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ESTIMADOR DE DENSIDADE KERNEL NO MAPEAMENTO DA PRODUÇÃO AGRÍCOLA NA MESORREGIÃO OESTE DO PARANÁ-BRASIL

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ABSTRACT

This work aimed to analyze the density of agricultural production located in the West Mesoregion of Paraná-Brazil from 2018 to 2020 using maps generated by the Kernel Density Estimator. The municipalities with the largest agricultural production are of interest in this research, since they provide raw materials for the agro-industry and cooperatives. The scenario under study explains the participation of municipalities that develop activities in the agricultural and livestock context and that propel the regional economy and the growth of the state of Paraná-Brazil. The municipality of Assis Chateaubriand presented itself close to the municipalities with the highest productions. The kernel map contributes to the self-explanatory analysis by allowing the mapping of the concentration of productions in the municipalities. The result suggests that the impacts of municipalities with large agricultural production and livestock, justify the initiatives that seek investment in infrastructure, which promote the growth of the agribusiness sector. The results also suggest that researchers and agribusiness managers apply the methodology for studies of current indicators, aiming for economic benefits. The spatial patterns that impact agriculture and livestock at local, regional, national and global levels can be applied to increase knowledge about the production chain. In the West of Paraná, agricultural and livestock production has enabled the generation of revenues for the municipalities. This study supports the identification of priority regions of agricultural production with practices of economic, social and environmental sustainability, aiming at integrated systems of agricultural production for the food supply.

Keywords: Agribusiness. Production concentration. Agricultural runoff. Producing regions.

RESUMO

Este trabalho teve como objetivo analisar a densidade da produção agrícola localizada na Mesorregião Oeste do Paraná-Brasil, no período de 2018 a 2020, por meio de mapas gerados pelo *Kernel Density Estimator*. Os municípios com maior produção agrícola são de interesse desta pesquisa, pois fornecem matéria-prima para a agroindústria e cooperativas. O cenário em estudo explicita a participação de municípios que desenvolvem atividades no contexto agrícola e pecuária e que impulsionam a economia regional e o crescimento do estado do Paraná-Brasil. O município de Assis Chateaubriand apresentou-se próximo aos municípios com maiores produções. O *kernel map* contribui para a análise autoexplicativa ao permitir o mapeamento da concentração das produções nos municípios. O resultado sugere que os impactos de municípios com grande produção agrícola e pecuária, justificam as iniciativas que buscam investimento em infraestrutura, que promovam o crescimento do setor do agronegócio. Os resultados também sugerem que pesquisadores e gestores do agronegócio apliquem a metodologia para estudos de indicadores atuais, visando benefícios econômicos. Os padrões espaciais que impactam a agricultura e a pecuária em níveis local, regional, nacional e global podem ser aplicados para aumentar o conhecimento sobre a cadeia produtiva. No Oeste do Paraná, a produção agropecuária tem possibilitado a geração de receitas para os municípios. Este estudo subsidia a identificação de regiões prioritárias de produção agrícola com práticas de sustentabilidade econômica, social e ambiental, visando sistemas integrados de produção agrícola para o abastecimento de alimentos.

Palavras-chave: Agronegócio. Concentração da produção. Escoamento agrícola. Regiões de produção.

INTRODUCTION

The agribusiness sector is a fundamental element in the development of the Brazilian economic system, given its significant participation in several economic indicators, including the Gross Domestic Product, thus demonstrating its importance and relevance in growth and development considering social and environmental aspects.

In this context, the study is justified by the fact of analyzing and mapping locations with a higher concentration of planting and agricultural production, and it shows the influence of these regions on the results of the agribusiness production chain that covers the West Mesoregion of the state of Paraná-Brazil and their reflexes to Brazil and the world. Considering that, global and synchronic connectivity, through interdisciplinary information, is a reality experienced in the agro-industrial production chains as well as in the integrated production logistics and its distribution channels.

Therefore, recent studies justify the importance of this study for possible decision-making in the agricultural scenario, aiming at the economic growth of local, regional, national and global scope. Therefore, the study aimed to map and demonstrate the impact that agricultural and livestock production has on the economic growth of the West of Paraná (Cima et al., 2022; Cima et al., 2024).

