The effect of farm size and farmland use on agricultural diversification: A spatial analysis of Brazilian municipalities

Abstract:

Brazilian agriculture is characterized by the prevalence of small farms and by regions with a high degree of rurality and dominance of the agricultural sector in the economy. These two characteristics affect the diversity of agricultural production in the country. Specifically, the article aims to analyze the effects of farm size and farmland use on agricultural diversification for 4,298 Brazilian municipalities from 1996 to 2017 (the last three agricultural censuses). The level of diversification was determined using three different agricultural diversification indices (Simpson, Shannon, and Effective Number). Empirically, we consider spillover effects by estimating spatial models at the municipal level using panel data, highlighting the importance of location and neighborhood. The study's findings indicate a tendency towards local concentration of agricultural production in the country, despite the balance between municipalities with diversified and concentrated production. The results showed a significant effect of small farms and the municipalities' rurality degree on the agricultural output diversification. The study provides insights into the discussion on measures to strengthen support for small properties and regions that diversify crops to ensure economic efficiency and food security.

Keywords: Diversification-Index, Small Farms; Rurality; Panel Data; Spatial Regression, Brazil

1. Introduction

Looking only at the quantity of food produced globally, we would conclude that market-based agriculture has successfully met food and energy needs for an expanding global population. However, the techniques used and specialization in crop production may have reduced biodiversity in rural areas, increased producers' dependence on the sector having stable prices, and increased agricultural regions' vulnerability to the effects of climate change (Bellon et al., 2020). Climate change poses risks to global goals such as poverty reduction, food security, human health, and economic prosperity. Adaptation pathways to climate change can promote food and water security, human health, air and water quality, and natural resource management (Denton et al., 2014).

The profitability of the agricultural sector depends on the prices and quantities of crops produced (revenue) and the prices and amount of inputs (production cost). As input and product prices become more volatile, production loss may increase and compromise the sector's economic sustainability. The model of market-based agricultural diversification strengthens farmers' economic resilience considering that a variety of crops meet market demand at different times of the year, eventually leading to a transfer of resources from a crop to crops mix to increase the sector's income and profit (Bellon et al. 2020). According to Di Bene et al. (2022), crop diversity improves crop productivity, resource use efficiency, and cropping system resilience in the long term. Among the main farming practices of agricultural diversification, the authors cite crop rotation, cover crops, multiple crops and intercropping, conservation agriculture, and organic agriculture.

Agricultural diversification strategy plays a vital role in reducing climate-related risks inherent to farming activity, has a positive nutritional and environmental impact, and increases the resilience of food systems. A series of studies have verified the positive effects of diversification of agricultural production, such as Di Falco and Chavas (2008), Di Falco et al.

(2010), Chavas and Di Falco (2012), Gurr et al. (2016), Donfouet et al. (2017), Waha et al. (2018), Mazzocchi et al. (2020), Vroege et al. (2020), Kurdy's-Kujawska et al. (2021). The United Nations encourages the adoption of diversified production systems by farmers. It increases food security, generates jobs in the countryside, climate change adaptation, increases household income, and provides agronomic benefits such as improving soil and plant health and reducing exposure to pests (FAO, 2012, 2018; Maggio et al., 2018).

According to Aguilar et al. (2015), some farmers prefer nothing to adopt a diversification of their production; this strategy can be explained by agricultural policies, increases in the value of human labor, and development of farming techniques to increase the scale of production and specialization. Isbell at el. (2021) surveys the literature on why agriculture has led to a decline in crop diversity and highlights some trends in agricultural development that reward specialization through economies of scale, government subsidy programs for commodity crops, and agricultural policies that benefit both conventional and large-scale production. Therefore, risk and uncertainty are the significant characteristics of agricultural output in developing countries. The adoption of crop diversification has increased recently due to prolonged droughts and other extreme weather events (Kurdy's-Kujawska et al., 2021).

This article focuses on two essential characteristics of Brazilian agriculture and their effects on the diversity of agricultural production in the country, namely, the prevalence of small farms and the regionalization of agriculture in municipalities and regions where the agricultural sector predominates. In 2017, about 77% of rural establishments in Brazil were classified as household farms, with an occupied area of 80.9 million hectares, which accounted for 23% of the total area of Brazilian rural establishments. Farm size is a crucial determinant of whether households adopt more diverse systems. Galli et al. (2020) have found that small farms ensure food and nutrition security for households at local, regional, and global levels and maximize the profits for the farmer and the household. Farmland use determines the expansion of agriculture in the territory (rurality degree), giving rise to different characteristics of the regional agricultural sector. Agricultural expansion and land use intensification can cause adverse environmental impacts, and implementing different land-use plans, mechanisms, and policies is crucial to mitigate some of these impacts (Di Falco & Zoupanidou, 2017).

Hence, based on the discussion above, the study was intended to answer the following fundamental question empirically: in addition to factors associated with demand and technology, does the size of the property and the intensity of land use influence agricultural diversification in Brazilian municipalities? The results of this study reduce the information gap on farm diversification and contribute relevant information to improve food security, income stability, and the nutritional level of the Brazilian population. Therefore, the specific objective of this study is to analyze the implications of farm size and farmland use for agricultural diversification in Brazilian municipalities from 1996 to 2017. Specifically, we examine three different agricultural diversification indices (Simpson, Shannon, and Effective Number) and estimate an empirical model with spatial effects, with farm size and farmland used as variables of interest and controlling for demand and technology effects. We selected 4,298 Brazilian municipalities covering the country's entire territory for the last three agricultural censuses (1996, 2006, and 2017).

Farm size influences diversification; the smaller the size, the greater the probability of diversifying (Mazzocchi et al., 2020). Small farms often struggle to participate in profitable markets and do not benefit from scale gains; therefore, diversification becomes necessary (Pfeifer et al., 2009). However, the results of García-Arias et al. (2015) demonstrate that larger farms, managed by younger owners or with higher incomes, have more resources to devote to other activities. Moreover, the literature analyzing the relevance of farm size for diversification activities is controversial. Van Zonneveld et al. (2020) surveyed the literature and found no clear correlation between farm size and on-farm diversification. The authors did a systematic literature review, including 13 detailed studies; six reported that on-farm diversification increases with farm size, four studies reported no effects, and three reported that on-farm diversification decreases with farm size. Accordingly, we can formulate the first hypothesis: Hypothesis 1 - farm size negatively influences agricultural diversification; the smaller the size, the greater the diversification.

According to Van Vliet et al. (2015), several factors influence the farmland use intensity and territory occupation, highlighting economic, technological, institutional, and locational factors, besides demographic and sociocultural factors. These factors can result in agricultural land expansion or contraction, defining the landscape's characteristics and regional agriculture. The second hypothesis can be formulated as follows: Hypotheses 2 - farmland use (or rurality degree) positively influences agricultural diversification. The more intensive the use, the greater the diversification.

The remainder of this paper is structured as follows. The second section presents an update of empirical studies on agricultural diversification; materials and methods are described in the third section; the fourth section presents results and discussion on diversification in Brazil, illustrated with maps, and provides the estimation results and the corresponding analysis. The conclusion is drawn in the last section.

2. Empirical evidence on the importance of agricultural diversification

An evolution in agricultural systems is necessary to achieve sustainability, balancing socioeconomic food production aspects with environmental objectives. Crop diversity emerges as an alternative for sustainable farmland ecosystems and global sustainability, making it an important research topic in socioeconomics, agricultural science, and geography (Di Bene et al., 2022; Song et al., 2021). Research results show that crop diversification significantly improves income stability, thereby supporting the idea of it being a resilience strategy (Mzyece & Ng'ombe, 2020; Ponce, 2020).

