agricultural production characteristics.

LITERATURE REVIEW

The Amazon region, whether considered from its edaphoclimatic dimension as a biome or from the legal-institutional perspective of the Legal Amazon, occupies a significant portion of the Brazilian territory. Although it constitutes a geographically unified region, its reality is characterized by profound socioeconomic and demographic heterogeneity. This complexity has led numerous studies to adopt diverse approaches in an effort to understand the processes of economic growth and development in the region.

Among these approaches, regional convergence analysis stands out, as employed by Vieira, Sonaglio, and Carvalho (2009) and Souza and Ferrera de Lima (2023), to investigate disparities among different Amazonian economies and their progress rhythm. This technique enabled both the measurement of developmental level gaps and the identification of factors influencing income, economic growth, and social conditions. The study by Almeida Freitas and Ferrera de Lima (2022), in turn, examined socioeconomic inequalities among municipalities located in different mesoregions of the Legal Amazon. Both studies provided evidence that, despite recent advances, the region still exhibits diversified economic structures both across regions (inter-regionally) and within them (intra-regionally).

There are several possible strategies to promote regional economic growth and development. One example is presented by Gonçalves Jr et al. (2023), who applied an inter-regional input-output model to assess the effects of replacing exports with domestic market allocation as a means of adding greater value to the national production chain. The results indicated that such replacement would produce more significant socioeconomic impacts in the states of the Southern region, due to their higher industrialization. Under this perspective, the states of the Amazon should be the focus of industrialization-oriented policies aimed at increasing local value added and, consequently, enhancing the socioeconomic benefits generated by a production shift toward the domestic market.

The model of economic growth and development adopted by a region may directly influence its sustainability level. When assessing the impacts of public policies aimed at sustainable regional development in 771 municipalities of the Legal Amazon—using the indicators of the Municipal Sustainability Barometer—Oliveira et al. (2019) identified a significant contradiction: municipalities featuring higher levels of economic development tend to exhibit less favorable environmental indicators, which reveals a disconnection between economic growth and environmental preservation. Nevertheless, the best national results in terms of environmental well-being, on average, are observed—to a limited extent—in municipalities classified as environmentally sustainable or potentially sustainable.

Results obtained by Araujo, Rodrigues, and Sousa (2019) indicate that Brazil faces a lack of spatial sustainability, particularly pronounced in peripheral regions such as the Legal Amazon. Economically more developed areas tend to exhibit lower levels of environmental preservation, even though they offer greater urban well-being, demographic instability, and more substantial rural development. The presence of industrial activities contributes to spatial well-being; however, to promote truly sustainable regional development, such initiatives must be accompanied by policies that address social and spatial issues. Establishing biotechnology industries in peripheral regions emerges as a promising alternative, since it combines innovation, productivity, and cleaner production processes, thereby contributing to sustainability and balanced territorial expansion.

Certain attributes, when accessible, may significantly enhance the structural conditions of agricultural establishments; when restricted, however, they tend to hinder this process. Among these attributes, access to credit and participation in cooperatives stand out. Alves and Lima (2018) highlighted the strategic role played by agricultural cooperatives in controlling production and enabling the scale required for the competitiveness of the country's main agricultural commodities, particularly within specific production chains. The direct involvement of cooperative members in the management of these organizations reflects a process of collective learning, which is essential for economic growth and endogenous development of the regions in which they operate. In this context, the strengthening of social capital—understood as the set of values, norms, and trust-based relationships that foster cooperation among individuals and communities—has proven to be one of the main drivers of progress in the regions that make up what is often referred to as the 'agribusiness Brazil'.

METHODS

DELIMITATION OF THE AMAZON BIOME

The territorial boundaries and the creation of municipalities in Brazil are defined by federal legislation based on demographic, economic, and logistical criteria (Dantas, 2015; IBGE, 2017a). Physical and environmental characteristics are not taken into account in the delimitation of municipal territories. As a result, municipalities located in biome transition zones commonly encompass two or more biomes within their boundaries, even if only partially.

The data offered by different information sources follow territorial scales determined by legislation. This means that, when extracting information at the municipal level from the Agricultural Censuses conducted by IBGE, some municipalities located in transition zones encompass multiple biomes. Such overlap hinders the identification of the portion of data corresponding to each biome within these municipalities.