LITERATURE REVIEW

This topic presents the theoretical bases necessary for adherence to and understanding of this study. The west region of Paraná-Brazil has a large-scale production chain. The productive potential is a wealth for society, promoting the generation of employment the integration of other sectors aimed at food production, environmental, economic and social sustainability.

The agricultural and livestock sector is present in all the economic activities that support a country, whether in the Gross Domestic Product, in the revenues, in the propulsion of other segments that depend on agribusiness to remain in the market, which is increasingly competitive. The presence of these segments, such as the provision of service, suppliers of inputs and raw materials, focusing on global sourcing, are necessary for the market advances of Paraná-Brazil in a global context.

In this sense, the advances in the information and communication technologies connected with the livestock and agricultural sectors, which have attracted the expressive attention of the agro-industrial and economic sectors due to their impact on transforming and improving sustainable practices, environmentally correct and safe involving agricultural activities (Novotna, 2023).

Agricultural and livestock production systems are characterized by many variables that represent their agricultural practices, production, climatic and economic conditions, and all these variables influence their consequences in economic and environmental terms (Gaugler et al., 2020).

The technological advances as well as emerging technologies are part of the events that make up the history of humanity. Digital technologies among all other emerging technologies contribute to advances in knowledge science. This trend as well as new advances are guiding elements for the development of society and the economy (Marcial and Pio, 2023).

In this work, digital technology was fundamental to identify, understand and visualize the spatializations of agricultural productions and their locations where their presence occurs in greater concentration, as well as systematize the results of the spatial distribution of these productions in a precise and coherent way in the west region of the State of Paraná-Brazil. The production flow in the region is a relevant aspect for the agribusiness and it is dependent on the highways and railways such as the one administered by Ferroeste.

The west region of Paraná is recognized as an agriculture that stands out for soil fertility. It is also considered as an example of high grain productivity, the strength of the sector, creates opportunities for the growth of different agribusiness chains, integrating producers, suppliers and customers. The climate and the partnership among producers, cooperatives and cerealists that strengthen the agro-industrial production chain (Lopes, et al., 2024). The climate and the partnership among producers, cooperatives, and cerealists that strengthen the agro-industrial production chain contribute to the development of agriculture and livestock (Lopes, et al., 2024).

Important sectors such as livestock and agriculture are essentials for the supply of food. In addition, this sector plays a substantial role on the world economy. Climatic adversities cause significant impacts on the production of these sectors around the world. Therefore, diagnoses of sustainable agricultural mappings are becoming increasingly important in view of population growth and their demands (Ahmad et al., 2022).

The *Kernel* density estimator is considered a non-parametric method and has been researched for a long time and there is a very vast literature dealing with the subject (Karczewski and Michalski, 2022). It consists of a probabilistic estimator of the intensity of the non-parametric point process through the Kernel function. The inputs for application are the occurrences of the variable in the area, and through a coordinate system, this function performs a count of all points within a region of influence, weighing them by the distance of each to the location of interest (Câmara and Carvalho, 2004).

The use of the Kernel Density Estimator is interesting, because it provides a view of the spatial distribution of the points, making it possible to investigate the punctual intensity of the agricultural productions of the west region of Paraná-Brazil. Thus, it will be possible to draw an overview of the scenario of the west region of Paraná, in addition to estimating the typology of

agricultural products, which are most, explored in the region and comparing the results among municipalities with large production.

For this reason, the Kernel density estimate offers an economic approach by acting as an efficient instrument in mapping agricultural productions on a local, regional, state and world scale, highlighting the areas of concentration of the greatest productions and contributing to the management of agribusiness (Luotamo et al., 2022).

The objective of this study was to make a diagnosis of agricultural production, namely pigs, poultry, milk, soybean, and corn, and with this to investigate large producing regions within this delimitation for the period, from 2018 to 2020. Thus, understand in which municipalities in the west region of Paraná the concentration of these productions is higher, quantifying, analyzing and specializing through the Kernel density estimator.