Isbell at el. (2021) researched the factors influencing the decision to maintain crop diversity among commercial and non-commercial seed producers in the US state of Vermont. The results suggest that seed producers maintain crop diversity for numerous reasons, including environmental, social, and cultural reasons. In addition to profit accumulation, diversity can act as a form of investment in natural capital and informal insurance for farmers whose value can be challenging to quantify in simple economic terms. The diversification of the production can bring market advantages, making it possible to migrate from the commodities market to the sale of differentiated goods with higher market value (Bowman & Zilberman, 2013; de Roest et al., 2017). In addition, farms might diversify by combining diversity of crop production with other income-generating activities such as livestock, agritourism, sales and processing of products on the farm, and nature conservation activities (Vroege et al., 2020; Monteleone et al., 2018).

Factors such as population size and individual income that determine the demand for agricultural products can drive agricultural diversification. Proximity to urban centers can generate consumer demand for a greater variety of local farm products (Zasada, 2011). Proximity to tourist sites or urban areas can drive diversification into on-farm non-agricultural products, such as agro-tourism activities, environmental services, and other products. However, the results from Boncinelli et al. (2018) revealed that farms located far from urban areas have a greater probability of diversifying than those close to urban areas. According to the authors, this result suggests the diversification process as an "endogenous" strategy to overcome the disadvantages arising from farm locations in more remote areas (i.e., high transport costs, fewer off-farm opportunities, and less networking) which reduces agriculture profitability.

Technological advances result in increased labor productivity in agriculture and labor migration to other sectors, resulting in decreased employment in the agricultural sector. Workers' gender seems to be a variable that influences diversification in agriculture. Decisions about agricultural land use, agricultural landscape, and activities linked to agrotourism are influenced by gender, and the presence of female farm workers is where to farm diversification activities (Villamor et al., 2014, Joo et al., 2013).

In the study by Pfeifer et al. (2009), farm size had a significant negative impact on the diversification of farm activities, suggesting that diversification may be a survival strategy for small properties that do not have the opportunity to increase in size. Research by Guarín et al. (2020) proposes a new typology of small farms in Europe, providing a picture of the diversity and nature of small farming. The findings suggest evidence of entrepreneurship and strong market linkages, suggesting diversification and multifunctionality in small farms in regions of Europe dominated by large-scale intensive agriculture.

According to FAO (2021), irrigation development is one aspect of agriculture intensification that has allowed total production to grow much faster than the cultivated area has grown. Irrigation resources and land quality are cited by some authors (Song et al., 2021; Alaofè et al., 2016) as physical environment factors that influence farmers' choice to adopt diversified crop production. The use of irrigation and soil improvement expands the production area and allows for diversification of production.

3. Materials and Methods

For this research, given the objective of building indicators of agricultural diversification in Brazil and analyzing the diversification factors, it will be necessary to divide the methodology into sub-items. Initially, we present the research database. In the following section, we explain the diversification indices. Finally, we describe the methods used to calculate and analyze farm diversification.

3.1 Database Specification

According to the last Agricultural Census (IBGE, 2017), Brazil has more than 5 million farms. Properties less than 100 ha represent 91% of Brazilian agricultural producers but occupy only 20% of the land. With 1,000 ha or more, large establishments represent 1% of producers but occupy 48% of the total area (IBGE, 2017). This inequality motivates studies encompassing the entire national territory to draw a complete picture of the reality of Brazilian agriculture.

In this sense, the database of the present study covers all municipalities in the Brazilian territory, using data from the last three Agricultural Censuses (1996, 2006, and 2017). Because the number of Brazilian cities has increased over the years, we use the Minimum Comparable Areas (MCA) as units of observation to compare the same geographic area over time, following the methodology proposed by Ehrl (2017). In the present case, 4,296 AMCs were considered, representing the municipalities existing in the 1990s.

In this research, we worked with the diversification of agricultural production, considering the Gross Value Production (GVP) of temporary crops, permanent crops, horticulture, and forestry, and the Gross Value Sold of heads of cattle, pigs, and poultry – according to the Brazilian Institute of Geography and Statistics - totaling 87 products.

The data covers the years 1996, 2006, and 2017 for the Brazilian municipalities. The monetary values were deflated to December 2017, based on the General Price Index - internal availability (IGP-DI) -, prepared by Fundação Getúlio Vargas (FGV). Other variables were obtained from additional secondary data sources. Tables 1 and 2 present a list of variables used in the research, their descriptions, and their respective descriptive statistics.

Table 1: Variables used in the research.

Variable	Description
diversity	Agricultural diversity indices (Simpson, Shannon, and Effective Number)
population	Population Density
wage	Wage (corrected values - 2017)
GDPpc	GDP per capita (corrected values - 2017)
demand	Vector Demand generated by POP, SAL and GDPpc
productivity	Productivity – Gross Value of Agricultural Production (GVP)/Planted Area
landfarm	Farm Land Use (Farm area Municipality/KM2 Municipality)
sizefarm	Average Farm Size (farm area Municipality/number of farms municipality)
female	The proportion of Female Agricultural Workers out of the total number of Agricultural Workers
assistance	The proportion of farms receiving technical assistance
fertilizer	The proportion of farms applying fertilizers and soil correctives
irrigation	The proportion of farms with crop irrigation

The *population*, *wage*, and *GDPpc* variables represent the effects of demand from municipalities. They were grouped into a single variable called *Demand*. The *productivity* variable characterizes the economic performance of agriculture in the cities. The technological characteristics of the municipalities' agriculture are captured by the variables *assistance*, *fertilizer*, and *irrigation*, representing the proportion of farmers in the municipality that make use of technical assistance, fertilizers, and irrigation, respectively. Finally, the variable female illustrates the importance of the female workforce in agriculture. The variables of interest are the effects of the size of the farm (*sizefarm*) and the intensity of agricultural use of land or rurality degree (*landfarm*) in the municipalities on the decision of producers to diversify their production. The explanatory variables chosen followed the literature (Benin et al., 2004; Anwer et al., 2019; Di Falco & Zoupanidou, 2017; Donfouet et al., 2017; Sambuichi et al., 2016, Parré & Chagas, 2022).

Table 2: Descriptive statistics of the data used in the analysis

	PANEL			1996			2006			2017		
Variables	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Simpson value	0.6	0.001	1.0	0.65	0.001	1.0	0.58	0.002	0.9	0.57	0.002	0.9
Shannon value	1.4	0.003	2.8	1.55	0.01	2.8	1.30	0.004	2.5	1.26	0.003	2.6
Effect. Num. value	4.4	1.0	15.7	5.29	1.0	15.7	4.13	1.0	12.0	3.92	1.0	13.4
demand	103.3	5.3	1,722.7	97.5	5.3	1,722.7	92.4	8.0	1,607.7	120.0	11.3	1,532.9

productivity	136.5	0.1	234,422	81.0	0.1	48,771	132.0	0.2	132,937	196.6	0.4	234,422
landfarm	62.9	0.01	100.0	67.1	0.01	100.0	60.8	0.01	100.0	60.8	0.01	100.0
sizefarm	89.3	0.3	4,293.3	103.5	0.3	4,293.3	82.2	0.3	3,023.6	82.1	0.3	2,722.6
female	27.6	0.8	86.8	29.3	1.0	50.2	27.5	0.8	86.8	26.0	1.4	59.7
assistance	29.2	0.04	100.0	29.2	0.04	100.0	30.4	0.04	100.0	28.1	0.1	100.0
fertilizer	45.7	0.05	100.0	49.3	0.05	100.0	39.0	0.05	100.0	48.9	0.2	100.0
irrigation	9.3	0.01	100.0	8.7	0.02	100.0	7.7	0.01	100.0	11.6	0.1	100.0

3.2 Agricultural Diversification Index

This study will use three indicators of agricultural diversity in the Brazilian municipalities, which share the same primary input (proportion of individuals about the total), namely: Simpson index (D), Shannon index (H), and the Effective Number (EN) (Shannon, 1948; Simpson, 1949; Magurran, 1988).