To address this issue, Garagorry and Penteado Filho (2008) adopted the criterion of biome predominance within municipal territories. According to this method, municipalities in which more than 50% of the territory is occupied by a given biome are considered to be fully included within that biome. This approach enables the alignment of official databases with environmental delimitations. It has been applied in studies such as those by Miranda, Magalhães, and Carvalho (2014) and Carvalho and Castro (2020), who used this criterion to delineate the Matopiba territory and the Cerrado biome. Following this logic, our study adopted the biome predominance criterion to ensure that the data obtained from the Agricultural Census, Prodes, and CNFP/MAP would be compatible with municipalities located within the Amazon biome.

MULTIVARIATE CLUSTER ANALYSIS

Ward's Method is a clustering analysis technique used to segment elements of a sample or population into groups. Its objective is to ensure that the elements within the same group are as similar as possible with regard to the analyzed variables, while elements belonging to different groups are heterogeneous among themselves (Mingoti, 2005). Thus, the method seeks to maximize the group's internal homogeneity while enhancing the differentiation between groups. The application of Ward's method involves the following steps:

- Selection of a similarity criterion: defining the criterion that will determine the degree of similarity between elements, considering multiple variables;
- Group formation: selecting the clustering algorithm;
- Determination of the number of groups: this may be defined *a priori*, based on prior knowledge and the study's objectives, or *a posteriori*, as a result of the exploratory analysis;
- Cluster validation: if the number of groups is defined *a posteriori*, formal procedures and subjective evaluations are applied at the researcher's discretion;
- Interpretation and analysis: characterizing the groups using descriptive statistics, hypothesis testing, or other analytical techniques.
- In this study, the analysis was performed at the municipal territorial scale, considering all 499 municipalities that are part of the Amazon biome. The following steps were carried out:
- Definition of relevant indicators;
- Construction of the database with the selected indicators for the municipalities within the biome;
- Characterization and analysis of the clusters.

DATA SOURCE

The database was constructed based on the municipal territorial delimitation adopted in this study. The information were obtained from special tabulations of the 2017 Agricultural Census, made available through the Automatic Recovery System (Sidra) of the Brazilian Institute of Geography and Statistics (IBGE, 2017b). Data on deforestation were sourced from Prodes/INPE, while information on areas designated for conservation was obtained from the National Register of Public Forests (CNFP/MAP). Cartographic datasets provided by IBGE (2021) were used, and the multivariate analyses were carried out using the *Philcarto* open-source software.

CONSTRUCTION OF VARIABLES

Agricultural censuses aim to depict the structure of the agricultural sector across multiple dimensions and provide a broad set of information, including data on agricultural establishments' access to factors that influence the production process. The heterogeneity of Brazilian agriculture motivated the construction of variables that capture different aspects of this diversity. In this study, the assessment of heterogeneity in agriculture within the Brazilian Amazon required the definition of variables that could depict the following dimensions: agrarian, production and economic, social, structural, technological, and environmental.

The agrarian structure may be analyzed under different perspectives, such as the proportion of establishments and land areas occupied by family and non-family farmers, the distribution of establishments by size class, the average area of establishments, and the form of access to the land. To synthesize these elements, the Land Gini Index, calculated by IBGE, was adopted as a measure of land distribution inequality at the municipal level.

The gross value of agricultural production (VBP), available in the Agricultural Census, was used to measure production and economic activity. The VBP encompasses animal, plant, and agro-industrial production. Animal production is subdivided into large and medium-sized livestock, poultry, and small animals, while plant production includes permanent and temporary crops, horticulture, floriculture, silviculture, and forest extraction. Since these two categories accounted for over 95% of the total VBP in 2017, the analysis considered the share of animal and plant VBP in total production as an indicator of the agricultural production structure at the municipal level.

The social data available in the Agricultural Census are limited and refer mainly to the education level of the farmer. In previous studies, educational attainment has been used as a proxy for the farmers' technical and innovative capacity. In this study, the proportion of farmers with at least high school education was adopted as an indicator for the social dimension, based on the assumption that higher educational levels may be associated with greater capacity for innovation and adoption of new technologies.

Environmental information in the Agricultural Census are also limited, particularly because they are restricted to land use. To address this limitation, official external datasets were incorporated, such as those from Prodes/INPE and CNFP/MAP. Data on deforestation (2017) and on public lands (2019) were used, including military areas, Indigenous lands, and strictly protected areas. These categories were selected because they portray areas with greater legal restrictions on the opening of new agricultural lands, and thereby serve as barriers to deforestation expansion.