STRATEGIC VISION FOR REGIONAL DEVELOPMENT OF THE AGRICULTURAL SECTOR

The agricultural and livestock sectors have been performing significantly in recent years. This sector has contributed to several segments of the economy and to the regional development of the state of Paraná and Brazil. The performance of agri-food production drives the primary sector, which includes rural producers, farmers and ranchers; the secondary sector, which includes the processing industry; and the tertiary sector, which includes service providers. The engagement of these sectors promotes regional development, revenue generation and, consequently, economic growth and development (NEVES, 2008).

In this context of analysis, Orsatto et al. (2023) report that with the process of modernization of agriculture, the western region of Paraná has been standing out in the quantity of soybeans and corn produced, as well as in other forms of agricultural activity. In addition, they report that municipalities that invest in the industrialization of agricultural products tend to increase their levels of development in relation to others.

For this study, a strategic vision of the municipalities with large productions is provided, contributing to the science and to the rural producers, promoting the growth and development of the agribusiness sector.

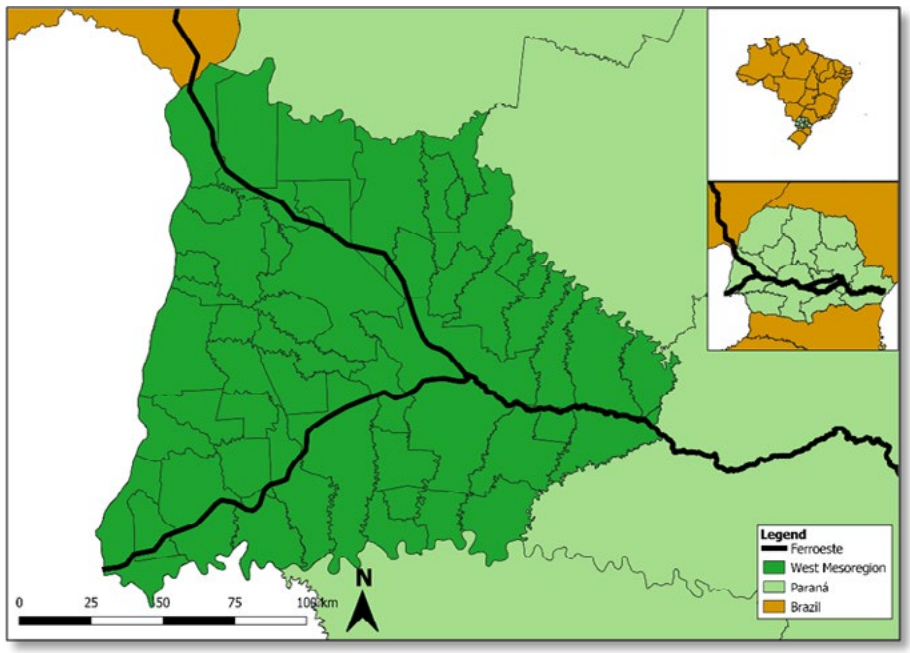
Therefore, it is possible to estimate areas of greater intensity of production occurrence. In order to achieve this aim, an analysis was carried out from a database available by IPARDES-PR, together with the Kernel density estimator, aiming to corroborate diagnoses regarding the use and occupation of the soil. Finally, the QGIS software and the R software was used for the processing of the data obtained and the combination of the results in thematic maps, for possible decision-making in the public and private sectors of the economic and agribusiness.

This work is divided into three parts. First, it was described how the performance of the visualization resources was used. In the second part, it was determined that the focus of interest was on mapping the agricultural production of large producer municipalities and finally identifying the concentration of agglomeration of the largest productions through the radius of influence of spatial distribution.

MATERIAL AND METHOD

The study aimed to analyze the influence of the livestock and agriculture sectors, in the productivity chain municipalities in the West Mesoregion of the state of Paraná-Brazil that make up 50 municipalities (Figure 1). Initially, a literature review was carried out based on scientific studies already published and documents from government agencies of the state of Paraná-Brazil that support research and development initiatives of public policies. The research is descriptive and quantitative in nature. The data were made available by the Paranaense Institute for Economic and Social Development (IPARDES, 2021) and collected in space and time from 2018 to 2020. The information was available by municipality with geolocated characteristics, for the West Mesoregion of Paraná. These pieces of information were important because they defined a representation of the municipalities analyzed, considering economic and productive aspects. Thus the variables analyzed were: pig production (quantity per head), poultry production (quantity per head), milk production (thousand/liters), soybean production (ton) and corn production (ton).