Several authors adopted the Simpson diversity index to analyze agricultural diversity (Sambuichi et al., 2016; Sen et al., 2017; Piedra-Bonilla et al., 2020a; Bellon et al., 2020). According to Magurran (1988), the Simpson index indicates the probability that any two individuals, randomly drawn from an infinitely large community, belong to different species. Still, according to the author, the most abundant species in the sample have a higher weight in the Simpson index, which is less sensitive to species richness compared to other indices. The index assumes the maximum value of 1 when there is only one species (complete dominance) and a value close to zero when there is a high number of species; thus, as the value of the index increases, diversity decreases[1]. For this reason, the Simpson index is generally expressed as its value subtracted from 1, making interpretation more intuitive: the higher the index, the greater the diversity. The index is defined as

$$D = 1 - \sum_{i=1}^{n} p_i^2 \qquad 0 \leq D \leq 1 \qquad (1)$$

where p_i is the proportional value of the *i*-th crop in the total value in a specific geographic location (municipality), and *n* is the total number of agricultural products in the area. It was

[1] According to Magurran (1988) this initial version of the index is given by i=1npi2

considered 87 products (temporary crops, permanent crops, horticulture, forestry, value of heads of cattle, pigs, and poultry).

We adopted the Simpson index in the econometric analysis of the study due to the following factors: a) the D index shows a similarity with the Herfindahl index, widely used in economic concentration literature; b) the index scale ranges from 0 to 1, making the interpretation simple and comparable between regions.

The Shannon diversity index is commonly used in agricultural diversity studies (Donfouet et al., 2017; Monteleone et al., 2018) and is expressed by:

$$H' = -\sum_{i=1}^{n} p_i \ln p_i \qquad H' \geq 0 \qquad (2)$$

where ln is the natural logarithm, and the other variables were already defined.

According to Magurran (1988), the Shannon index presents values between 1.5 and 3.5.

The Effective Number is an indicator of diversity derived from the Shannon index:

$$EN = exp^{H'} \qquad EN \geq 0 \qquad (3)$$

where exp is the exponential function; for example, the Effective Number with a value of 4 indicates that a municipality has approximately 4 types of major crops.

3.3 Empirical Framework

The farmer's choice to adopt productive diversification can be perceived as an investment decision based on the maximization of expected utility (Vroge et al., 2020). We formalize the investment decision of farmers following Vroge et al. (2020) and Wolnni & Anderson (2014) with some minor adjustments to fit the context of our study. The farmer is assumed to adopt agricultural diversification if and only if:

$$E\left[U_i^d\left(\pi_i^d, Tc_i^D, \Delta\pi_i^D\right)\right] > E[U_i^{ND}(\pi_i^{ND})] \qquad (4)$$

with

$$\pi_i^a = p_i^a\left(a_j, S_i\right)q_i^a(S_i, L_i) - C_i^a v_i^a \qquad (5)$$

where U_i^a is utility of farmer i from activity a (D = diversification in activity a, ND = no diversification in activity a), π_i^a is the profit, TC_i^a is the transaction cost of converting from not diversify farming to diversify farming, $\Delta\pi_i^a$ is the increase in profit experienced by farmer i as a result of the chosen activity, p are output prices, q is the production function, S are structural farm characteristics, L are locational factors on the farm, C and v are quantity and prices of inputs used on the farm.

According to Di Falco & Zoupanidou (2017), agricultural production is a process that involves the choice of inputs to obtain a certain level of production. Another critical decision by farmers is which crops they will produce in a given period (harvest) and how much land each. The decision involves a socioeconomic and physical environment analysis, considering farmers and farm characteristics, the available resources and technologies, the crop's demand and prices, government incentives, and the natural production region characteristics (Anwer et al., 2019; Benin et al., 2004; Sen et al., 2017; Culas & Mahendrarajah, 2005; Donfouet et al., 2017; Waha et al., 2018; Davis et al., 2012; Bellon et al., 2020, Parré & Chagas, 2022).

Therefore, in the present study, we estimate a-spatial and spatial data panels for the 4,296 municipalities of Brazil from 1996 to 2017 (3 years Census), totaling 18,888 observations.

Specifically, to verify the determinants of agricultural diversification, the following a-spatial function will be estimated:

$$D_{it} = \alpha + \sum_{k=1}^{K} \beta_k \, x_{it} + \mu_i + \eta_t + \varepsilon_{it} \qquad (6)$$

where the subscript i denotes municipality (i = 1,…, 4,296), the subscript t denotes time periods (t = 1, 2, 3), and k (j = 1,…, K) denotes the K independent variables. D_{it} is the Diversification index in logs, α is the constant term, x_{it} is a vector representing the independent variables in logs, and β_k is a vector of parameters related to each one; ε_{it} is the error term.

The neighborhood may influence some explanatory factors of diversification in a given farm or region. In technical terms, an explanatory variable in one municipality may have an indirect effect, influencing the dependent variable (spatial spillover). In this sense, the spatial models (SLX, SDM, or SDEM) are applied in this study, which incorporates the spatial effects in the explanatory variables (Gibbons & Overman, 2012; Elhorst & Vega, 2015; Jiang et al., 2014, 2018, Vroege et al. 2020; Parré & Chagas, 2022).

Some tests are performed to choose the best specification of the spatial panel data models. Mutl and Pfaffermayr (2011) extend the procedure of the Hausman test for a spatial panel data model in which the random and fixed effects estimators are compared and tested to determine whether the data support the assumption of random effects. If the random-effects hypothesis is not rejected, then the random effects methods must be used. Millo and Piras (2018) developed Lagrange-LM Multiplier tests for deciding whether SAR or SEM better fit the data. The LM tests for choosing between SAR and SEM can be of the standard type or the locally robust type, which has suboptimal statistical properties to ideal conditional tests. These assume that there is no SEM component (SAR) in the data generation process and, when rejected, indicate that these spatial effects are present.

4. Results and Discussion

4.1 Agricultural production diversification in Brazil

Mazzocchi et al. (2020) state that research on agricultural diversification should incorporate time dynamics to verify changes in the diversification process. Figure 1 shows that during the analyzed period, the diversification indexes showed a continuous decrease in values, indicating production concentration. Piedra-Bonilla et al. (2020) also obtained an average value of the Simpson index equal to 0.59 for municipalities in Brazil in 2006. However, these authors did not calculate the indexes for 1996 and 2017. Parré & Chagas (2022) also showed a trend of production concentration from 2002 to 2018 in Brazil, according to Simpson's and Shannon's indices. Figure 1 also shows a decrease in the Effective Number, with a value of 4 in 2017, a value equal to what Aguilar et al. (2015) calculated for the USA.