One of the main contributions of the Agricultural Census is making available information on the use of technologies and the structural characteristics of agriculture at the municipal level. To synthesize these aspects, two municipal indices were developed:

- Structural Condition Index (*IDEstrut*),
- Technological Index (*IDTec*).

The criteria and methods used to construct these indices are detailed in Table 1

Table 1 | Variables used in the construction of the Structural Condition Index and the Technological Index.

Index	Variable
	Structural
IDEstrut	Establishments with access to electricity
	Establishments with access to technical guidance
	Establishments affiliated with cooperatives and/or professional associations
	Establishments with access to credit
	Establishments with access to internet
	Establishments with access to technical information
	Technological
IDTec	Establishments with access to fertilizers[1]
	Establishments with access to pesticides[1]
	Establishments with access to lime[1]
	Establishments with access to irrigation
	Establishments practicing no-till farming
	Establishments equipped with tractors
	Establishments equipped with seeders and/or planters
	Establishments equipped with harvesters
	Establishments equipped with fertilizer and/or lime spreaders

[1] Includes agricultural establishments that employ some technique, even if they did not apply it during the Agricultural Census reference year because it was not needed.

Source: Prepared by the authors.

The construction of the indices is based on the average proportion of agricultural establishments that have access to specific services, infrastructure, and technologies in relation to the total number of agricultural establishments in each municipality. This relationship is expressed by the following formula:

$$IDEstrut = \sum \frac{EE_i}{TE_m} / N_v \qquad (1)$$

In which,

$IDEstrut$ = Structural Condition Index of the municipality;

EE_i = total number of establishments in the municipality with access to some structural condition;

TE_m= total number of establishments in the municipality;

N_v = number of variables used in the construction of the index.

$$IDTec = \sum \frac{ET_i}{TE_m} / N_v \qquad (2)$$

In which,

$IDTec$ = Technological Index of the municipality;

ET_i = total number of establishments in the municipality with access to some technology.

The set of variables that comprise the Structural Condition Index (IDEstrut) provides indications of municipalities with more developed infrastructure, which favors the adoption of new technologies and innovations in the production process. Many of these variables were extensively discussed by Souza Filho et al. (2011) as key factors in the incorporation of technological innovations in agriculture.

The construction of the Technological Index (IDTec), in turn, was based on variables used in researches aimed at identifying technological patterns, particularly the studies by Lobão and Staduto (2020) and Souza et al. (2018, 2019). The role of technology in the agricultural sector has become increasingly relevant, and directly impacts VBP, as pointed out by Vieira Filho, Gasques, and Ronsom (2020). The variables used in the multivariate cluster analysis are summarized in Table 2.

Table 2 | Description of constructed variables.

Dimension	Variable	Description	Source
Agrarian	*giniterra*	Land Gini Index at the municipal level	Agricultural Census 2017
Production/ Economic	*vbpanim* *vbpveg*	Proportion of animal/plant gross production value in the municipality's total agricultural gross production value	
Social	*escol*	Proportion of establishments with farmers who have completed secondary or higher education	
Structural	*IDEstrut*	Structural Condition Index	
Technological	*IDTec*	Technological Index	
Environmental	*desacum*	Proportion of accumulated deforested area	INPE and CNFP
	conserv	Proportion of land designated for conservation, public lands, and Indigenous territories	

Source: Prepared by the authors.

RESULTS OF THE MULTIVARIATE ANALYSIS

CONFIGURATION OF AGRICULTURE IN THE BRAZILIAN AMAZON

A brief analysis of the information explored within each dimension enables outlining the agricultural landscape within the Brazilian Amazon. Agricultural establishments in the region occupy 24.42% of the country's total area and account for 13.38% of all agricultural establishments nationwide. The Amazonian agrarian pattern reflects the national reality, characterized by the predominance of family farming on smaller plots of land. However, the Land Gini Index suggests a relatively more balanced land distribution in the Amazon when compared to Brazil as a whole.

Despite its vast territorial extension, agriculture in the Amazon has a modest share in the national economy, and accounts for only 11.5% of Brazil's agricultural gross value of production (VBP). Plant production accounts for 52.23% of the regional VBP, while livestock production accounts for 43.71%. Also, the agricultural sector in the Amazon employs 2.34 million people, which corresponds to 15.5% of the national agricultural workforce.