Figure 1 | Delimitation of the Area of Study



Source: own research

The intention to study the west region of the Paraná state was based on its agro-industrial production chains as well as its strategic geolocation, which favors the flow of agricultural production and its derivatives to the large centers of commercialization, distribution and consumption.

The criterion of choice of the largest producers of agricultural and livestock production was based on the local Moran index (I_i), which varies from -1 to 1, according to Moran methodology (Moran, 1950). This index allows get the autocorrelation using the locations of the features and the values (Anselin and Arribas-Bel, 2013; Koshiyama, et al., 2011) .

The Kernel density estimator can be understood as the technique applied to analyze the behavior of point patterns, which estimates the punctual intensity of the process throughout the study region. In the *Kernel* density function estimation method for a random variable U with observations in $u_1, u_2, \dots, u_n$ locations, the $f(u)$ density function e can be estimated (Wand and Jones, 1995) by:

$$\hat{f}(u) = \frac{1}{n\lambda}\sum_{i=1}^{n} K\left(\frac{u-u_i}{\lambda}\right), \quad (1)$$

where, λ it is the radius that is a smoothing parameter called *bandwidth,* within which $u_1, u_2, \ldots, u_n$ observations are obtained, n is the number of observations, *and* K(·) is the kernel function, which has several forms presented in both Wand and Jones (1995). In this work, the quartitic function was used, which gives greater weights to the locations of the nearest municipalities, and can be expressed by:

$$K\left(\frac{u-u_i}{\lambda}\right) = \frac{15}{16}\left(1-\frac{u-u_i}{\lambda}^2\right)^2, \quad (2)$$

being, $\left|\frac{u-u_i}{\lambda}\right| \leq 1$.

In the study, was used an estimated of the univariate kernel density. An analysis was necessary to elaborate a diagnosis of the agricultural productions existing in the 50 municipalities of the West Mesoregion of Paraná. The geotechnologies was used with the software QGIS Team Developer (2024) and R Development Team, (2024) made it possible to identify the largest producer municipalities.

The database was acquired from the Paranaense Institute of Economic and Social Development. To determine the mean distance, standard deviation, minimum and maximum distance of each of the points, the algorithm called Distance Matrix (Rizzatti et al., 2020) of QGIS 3.36.0 was used. For the determination of mean and mean of standard deviation of distances, the *shapefile* data was exported to the electronic spreadsheet format. In the spreadsheet was calculated the mean of the mean distance and the mean of the standard deviation of the production distances.

The radius of λ influence was estimated from the subtraction and addition of the mean distance($\overline{U}$) of each point with the mean of the standard deviation ($\overline{U}\sigma$) in order to approximate an adequate value to the points, according to equation 3.

$$\lambda = \overline{U} \pm \overline{U}\sigma, \quad (3)$$

where, $\overline{U}$: general mean distance of means $\overline{U}\sigma$; mean of standard deviation of distances. The radius of influence obtained from equation 3 that best represented the data set of this study was the lowest value, being $\hat{\lambda} = 46$ km due to the fact that it does not generate discontinuity or oversoftening of the classes. The point vector layer related to the productions was imported in QGIS

3.36.0 software (QGIS Team Developer, 2024) with the csv type (separated by commas), and the *shapefile is* designed in the SIRGAS 2000 reference coordinate system (EPSG: 5880) Brazil Polyconics. The function used was quartic *Kernel*. This function weighted the points observed within the circular search radius, so that the points closest to the site to be estimated receive greater weight (Wand and Jones, 1995).

In QGIS 3.36.0, the heat map algorithm called Kernel Density Estimation (Kinney, 1993) was used. With the kernel density raster generated, which was established at the number of five classes, it is understood as ideal for mapping agricultural production. The natural breaks of Jenks were used because they represent the natural scaling of the data series, grouping them concerning similarity (Mesquita et al., 2022). The range in each class was calculated by means of the Jenks method in the free software R in version 4.3.3.