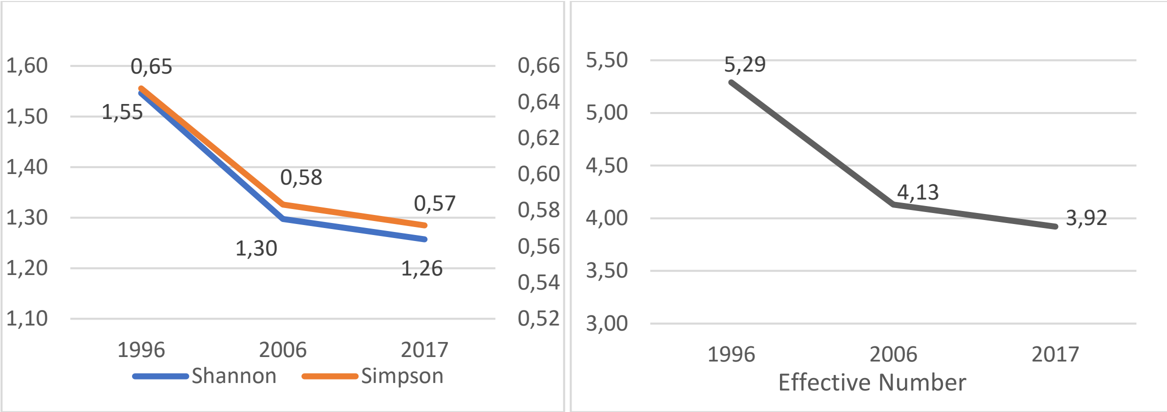
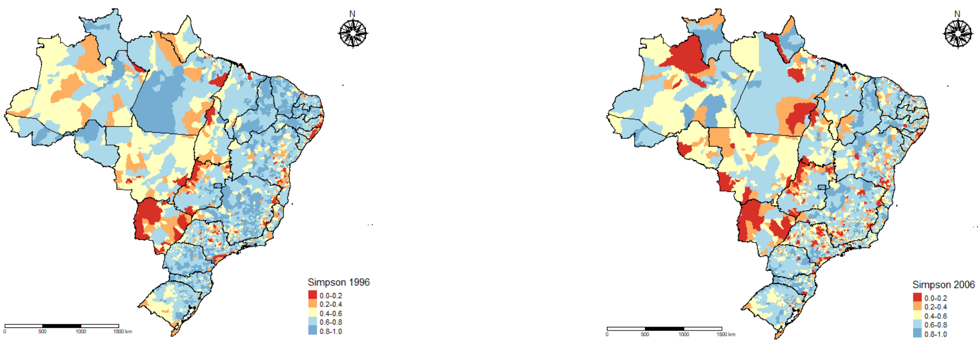


Figure 1 Shannon, Simpson, and Effective Number for Brazilian municipalities.
Source: Research results. Medium values

Figure 2 shows Simpson's index maps for municipalities in Brazil for the years 1996, 2006, and 2017. We prepared the maps using the same diversity classification categories to illustrate the Spatio-temporal dynamics of the index. Considering an average value of 0.6, we can divide the municipalities into two large groups, above and below the average. In 1996, Brazil had 30% of the municipalities below and 70% above this average. In 2017 the values changed to 46% below average and 54% above. This finding demonstrates a balance between municipalities with diversified and concentrated production, with a slight tendency toward local concentration of agricultural production in the country.



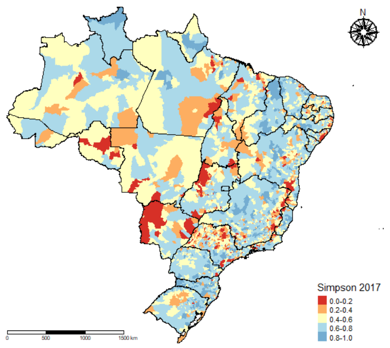
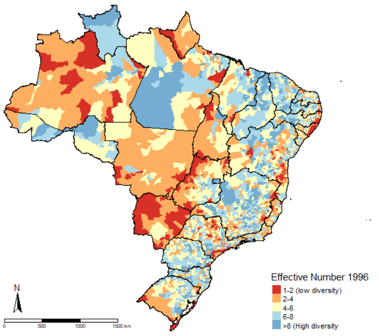
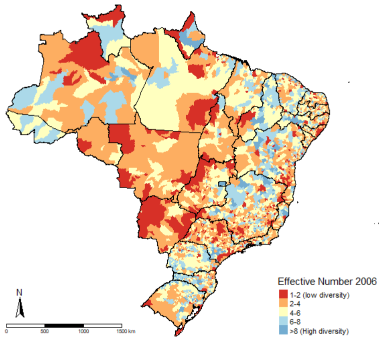


Figure 2: Maps Simpson Index 1996, 2006, and 2017 – Municipalities, Brazil. Source: Research results.

Brazil's results regarding the Effective number at the municipal level are unprecedented. They can be considered essential to this study to understand Brazil's agricultural production evolution. The findings indicate that the process of agricultural diversification has decreased in most municipalities in Brazil. Figure 3 demonstrates this dynamic; in 1996, most municipalities had an Effective Number value between 6 and 8 (blue), which means that there were at least six types of crops in most municipalities; by 2017, most municipalities were in the range of 2 to 4 (orange). Our analysis revealed interesting trends between and within different production regions. These results show that, nationally, the municipalities are grouped in low (Central-West, State of São Paulo) and high diversity (Northeast Region and states of Santa Catarina and Minas Gerais). Parré & Chagas (2022) calculated the Effective Number for states of Brazil and found a decrease in its value of -0.91% per year from 2002 to 2018.

It is possible to compare this result with similar studies for the United States (Aguilar et al., 2015), India (Smith et al., 2019), and China (Lui et al., 2022). While the United States (1978-2012) experienced a reduction in crop diversity and China (1980-2014) experienced an increase in diversity, India (1956-2008) presented a situation of stability in its districts. Brazil's results are like those obtained for the USA (average 4, with a heterogeneous pattern between regions) but lower than those calculated for China (average 7, with an increase in diversity in two-thirds of the municipalities) and India (average 6, with stability). Despite the difference in intensity, all countries show a typical behavior, with changes in agricultural diversification varying between and within regions.





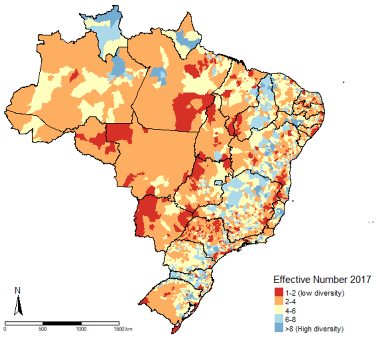
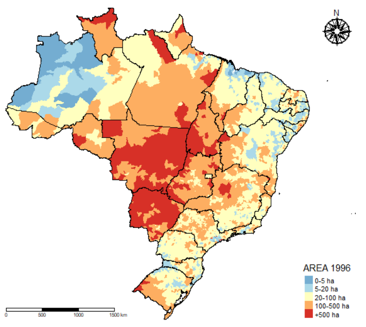


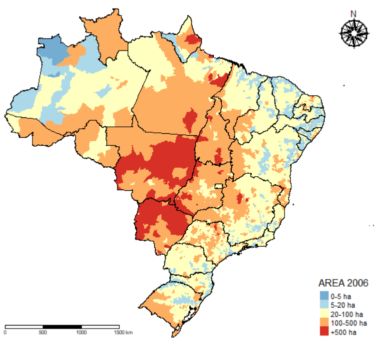
Figure 3: Maps Effective Number 1996, 2006, and 2017 – Municipalities, Brazil. Source: Research results.

The global agricultural land area was 4.8 billion hectares (ha), about 38 percent of the global land surface. Roughly one-third of this is used as cropland (1.6 billion ha in 2019), while the remaining two-thirds consist of permanent meadows and pastures (3.2 billion ha in 2019). Although agricultural land decreased since 2000, it increased on average by 0.1 percent each year over the 1961–2019 period, with a significant expansion up to the 1990s (FAO, 2021). In the Brazilian case, there was a considerable increase in the cropland, from 54.9 million hectares in 2000 to 63.5 million in 2019 (FAO, 2021).

According to Embrapa (2018), land use in Brazil can be divided as follows: Crops and planted forests occupy 9% of the territory; cultivated pastures, 13%; and the native ones, 8%. Permanent Preservation Areas (indigenous lands, conservation units), native vegetation on non-registered lands, and areas on private properties separated according to environmental legislation – such as Legal Reserve and protection areas – represent 66% of the Brazilian territory. Cities and infrastructure occupy the remaining 4 % of the total area.