From a social perspective, the education level of Amazonian farmers is similar to the national average: approximately 23.72% have completed secondary or higher education. This percentage is low, considering that education is a factor that may indicate greater technological aptitude and innovation capacity. As a result, over 70% of farmers may face difficulties in adopting new agricultural practices and technologies.

Agricultural innovation depends on various structural conditions, such as access to electricity, technical assistance, associations, information, internet, and rural credit. These elements, included in the Agricultural Census, were used to construct the Structural Condition Index (IDEstrut). In Brazil, on average, 38.3% of agricultural establishments have access to at least one of these services, whereas in the Amazon, this percentage drops to 29.8%.

Technological advancement has been crucial both for increasing productivity and for reducing pressure on new land, promoting the so-called 'land-sparing' effect. However, the technological standard of Brazilian agriculture is low. Only 47.72% of Brazilian agricultural establishments nationwide use fertilizers—a technology widely adopted since the 1970s. In the Amazon, this percentage is even lower, only 19.33%. Regarding other technologies included in the Agricultural Census, the average rate of technological adoption is 16.1% for Brazil and 8.3% for the Amazon.

The environmental dimension reveals a paradox. On one hand, 23.9% of all deforestation across Brazil's six biomes occurred in the Amazon. On the other hand, the region contains 90% of the public lands designated for full protection, which highlights its significant potential for the conservation of native forests. Recent data from Prodes/INPE indicate that between 2017 and 2022, the Amazon was the biome with the highest deforestation increase, a 7.5% rise, which is equivalent to 5.3 million hectares deforested during that period.

PRODUCTION PROFILES AND CLUSTERS IDENTIFIED

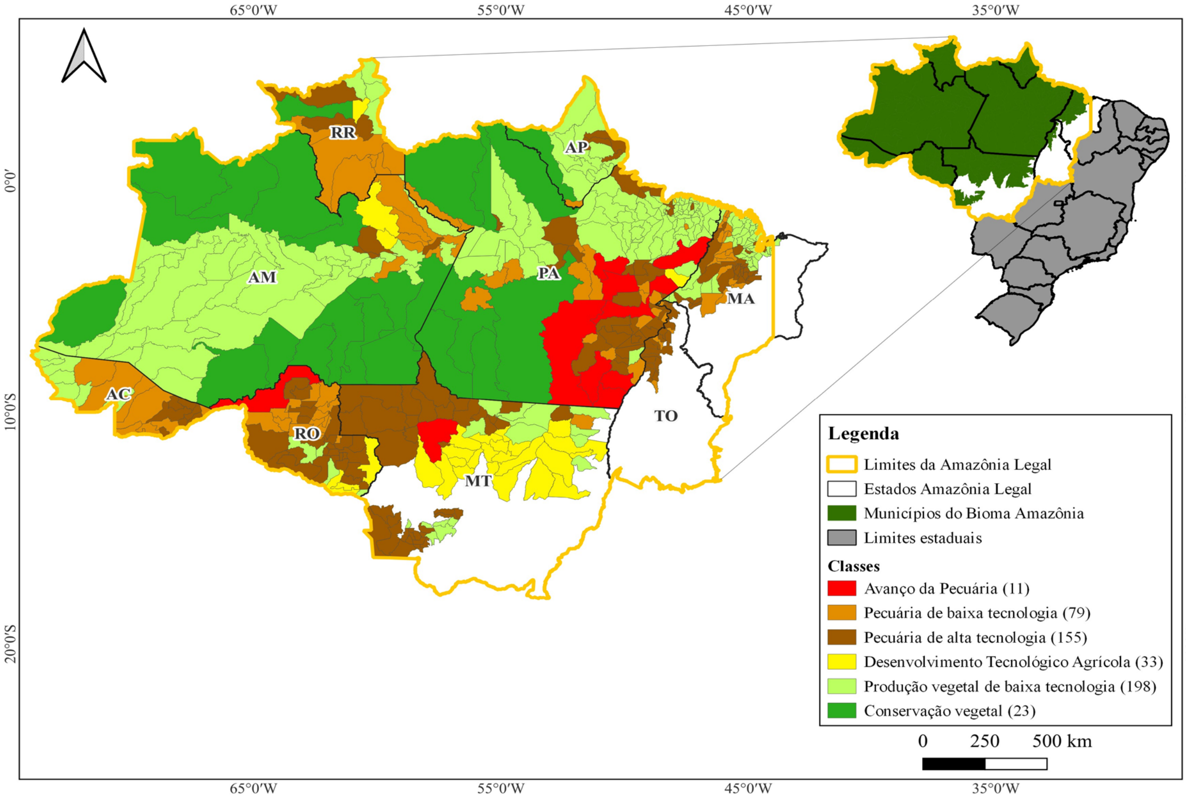
The multivariate analysis produced six clusters, organized into two broad production profiles: livestock farming and plant production. The differences among these groups were primarily determined by structural, technological, and environmental factors.