The criterion of choice of the largest agricultural producers was carried out through the Moran Local Index *(LISA*), this technique of spatial statistics of area allows to perform clusters of the High-High type (H-H), that is regions with high agricultural production, surrounded by neighbors also with high agricultural production. These indexes provide the identification of areas with statistically significant spatial dependence (Moran, 1948). *Kerne*l density maps were generated, also known as heat map, classified by Jenks method with relative densities (Rizzatti et al., 2020), using color scale, divided into five classes being blue, light blue and blue water representing low values, and the red and orange colors high heat density values for pig, poultry, milk, soybean and corn production.

ANALYSIS AND DISCUSSION OF RESULTS

Table 1 presents the descriptive statistics of the mean distances of the municipalities with the highest agricultural production from 2018 to 2020 in the West Mesoregion of Paraná-Brazil. The variables under study are production of pigs, poultry, milk, soybean and corn. The analysis included these variables, which are the main components of regional agricultural and livestock activity. In the study period, the number of municipalities with the largest productions of each variable was indicated by n*. The coefficient of variation (CV) indicates an average variability for the variable pigs, high for the variables poultry and milk and very high for soybean and corn (Pimentel Gomes, 2002).

Table 1 | Descriptive statistics of the means of the distances, in km, of the locations

Variable	n*	Min	Q1	Q2	Mean	Q3	Max	SD	CV
Pig	7	34.223	36.817	39.218	41.000	46.423	49.967	5.654	13.790
Poultry	6	35.842	35.927	40.528	46.020	56.112	72.676	14.149	30.745
Milk	6	43.010	43.112	48.633	55.224	67.334	87.211	16.979	30.746
Soybean	8	50.803	57.625	61.585	70.696	69.766	138.977	28.239	39.944
Corn	8	48.835	53.767	60.890	68.403	72.588	127.304	25.275	36.950

Note: n*: number of municipalities with largest producing, Min: minimum value, Q1: first quartile, Q2: second quartile, Med: Mean, Q3: third quartile, Max: maximum value, SD: standard deviation, CV: coefficient of variation.

Source: Own calculations

Table 1 shows the minimum distance values of agricultural production, a relevant aspect is in the production of pigs and poultry production that presented the minimum distance values of the locations being 34.223 km and 35.842 km respectively. This scenario shows that both pig and poultry producers are seeking to install nearby production units which contributes to the production flow. Whereas soybean and corn production showed maximum values of distances of the locations namely: 138.977 km and 127.304 km respectively. This allows to highlight the importance of a runoff project, such as rail, to optimize the displacement of these productions.