The average size of farms in Brazil decreased from 103 hectares in 1996 to 82 hectares in 2017 (Table 2). The spatial distribution of this variable showed little change between the years analyzed, with the largest farms (area greater than 500 hectares) located mainly in the states of Mato Grosso and Mato Grosso do Sul (Figure 4).





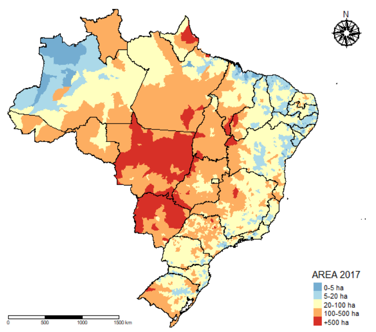


Figure 4: Maps average area (size farm) 1996, 2006, and 2017 – Municipalities, Brazil.
Source: Research results.

Van Vliet et al. (2015) carried out a comprehensive review of the literature on agricultural land use in Europe. They observed that land-use change studies distinguish between the immediate causes of land-use change and the underlying driving forces, where the primary reasons are human activities or immediate actions at a location. In contrast, the underlying driving forces denote the social processes that drive these immediate changes. The systematic review of case studies revealed changes in the expansion and contraction of agricultural land and in land management intensity, landscape elements, agricultural land use activity, and production specialization/diversification. Economic, technological, institutional, and locational factors were frequently identified as underlying factors, while demographic and sociocultural factors were mentioned less regularly (Van Vliet et al., 2015).

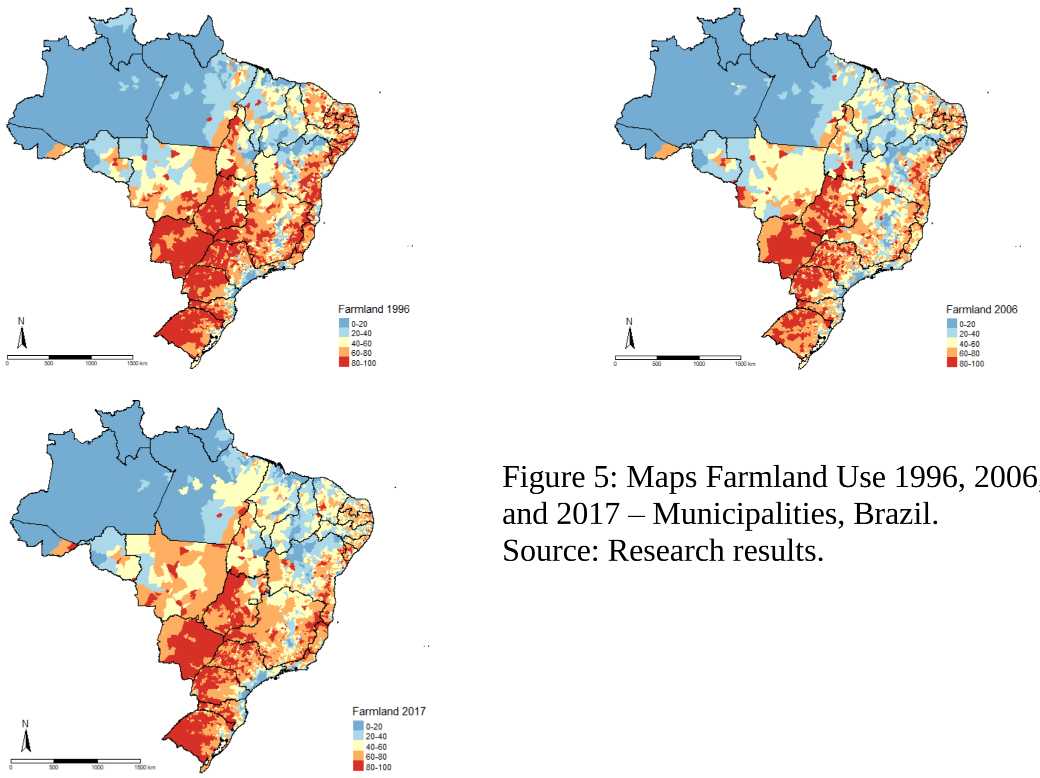


Figure 5: Maps Farmland Use 1996, 2006, and 2017 – Municipalities, Brazil.
Source: Research results.

In the case of Brazil, Figure 5 shows a significant occupation of agriculture in the interior of the country. With an emphasis on the interior of the Southeast and South regions and the entirety of the Midwest region. The Amazon region has a low percentage of land area devoted to agriculture. This panorama remained constant during the period analyzed in the study. However, within the regions, there is a change in land use, with agriculture suffering pressure from urbanization and changes in the regions' infrastructure, mainly in the Southeastern and Southern areas of the country.

4.2 Empirical Results

After checking the Hausman test[2], which indicated the application of the fixed effects model, we employ the Lagrange Multiplier (LM) test to identify whether spatial models are more appropriate than non-spatial models. These tests also allow you to choose between models from the SAR or SEM family (Anselin et al., 1996). The results are exhibited in Table

[2] chisq = 394.78, df = 8, p-value < 2.2e-16

3. The tests indicated that the appropriate model is the SEM family model. The null hypothesis of the non-existence of spatial effects was not rejected for the robust lag test, considering individual and time fixed effects. The last column presents the SLX specification, with the explanatory variables' lags. In this case, the test values in their standard version are statistically not significant, meaning that the residuals have no spatial dependence.

Table 3: Lagrange Multiplier Tests for Spatial Dependence on Panel Data

	Specifications			
Tests	Individual fixed effects	Time-period fixed effects	Individual and Time-period fixed effects	SLX with Individual and Time-period fixed effects
LM test spatial lag	85.411***	6.670***	10.564***	1.304
	(0.000)	(0.000)	(0.001)	(0.253)
LM test spatial error	77.764***	12.471***	14.273***	2.332
	(0.000)	(0.000)	(0.000)	(0.127)
Robust LM test spatial lag	11.519***	4.402**	8.795***	5.126**
	(0.000)	(0.036)	(0.003)	(0.023)
Robust LM test spatial error	3.872**	10.202***	12.469***	6.155**
	(0.049)	(0.001)	(0.000)	(0.013)

Source: Results of research.

Note: Queen Matrix; *Figures in parentheses are the p-value;* *p<0.1, **p<0.05, ***p<0.01

The neighborhood effects are essential for analysis when adopting crop diversification (spatial spillover), as shown in the statistical test. Also, some of the farmers' decisions are strongly influenced by the behavior of agents located in neighboring regions (Vroege et al., 2020; Lapple et al., 2017), which confirms the empirical tests. We analyzed the results of the SDEM and SLX models to verify the determinants of agricultural diversification for the municipalities in Brazil.

As shown inTable 4, the components of the demand vector - population, GDP per capita, and wage - demonstrated a negative global impact on agricultural diversification, as was found in Boncinelli et al. (2018) and Liu et al. (2022). The diversification process becomes a strategy to overcome the disadvantages of locating in isolated areas with low profitability. The results of Liu et al. (2022) pointed out that population density has a negative impact on crop diversity in China, indicating that high population density counties have lower diversity. For the authors, this result is influenced by the fact that China has a large population concentrated in rural areas; therefore, farmers will choose crops to plant according to their knowledge, tradition, and preferences. However, in our study, when spatially lagged variables are incorporated, the effects of local demand spillover are positive on diversity (Table 4), indicating, as Zasada (2011) concluded, that proximity to urban centers can generate consumer demand for a greater variety of local farm products.

The productivity variable had a negative and significant global effect and a non-significant spillover effect. Parré and Chagas (2022) also obtained a negative sign for productivity considering the states of Brazil. They explained that the possible cause is that the variable is calculated based on monetary values, which gives high weight to the agricultural commodity market.