The clusters associated with livestock farming were subdivided into three categories: 1. Livestock expansion through deforestation; 2. Low-tech livestock farming; 3. High-tech livestock farming. These groups were predominant in Rondônia, the state which has the highest percentage of deforestation in the region, which suggests that livestock farming has been one of the main drivers of this process.

Municipalities with a production profile more oriented toward plant production were grouped into three other clusters: 4. Agricultural technological development; 5. Low-tech plant production; 6. Vegetation conservation. These clusters cover most of the Amazon region and are more prominent in the states of Amazonas, Pará, and Mato Grosso.

The clusters were geographically distributed as follows: Cluster 1, predominantly in southeastern Pará, as well as in municipalities such as Porto Velho (RO) and Juara (MT). Cluster 2, municipalities in the central-southern regions of Acre and Roraima, northeastern Amazonas, central-northern Rondônia, and some scattered areas in Pará and Maranhão. Cluster 3, mostly concentrated in Rondônia, Tocantins, western Mato Grosso, southern Acre, southeastern Pará, and northwestern Maranhão. Cluster 4, municipalities bordering the Amazon biome in central Mato Grosso, one of the country�s main agricultural hubs. Cluster 5, municipalities located in central Amazonas, Pará, and Amapá. Cluster 6, areas in the northern and southern regions of Amazonas and Pará. Figure 1 illustrates this spatial distribution, highlighting the production differences among municipalities within the Brazilian Amazon.

Figure 1 | Results of the multivariate analysis of municipalities in the Amazon biome in 2017.



Source: Prepared by the authors based on the constructed variables.

CLUSTER 1: DEFORESTATION EXPANSION AND EXTENSIVE LIVESTOCK FARMING

Cluster 1 stands out for grouping municipalities directly associated with the expansion of deforestation, a process largely driven by extensive livestock farming (Barreto, Pereira and Arima, 2008; Fearnside, 2007). Low levels of technological adoption, structural weaknesses, and land concentration are defining features in this group. The expansion of livestock farming occurs primarily at the expense of forest areas, and reflects an extensive and inefficient production model. Studies indicate that rural credit has played a significant role in the expansion of livestock farming in the Amazon (Freitas Junior and Barros, 2021), and suggest the need to revise financing criteria by incorporating environmental considerations and deforestation levels.

CLUSTER 2: LIVESTOCK PRODUCTION BY SMALL AND MEDIUM-SCALE FARMERS

Cluster 2 includes municipalities where livestock production occurs under precarious structural conditions, with low levels of farmer education and limited access to technology. This group has the lowest Land Gini Index, suggesting a less concentrated agrarian structure and the predominance of small and medium-scale farmers. However, the lack of qualification and limited access to technological input place these farmers in a vulnerable position, hindering their participation in agricultural modernization processes.

CLUSTER 3: TECHNIFIED LIVESTOCK FARMING IN CONSOLIDATED AREAS

Like cluster 2, cluster 3 is also characterized by municipalities where livestock farming is the predominant activity. However, this group exhibits better structural indicators, higher levels of farmer education, and greater access to technology. The Land Gini Index is the second highest among the clusters, indicating a more concentrated land ownership structure. The predominance of this cluster in the states of Mato Grosso and Rondônia suggests that it depicts consolidated agricultural areas, where extensive livestock farming has incorporated some level of technology to improve productivity.

CLUSTER 4: AGRIBUSINESS AND COMMODITY PRODUCTION HUB

Cluster 4 gathers municipalities focused on plant production and is characterized by higher education levels, better structural conditions, and greater access to technology. This group has the highest Land Gini Index, which indicates high level of land concentration, typical of regions oriented toward agribusiness and the production of agricultural commodities such as soybean and corn. This cluster stands out for having recorded the smallest increase in deforested area between 2007 and 2017, which suggests that agricultural lands in these municipalities are already consolidated.