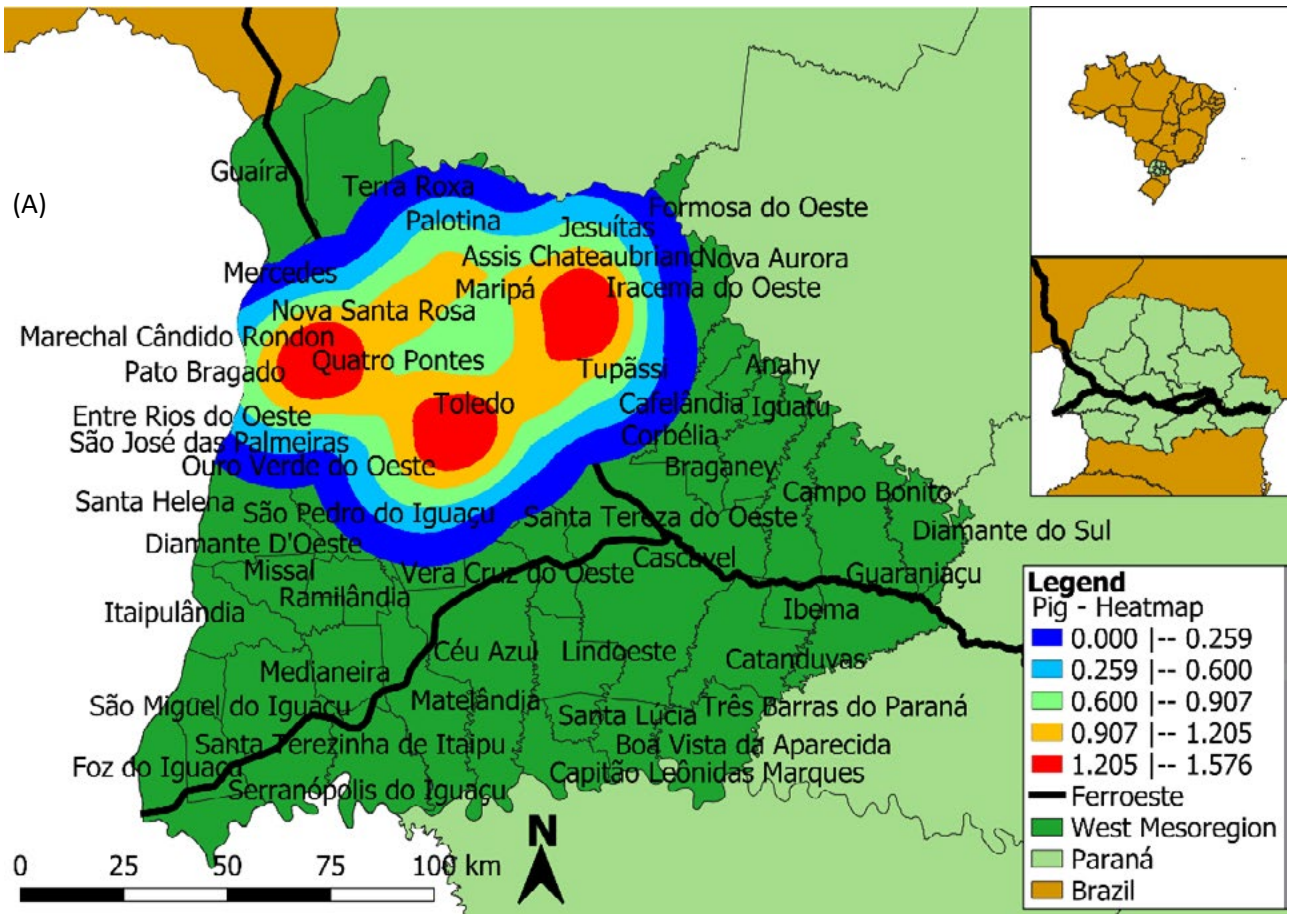
Figures 2 – 4 show that the highest density of production of pigs, poultry, milk, soybean and corn are located in the municipalities of Maripá, Toledo, Assis Chateaubriand, Corbélia, Nova Aurora, Jesuítas, Tupãssi, Ouro Verde do Oeste, Marechal Cândido do Rondon, Quatro Pontes, Anay, Vera Cruz do Oeste and Cascavel. In these regions are predominant agricultural and livestock activity with the presence of high-tech rural properties that make use of precision agriculture (Figure 2). In this sense, Zhao et al. (2019) report that Kernel density estimate is an efficient technique for mapping agricultural data.