Although some regions present a process of development and urbanization, a large part of the Brazilian territory is used for agricultural activities. Farmland is constantly changing, following different development trajectories. Some livestock areas have been occupied by crops, while livestock has been moved to frontier areas. Table 4 also presents the effect of the variable farmland on diversity, and the positive and significant sign explained by the variable indicates that regions where agriculture is important and dominant present greater diversification of production. However, this variable had no significant spillover effect.

According to Table 4, farm size has the most prominent global direct effect on the diversity of Brazilian agriculture, and this effect is negative. This effect demonstrates the importance of small farms in agriculture in Brazil and their role in economic resilience and food security. These farmers also understand that diversifying their portfolios reduces risk (Pfeifer et al., 2009; Weltin et al., 2017). The local spillover effect in the SDEM model is positive, but with a small coefficient value and significant only at 10%. This result may indicate that large farms are starting a process of diversifying their production, meeting local demand.

The number of people working in agriculture worldwide, including forestry and fishing, fell by 17% in the 2000-2020, reaching 874 million in 2020, or 173 million less than in 2000 (FAO, 2021). In the case of Brazil, the drop was more significant – 26%, from 11.7 million in 2000 to 8.6 million in 2019 (FAO, 2021). According to data from FAO (2021), the shares of women in agricultural employment in Brazil decreased from 22.7% in 2000 to 19.0% in 2019. This decrease also occurred worldwide, with women representing 36.7% of total farm workers in 2019 compared to 38.7% in 2000.

Mazzochi et al. (2020) used the percentage of female farm managers to verify the potential connection between gender and the choice of different agricultural activities in the municipalities of Italy. The results indicated that the percentage of female farm managers did not influence the implementation of agricultural activity diversification.

In the present study, the percentage of female workers in agriculture was used to verify the relationship between labor gender and diversification. The global results are the same as those obtained by Mazzochi et al. (2020), that is, not significant (Table 4). However, when considering the local effects, a negative relationship was observed between the percentage of female workers and farm diversification, contrary to what was expected in the literature (Villamor et al., 2014). This result may be influenced by the low percentage of female workers in Brazilian agriculture, which is only 28% (Table 2).

Table 4 shows that the technical assistance variable had a negative and significant global effect and a non-significant local spillover effect. According to Table 2, on average, only 29% of Brazilian farms receive assistance, and apparently, the guidance received by farmers is not encouraging them to diversify their production. We can also expect municipalities with more diversified agriculture to have little technical assistance coverage. According to Table 4, the fertilizer variable presented a global positive effect on diversity and a non-significant spillover effect. This finding reveals that farmers who adopt diversification have a sophisticated technological level with fertilization and soil correction practices.

Table 4: Spatial panel model for the determinants of agricultural diversity, 1996-2017 (Two-ways)

	SDEM	SLX
lnDEMAND	-0.111***	-0.111***
	(0.022)	(0.027)
lnPRODUCTIVITY	-0.055***	-0.055***
	(0.004)	(0.006)
lnFARMLAND	0.083***	0.083***
	(0.012)	(0.015)
lnSIZEFARM	-0.208***	-0.207***
	(0.012)	(0.015)
lnFEMALE	-0.003	-0.003
	(0.013)	(0.016)
lnASSISTANCE	-0.014**	-0.014**
	(0.005)	(0.007)
lnFERTILIZERS	0.025***	0.025***
	(0.007)	(0.009)
lnIRRIGATION	0.030***	0.030***
	(0.004)	(0.005)
*W*lnDEMAND*	0.131***	0.133***
	(0.042)	(0.051)
*W*lnPRODUCTIVITY*	-0.006	-0.006
	(0.010)	(0.012)
*W*lnFARMLAND*	0.013	0.013
	(0.028)	(0.033)
*W*lnSIZEFARM*	0.047*	0.048
	(0.025)	(0.030)
*W*lnFEMALE*	-0.068**	-0.070*
	(0.030)	(0.036)
*W*lnASSISTANCE*	0.001	0.001
	(0.012)	(0.014)
*W*lnFERTILIZERS*	0.016	0.017
	(0.015)	(0.018)
*W*lnIRRIGATION*	-0.026***	-0.027***
	(0.006)	(0.008)
Spatial lag of error term	0.048**	
	(0.014)	
Observations	12,888 (n = 4,296, T = 3)	12,888
AIC	-1.1521	-1.1524

R^2	0.0437	0.0444
F Statistic		24.91^{***} (16, 8574 df)

Source: Research results.

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

In global terms, irrigation positively affected Brazilian agriculture's diversification (a positive and significant sign). This result is corroborated by previous studies (Song et al., 2021; Alaofè et al., 2016). The authors explain that water availability can expand the cultivated area, allowing a greater diversity of production.

However, irrigation has a negative and significant spillover effect, and the literature also discusses this situation. The findings by Liu et al. (2022) for counties in China revealed that irrigation had negative spillover effects on crop diversity. The authors consider that this small negative impact occurs because irrigation contributes to large areas of farmland that can be specialized, which, in turn, reduces crop diversity.

The regression coefficients from the study by Jong et al. (2021) indicated significantly negative relationships between agricultural production (the proportion of irrigated area and land quality) and crop diversity. The authors justified the results by arguing that improvements in agricultural production conditions, including advances in water resource reliability and improvements in farmland fertility, can reduce crop diversity by contributing to large-scale agricultural operations based on monocropping to maximize labor productivity.

5 Conclusions

This article analyzes the impact of farm size and farmland use on agricultural diversification for Brazilian municipalities using data from the last three Agricultural Censuses (1996, 2006, and 2017), as well as other factors that influence this diversification. Additionally, the spatial spillover effects were incorporated into the explanatory variables.

The results of our research indicate that the diversification indexes showed a continuous decrease, indicating production concentration in the considered period. The findings also demonstrate a tendency towards local concentration of agricultural production in the country, despite the balance in production, meaning that about half of the Brazilian municipalities exhibit diversified production and about half exhibit concentrated production. As far as we know, the results for Brazil concerning the Effective Number at the municipal level are unprecedented and indicate an average value of 4 with a heterogeneous pattern among the regions of the country.

The data indicate that the average size of farms in Brazil decreased from 103 hectares in 1996 to 82 hectares in 2017. In addition, the regression results support our first H1 hypothesis that farm size negatively influences agricultural diversification; the smaller the average farm size, the greater the diversification. The local spillover effect is positive but significant only at 10%, indicating that large farms are starting a process of diversifying their production to meet local demand. This finding contributes to the international literature on agricultural production diversity and to the formulation of public policies encouraging small farms in Brazil.

The research results support hypothesis H2 that farmland use positively influences diversification. Municipalities with a high degree of rurality present greater diversification of production. This effect is observed mainly in traditional Southeast and South agricultural regions.

As for the other variables that determine agricultural diversification, the results for Brazilian municipalities are in line with the specialized literature. The demand vector had a negative global impact; however, the demand spillover effects were positive on diversity, indicating that the proximity to urban centers can generate consumer demand for a greater variety of local farm products. The productivity variable had a negative and significant global effect and a non-significant spillover effect. The percentage of female agricultural workers was utilized to verify the relationship between labor gender and diversification, and global results were non-significant. The technical assistance variable had a negative and significant global effect, influenced by the fact that municipalities with more diversified agriculture have little specialized assistance coverage. Fertilizer and irrigation variables presented a global positive effect on diversity and a non-significant spillover effect. This finding reveals that farmers who adopt diversification have a sophisticated technological level.

The findings of this research can help to understand the role of agricultural diversification in national food security strategies and the factors needed to encourage more diversified production. Future research should focus on improving technical assistance conditions for small farms and integrating diversification and farm management strategies to reduce risks in Brazilian agriculture.