CLUSTER 5: PLANT PRODUCTION AND EXTRACTIVISM WITH LOW ENVIRONMENTAL IMPACT

Cluster 5 gathers municipalities where farmers have low levels of education and limited access to infrastructure and agricultural technologies. However, this group is distinguished by having one of the lowest levels of accumulated deforestation up to 2017. This profile suggests an economy based on small-scale production, with a strong presence of extractivism, especially due to the geographic location of these municipalities.

CLUSTER 6: CONSERVATION AREAS UNDER DEFORESTATION PRESSURE

Cluster 6 comprises municipalities featuring the largest areas allocated to environmental conservation, yet paradoxically characterized by low educational levels, poor infrastructure, and limited access to technologies. This group plays a strategic role in curbing deforestation. It includes municipalities such as Altamira (PA), located in agricultural frontier regions near already consolidated areas in Mato Grosso and Rondônia. Despite its conservation-oriented profile, more than half of this cluster's VBP comes from animal production, with livestock expansion advancing over forest areas. Between 2007 and 2017, deforestation in this cluster increased 17.3%, a significant share of the total deforestation over the period.

Table 3 summarizes the information regarding the number of municipalities per cluster, the number of agricultural establishments involved, the increase in deforested area between 2007 and 2017, and the gross value of agricultural production (VBP).

Table 3 | Summary of the results obtained by multivariate analysis.

Cluster	Characteristic	General results
1	Expansion of livestock farming	- Number of municipalities: 11 - Number of facilities: 37,314 - Deforestation increase (2007–2017): 1,201,834 ha - VBP: R$ 3.9 billion (64.7% from livestock production)
2	Low-tech livestock farming	- Number of municipalities: 79 - Number of facilities: 105,048 - Deforestation increase (2007–2017): 1,035,959 ha - VBP: R$ 4.9 billion (78.4% from livestock production)
3	High-tech livestock farming	- Number of municipalities: 155 - Number of facilities: 166,033 - Deforestation increase (2007-2017): 1,218,199 ha - VBP: R$ 14.9 billion (82.1% from livestock production)
4	Agricultural technological development	- Number of municipalities: 33 - Number of facilities: 20,952 - Deforestation increase (2007-2017): 483,391 ha - VBP: R$ 16.4 billion (88.7% from plant production)
5	Low-tech plant production	- Number of municipalities: 198 - Number of facilities: 313,942 - Deforestation increase (2007-2017): 1,139,123 ha - VBP: R$ 12.2 billion (71.1% from plant production)
6	Vegetation conservation	- Number of municipalities: 23 - Number of facilities: 35,669 - Deforestation increase (2007-2017): 1,059,511 ha - VBP: R$ 1.3 billion (54.9% from livestock production)

Source: Prepared by the authors based on constructed variables.

These findings offer a comprehensive understanding of the characteristics of each cluster and of the economic and environmental significance of agriculture and livestock farming in the Amazon region. These results convey essential information for the development of public strategies and policies, and enable a more targeted approach based on the quantitative analysis of the municipalities and agricultural establishments in each group. This level of detail allows for the identification of strategic priorities and fosters the promotion of more sustainable agricultural practices in the region.

Clusters 1, 2, and 3 highlight the need for a model shift from extensive livestock farming to integrated production systems or intensification through confinement, thereby reducing pressure on forest areas. Cluster 1, in particular, deserves special attention: although it gathers only 11 municipalities, it includes 37,000 agricultural establishments and accounted for an increase of 1.2 million hectares of deforested land in just one decade. The same reasoning applies to cluster 6, given livestock production's relevance in this group's VBP. Implementing alternative production systems in these municipalities is essential, considering their potential for forest conservation.

Clusters 5 and 6 also demand urgent actions to contain deforestation advance. Together, they accounted for 18.6% of the deforested area between 2007 and 2017, highlighting the need for inclusive strategies that combine environmental preservation with socioeconomic development. The large number of agricultural establishments in these groups (over 313 thousand) reinforces the importance of strengthening extractivism production chains through local agro-industrialization. Furthermore, improving infrastructure—including access to electricity, technical assistance, information, and rural credit—is essential to ensure productive inclusion and enhance the sustainability of these activities.