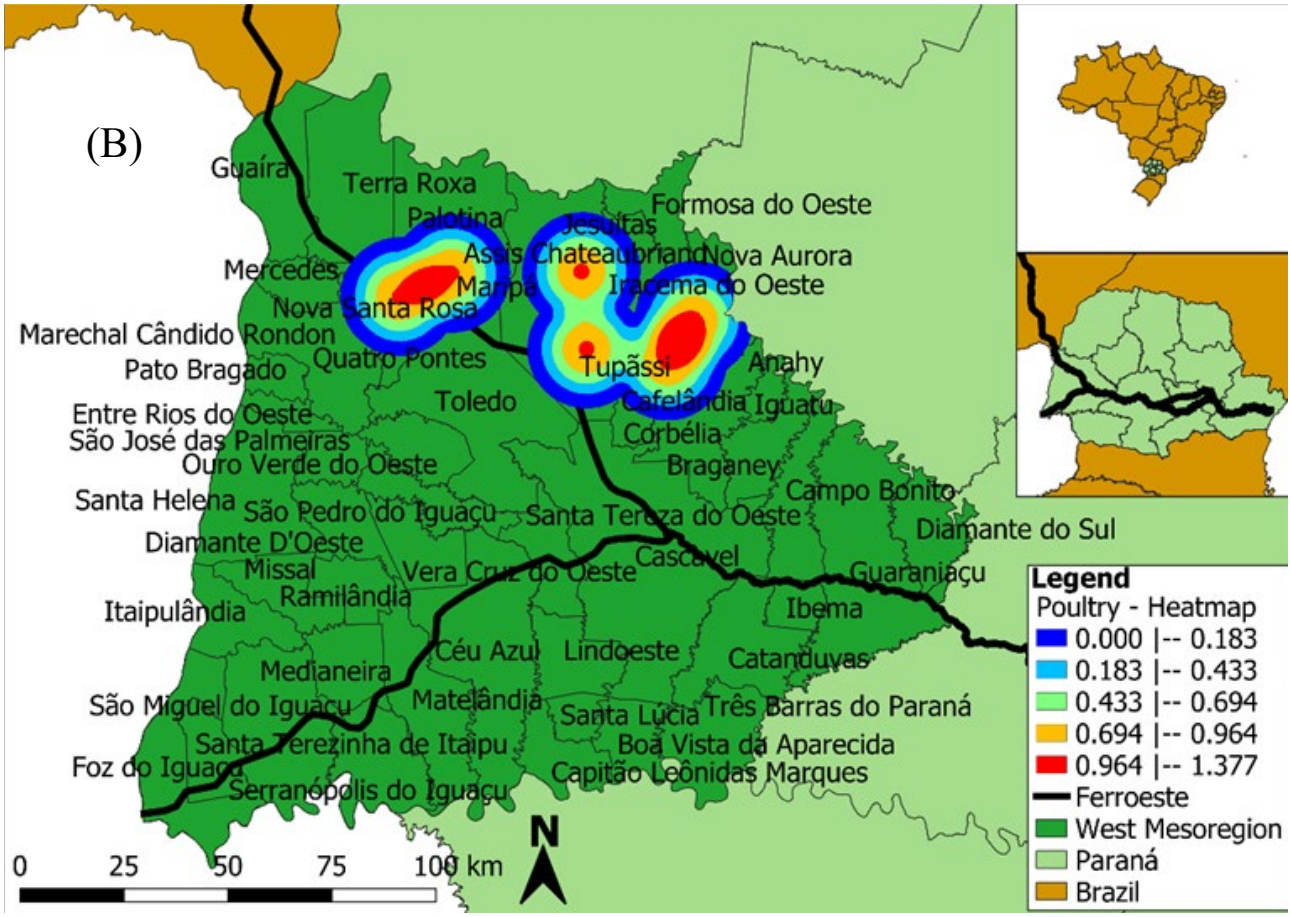
It is possible to highlight in Figure 2(A) that the municipality of Toledo, Assis Chateaubriand, Ouro Verde do Oeste, Marechal Cândido do Rondon, Jesuítas and Tupãssi presented higher concentrations, with kernel density values in class 4 between 0.907 and 1.205, represented in orange color, and in class 5 with values between 1.205 and 1.576 represented with red color for pig production, forming clusters. This shows where the incidence of pig production is more accentuated,

thus showing the strong presence of rural producers acting in this activity, the result shows that the west region of Paraná is considered one of the largest pig producers in Brazil, increasing its scope and interest of the major world exporters, such as the European Union and Asia.

Figure 2(B) shows that the highest intensities of poultry production were located in the municipalities of Assis Chateaubriand, Nova Aurora, Jesuítas and Tupãssi with values in class 4 between 0.694 and 0.964, represented in orange color, and in class 5 with values from 0.964 to 1.377. The behavior is justified due to the location of the agro-industry, which is closed to these municipalities, with pig producers and cooperatives operating in the poultry sector.

Figure 2 | Kernel density estimate map for the largest municipalities producing pig (A) and poultry (B) in the west region of Paraná-Brazil