References

Aguilar J., Gramig G.G., Hendrickson J.R., Archer DW, Forcella F., Liebig M.A., 2015. Crop Species Diversity Changes in the United States: 1978–2012. PLoS ONE 10(8): e0136580. doi:10.1371/journal.pone.0136580.

Alaofè, H., Burney, J., Naylor, R., Taren, D. Solar-powered drip irrigation impacts on crops production diversity and dietary diversity in northern Benin. Food and Nutrition Bulletin. 2016. V. 37 (2), 164–175. https://doi.org/10.1177%2F0379572116639710

Anselin, L., Bera, A.K., Florax, R. and Yoon, M.J. (1996) Simple diagnostic tests for spatial dependence. Regional Science and Urban Economics, 26(1), 77-104.

Anwer M.E.; Sahoo, B.K.; Mohapatra, S., 2019. Spatio-temporal variations in agricultural diversification in India: determinants and convergence. Journal of Agribusiness in Developing and Emerging Economies. Vol. 9 No. 5. pp. 476-502.

Bellon, M.R.; Kotu, B.H.; Azzarri, C.; Caracciolo, F., 2020. To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana. World Development, V. 125, https://doi.org/10.1016/j.worlddev.2019.104682.

Benin, S., Smale, M., Gebremedhin, B., Pender, J., Ehui, S., 2004. The economic determinants of cereal crop diversity on farms in the Ethiopian highlands. Agricultural Economics, v. 31, n. 2-3, p. 197-208.

Boncinelli, F., Bartolini, F., Casini, L. Structural Factors of Labour Allocation for Farm Diversification Activities. 2018. Land Use Policy 71:204–12. https://doi.org/10.1016/j.landusepol.2017.11.058

Bowman, M.S., Zilberman, D., 2013. Economic factors affecting diversified farming systems. Ecol. Soc. 18 (1), 33.

Chavas, Jean-Paul; Di Falco, Salvatore, 2012. On the productive value of crop biodiversity: evidence from the highlands of Ethiopia. Land Economics, v. 88, n. 1, p. 58-74.

Culas, R.; Mahendrarajah, M., 2005. Causes of Diversification in Agriculture Over Time: Evidence From Norwegian Farming Sector. EAAE 2005 ed. Copenhagen, Denmark: European Association of Agricultural Economists.

Davis, A.S., Hill, J.D., Chase, C.A., Johanns, A.M., Liebman, M., 2012. Increasing cropping system diversity balances productivity, profitability and environmental health. PLoS One 7 (10): e47149. doi:10.1371/journal.pone.0047149

de Roest, K.; Ferrari, P.; Knickel, K., 2017. Specialisation and economies of scale or diversification and economies of scope? Assessing different agricultural development pathways. Journal of Rural Studies, v. 59, p. 222-231.

Di Bene, C.; Francaviglia, R.; Farina, R.; Alvaro-Fuentes, J.; Zornoza, R. Agricultural Diversification. *Agriculture* **2022**, *12*, 369. https://doi.org/10.3390/agriculture12030369

DiFalco, S.; Mintewab, B.; Yesuf, M. Seeds for livelihood: Crop Biodiversity and Food Production in Ethiopia. Ecol. Econ. 2010, 69, 1695–1702.

Di Falco, S.; Chavas, J.P., 2008. Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. Land Economics, v. 84, n. 1, p. 83-96.

Di Falco, S.; Bezabih, M.; Yesuf, M., 2010. Seeds for livelihood: crop biodiversity and food production in Ethiopia. Ecological Economics, v. 69, n. 8, p. 1695-1702.

Di Falco, S., Zoupanidou, E., 2017. Soil fertility, crop biodiversity, and farmers' revenues: Evidence from Italy. Ambio 46, 162–172 . https://doi.org/10.1007/s13280-016-0812-7

Donfouet, H. P. P.; Barczak, A.; Détang-Dessendre, C.; Maigné, E., 2017. Crop production and crop diversity in France: a spatial analysis. Ecological Economics, v. 134, p. 29-39.

Ehrl, P. 2017. Minimum Comparable Areas for the period 1872-2010: an aggregation of Brazilian municipalities. Estudos Econômicos (São Paulo). 47. 215-229.

Elhorst, J. P., & Vega, S. H. (2015). The SLX model. Journal of Regional Science, 55(3), 339-363.

Embrapa (Empresa Brasileira De Pesquisa Agropecuária). Visão 2030: o futuro da agricultura brasileira. 2018., p. 212.

FAO. Crop diversification for sustainable diets and nutrition: The role of FAO's Plant Production and Protection Division, Technical report. Rome: Plant Production and Protection Division, Food and Agriculture Organization of the United Nations. 2012 https://www.fao.org/ag/agp/greenercities/pdf/CDSDN.pdf

FAO. "Transforming Food and Agriculture to Achieve the SDGs: 20 Interconnected Actions to Guide Decision-Makers." Technical Reference Document. 2018. https://www.fao.org/3/I9900EN/i9900en.pdf

FAO. World Food and Agriculture - Statistical Yearbook 2021. Rome. https://doi.org/10.4060/cb4477en

Galli, F.; Grando, S.; Adamsone-Fiskovica, A.; Bjørkhaug, H.; Czekaj, M.; Duckett, D.G.; Almaas, H.; Karanikolas, P.; Moreno-Pérez, O.M.; Ortiz-Miranda, D.; et al. How do small farms contribute to food and nutrition security? Linking European small farms, strategies and out comes in territorial food systems. Glob. Food Secur. 2020. https://doi.org/10.1016/j.gfs.2020.100427

García-Arias, A., Vázquez-González, I., Sineiro-García, F., Pérez-Fra, M. Farm diversification strategies in Northwestern Spain: factors affecting transitional pathways. Land Use Policy, 2015, 49, 413–425. https://doi.org/10.1016/j.landusepol.2015.08.011

Gibbons, S., & Overman, H. G. (2012). Mostly pointless spatial econometrics? Journal of regional Science, 52(2), 172-191.

Guarín, A., Rivera, M., Pinto-Correia,T., Guiomar, N., Šūmane, S., Moreno-Pérez, O. A new typology of small farms in Europe, Global Food Security, v. 26, 2020, https://doi.org/10.1016/j.gfs.2020.100389

Gurr, G.M., Lu. Z., Zheng. X., Xu. H., Zhu, P., Chen, G., Yao, X., Cheng, J., Zhu, Z., Catindig, J.L., Villareal, S., Chien, H.V., Cuong, L.Q., Channoo, C., Chengwattana, N., Lan, L.P., Hai, L.H., Chaiwong, J., Nicol, H.I., Perovic, D.J., Wratten, S.W., Heong, K.L., 2016. Multi-country evidence that crop diversification promotes ecological intensification of agriculture. Nature Plants, v. 2, n. 3. Doi: 10.1038/nplants.2016.14

IBGE - Instituto Brasileiro de Geografia e Estatística. 2020. *População residente estimada*. Accessed December 2021, available at: https://sidra.ibge.gov.br/tabela/6579

IBGE - Instituto Brasileiro de Geografia e Estatística. 2020. *Pesquisa Agrícola Municipal*. Accessed September 2021, available at: https://sidra.ibge.gov.br/pesquisa/pam/tabelas

IBGE - Instituto Brasileiro de Geografia e Estatística. 2020. Produto Interno Bruto. Accessed December 2021, available at: https://sidra.ibge.gov.br/tabela/5938.

Isbell, C., Tobin, D., Reynolds, T. Motivations for maintaining crop diversity: Evidence from Vermont's seed systems, Ecological Economics, v. 189, 2021, https://doi.org/10.1016/j.ecolecon.2021.107138

Jiang, L., Folmer, H., & Ji, M. (2014). The drivers of energy intensity in China: A spatial panel data approach. China Economic Review, 31, 351-360.