Although it represents part of Brazil's consolidated agricultural hub, cluster 4 should continue incorporating new technologies to sustain productivity gains. This group accounted for only 8% of total deforestation between 2007 and 2017, which indicates that its agricultural areas are already stabilized. However, strategies to promote the dissemination of sustainable agricultural practices may still be strengthened, and encourage the adoption of techniques such as no-till farming, crop rotation, and minimum tillage among farmers who have not yet implemented them.

FINAL CONSIDERATIONS

This study aimed to assess the heterogeneity of agriculture and livestock farming in Brazilian Amazon by using official databases to explore the multiple dimensions that characterize agricultural establishments in the area. During the research, some limitations were identified, particularly regarding the availability of certain data, which restricted some of the analyses. For instance, although deforestation may occur legally or illegally, this distinction could not be taken into account, as the Prodes/INPE system only provides results aggregated at the municipal level.

Another important limitation was the exclusion of the number of employed persons from the cluster formation. Variables relating the number of workers to the number of agricultural establishments, the gross production value (VBP), and the area occupied were tested, but the results diverged from the expected characteristics. This occurred because these metrics reflect productivity indicators, whereas the other analyzed indicators capture proportions related to production and environmental aspects.

Despite these constraints, the results obtained were coherent and satisfactory, and met the criteria established for the cluster multivariate analysis. The resulting classification identified six distinct groups of municipalities with different production patterns: extensive livestock farming, low-tech livestock farming, high-tech livestock farming, agriculture with technological development, low-tech plant production, and forest conservation. This diversity highlights the heterogeneity of Brazilian agriculture, even within a single biome.

More than describing this heterogeneous pattern, it is essential to implement effective strategies and public policies to contain deforestation, and promote an agricultural sector aligned with sustainability principles. This need becomes even more urgent considering that the Amazon is at the center of global attention, and the demands for sustainable development in the region are increasingly rigorous. Just as the Brazilian state played a crucial role in the growth and consolidation of the country's agriculture as a global reference, the public sector is now expected to play a strategic role in coordinating sustainable policies, in partnership with state and municipal governments and local production sectors.

The recovery of degraded areas may occur naturally, through the biome's regenerative capacity, or be induced through reforestation projects. However, spontaneous regeneration is unlikely in regions already consolidated as agricultural hubs, especially those integrated into international commodity markets such as soybean and corn, which drive the local economy. Therefore, a priority strategy should be the monitoring and control of deforestation in municipalities where native vegetation is still preserved. This is particularly important in southern Amazonas and in Pará, regions where the agricultural frontier is rapidly advancing.

The adoption of new production systems is another essential measure to reduce pressure on forests. Currently, several sustainable systems are already included in financing policies, such as the ABC+ Plan and the National Program for Strengthening Family Farming (Pronaf). No-tillage systems (SPD) and agroforestry systems (SAF) are viable alternatives for agricultural crops, while crop-livestock integration (ILP), crop-livestock-forest integration (ILPF), and livestock-forest integration (IPF) may significantly reduce the environmental impact of livestock farming. Additionally, the adoption of confinement systems may represent a solution for ranchers still operating under extensive production models.

On one hand, to ensure the sustainability of Amazonian agriculture, it is essential to invest in the dissemination and adoption of new technologies. In municipalities where agricultural production is already consolidated, monitoring technological advancements is necessary to maintain productivity without expanding the area used. These municipalities have better structural conditions and are home to agricultural establishments which are wealthier, integrated into dynamic production chains.

On the other hand, greater efforts are needed to include farmers operating under low-tech and structurally deficient conditions. The expansion and reactivation of technical assistance and rural extension services are crucial to integrate smallholders who have historically been left out of agricultural modernization. Although a uniform technological standard among different profiles of farmers is not expected, these measures may help reduce inequalities and mitigate the impacts of future technological changes.

The granting of rural credit may be an important regulatory tool and encourage sustainable production practices. Financing may incorporate effective mechanisms to restrict farmers who intend to expand their areas illegally. Thus, credit may be conditioned to the adoption of good environmental practices, efficient land use, and compliance with current environmental regulations.

In the face of climate change and environmental pressures, transforming the production model in the Amazon is urgent. The agenda for sustainable agriculture in the region must be structured with short-, medium-, and long-term goals, involving various public and private actors. To ensure that agricultural development in the Amazon aligns with sustainability principles, a coordinated and continuous effort is essential, one that includes robust public policies, appropriate incentives, and strong participation of local communities.

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