Jiang, L., Folmer, H., Ji, M., Zhou, P., 2018. Revisiting cross-province energy intensity convergence in China: A spatial panel analysis. Energy Policy, Vol. 121, 252-263.

Joo, H., Khanal, A., Mishra, A. Farmers' Participation in Agritourism: Does It Affect the Bottom Line? Agricultural and Resource Economics Review. 2013. 42(3), 471-490. https://doi.org/10.1017/S1068280500004949

Kurdy´s-Kujawska, A.; Strzelecka, A.; Zawadzka, D. The Impact of Crop Diversification on the Economic Efficiency of Small Farms in Poland. Agriculture 2021, 11, 250. https://doi.org/10.3390/agriculture11030250

Lapple, D., Holloway, G., Lacombe, D.J., O'Donoghue, C., 2017. Sustainable technology adoption: a spatial analysis of the Irish Dairy Sector. Eur. Rev. Agric. Econ. 44, 810–835. https://doi.org/10.1093/erae/jbx015.

Liu Z., Tang G., Zhou Y., Sun J., Wu W., Yang P. Why can China maintain a high crop diversity? A spatial-temporal dynamic analysis. *Progress in Physical Geography: Earth and Environment*. 2022;46(2):217-231. doi:10.1177/03091333211055850

Magurran, A. E., 1988. Ecological Diversity and its Measurement. Princeton, NJ: Princeton University Press. 179p.

Maggio, G., Sitko, N. & Ignaciuk, A. 2018. Cropping system diversification in Eastern and Southern Africa: Identifying policy options to enhance productivity and build resilience. FAO Agricultural Development Economics Working Paper 18-05. 2018. Licence: CC BY-NC-SA 3.0 IGO. https://www.fao.org/3/CA1562EN/CA1562EN.pdf

Mazzocchi, C.; Orsi, L.; Ferrazzi, G.; Corsi, S. The Dimensions of Agricultural Diversification: A Spatial Analysis of Itali Municipalities. Rural Sociol. 2020, 85, 316–345. https://doi.org/10.1111/ruso.12291

Millo, G.; Pirras, G., 2018. Econometric Models for Spatial Panel Data. Available at: <https://cran.r-project.org/web/packages/splm/splm.pdf>.

Monteleone, M.; Cammerino, A.R,B.; Libutti, A., 2018. Agricultural "greening" and cropland diversification trends: Potential contribution of agroenergy crops in Capitanata (South Italy). Land Use Policy, v. 70, 591–600. doi.org/10.1016/j.landusepol.2017.10.038

Mutl J., Pfaffermayr M. The Hausman Test in a Cliff and Ord Panel Model." Econometrics Journal, 2011. 14, 48-76.

Mzyece, A.; Ng'ombe, J.N. Does Crop Diversification Involve a Trade-Off Between Technical Efficiency and Income Stability for Rural Farmers? Evidence from Zambia. *Agronomy* 2020, *10*, 1875. https://doi.org/10.3390/agronomy10121875

Parré, J.L., Chagas, A.L.S. Determinants of agricultural diversification in Brazil: a spatial econometric analysis. Lett Spat Resour Sci 2022. https://doi.org/10.1007/s12076-021-00295-0

Pesaran, M. H., 2004. General diagnostic tests for cross section dependence in panels. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=572504.

Piedra-Bonilla, E. B.; Cunha, D. A.; Braga, M. J., 2020. Climate variability and crop diversification in Brazil: An ordered probit analysis. Journal of Cleaner Production, v. 256, 120252, https://doi.org/10.1016/j.jclepro.2020.120252.

Pfeifer, C.; Jongeneel, R.; Sonneveld, M.; Stoorvogel, J. Landscape properties as drivers for farm diversification: A Dutch case study, Land Use Policy, v. 26, Issue 4, 2009, https://doi.org/10.1016/j.landusepol.2009.01.007

Ponce, C. Intra-seasonal climate variability and crop diversification strategies in the Peruvian Andes: A word of caution on the sustainability of adaptation to climate change, World Development, v. 127, 2020. https://doi.org/10.1016/j.worlddev.2019.104740

Sambuichi, R. H. R., Galindo, E.P., Pereira, R.M., Constantino, M., Rabetti, M.D.S., 2016. Diversidade da Produção nos Estabelecimentos da Agricultura Familiar no Brasil: uma análise econométrica baseada no cadastro da Declaração de Aptidão ao Pronaf (DAP). Texto para Discussão, v. 50, n. TD 2202.

Sen, B.; Venkatesh, P.; Jha, G.K.; Singh, D.R.; Suresh, A., 2017. Agricultural Diversification and its Impact on Farm Income: A Case Study of Bihar. Agricultural Economics Research Review. Vol. 30, 77-88. doi: 10.5958/0974-0279.2017.00023.4

Simpson, Edward H., 1949. Measurement of diversity. nature, v. 163, n. 4148, p. 688.

Shannon, Claude. E., 1948. A Mathematical Theory of Communication. The Bell System Technical Journal, Vol. 27, 379–423, 623–656, July, October. http://people.math.harvard.edu/~ctm/home/text/others/shannon/entropy/entropy.pdf

Smith J.C., Ghosh A., Hijmans, R.J. Agricultural intensification was associated with crop diversification in India (1947-2014). PLoS ONE. 2019. 14(12).https://doi.org/10.1371/journal.pone.0225555

Song, X.; Wang, X.; Li, X.; Zhang, W.; Scheffran, J. Policy-oriented versus market-induced: Factors influencing crop diversity across China. Ecological Economics. 2021. v 190. https://doi.org/10.1016/j.ecolecon.2021.107184

Van Vliet, J., de Groot, H.L.F., Rietveld, P., Verburg, P.H. Manifestations and underlying drivers of agricultural land use change in Europe, Landscape and Urban Planning, V 133, 2015, p. 24-36. https://doi.org/10.1016/j.landurbplan.2014.09.001

van Zonneveld, M., Turmel, M.S., Hellin, J. Decision-Making to Diversify Farm Systems for Climate Change Adaptation. Front. Sustain. 2020 Food Syst. 4:32. https://doi.org/10.3389/fsufs.2020.00032

Villamor, G., van Noordwijk, M., Djanibekov, U., Chiong-Javier, M.E., Catacutan, D. Gender differences in land-use decisions: shaping multifunctional landscapes? Current Opinion in Environmental Sustainability, V 6, P 128-133, 2014, https://doi.org/10.1016/j.cosust.2013.11.015.

Vroege, W., Meraner, M., Polman, N., Storm, H., Heijman, W., Finger, R., 2020. Beyond the single farm – A spatial econometric analysis of spill-overs in farm diversification in the Netherlands. Land Use Policy, 99. https://doi.org/10.1016/j.landusepol.2020.105019

Waha, K., van Wijk, M.T., Fritz, S., See, L., Thornton, P.K., Wichern, J., Herrero, M., 2018. Agricultural diversification as an important strategy for achieving food security in Africa. Global Change Biology, v. 24, n. 8, 3390-3400. https://doi.org/10.1111/gcb.14158

Wollni, M., Andersson, C. Spatial patterns of organic agriculture adoption: Evidence from Honduras, Ecological Economics, v. 97, 2014, https://doi.org/10.1016/j.ecolecon.2013.11.010

Yuheng Li, Hans Westlund, Yansui Liu, Why some rural areas decline while some others not: An overview of rural evolution in the world, Journal of Rural Studies, Volume 68, 2019, Pages 135-143, https://doi.org/10.1016/j.jrurstud.2019.03.003

Zasada, I. Multifunctional Peri-Urban Agriculture—A Review of Societal Demands and the Provision of Goods and Services by Farming. 2011. Land Use Policy 28(4):639–48. https://doi.org/10.1016/j.landusepol.2011.01.008