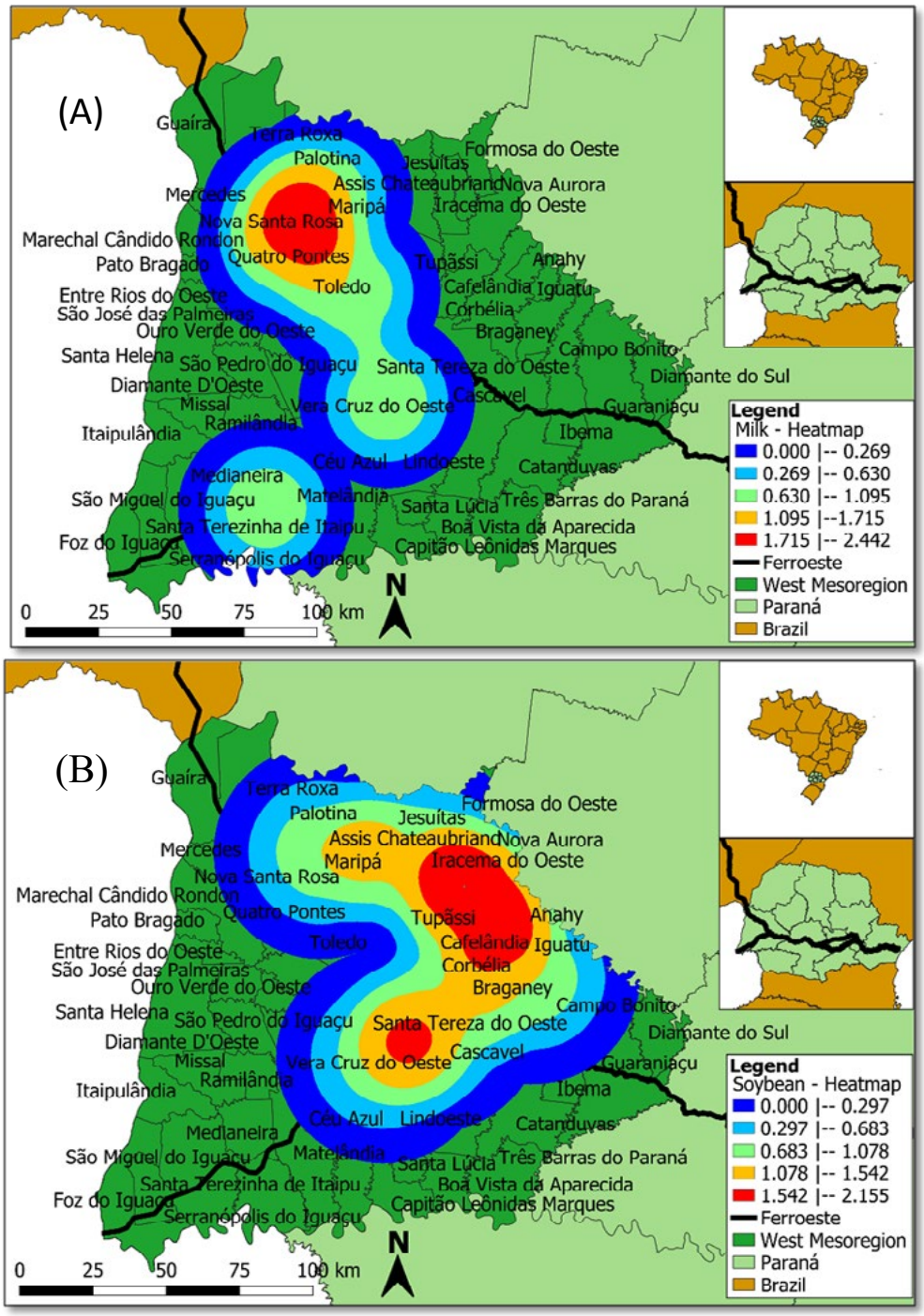


Source: own research

By the Kernel heat map for milk production, in Figure 3(A) it is visible that the highest production concentrations were found in the municipality of Quatro Pontes and Assis Chateaubriand, class 4 with values between 1.095 and 1.715 and in class 5 with values from 1.715 to 2.442, represented by orange and red, respectively. The municipalities in these locations propel the dairy region of the State of Paraná, providing the generation of employment and income for rural milk producers and service providers that operate in this sector.

In Figure 3(B), the Kernel heat map showed that the influence rays of the largest soybean producers were located in the municipalities of Corbélia, Nova Aurora, Iracema do Oeste, Anay, Vera Cruz do Oeste and Cascavel being the highest values in classes 4 with values of 1.078 and 1.542, orange color, and in class 5 with values between 1.542 and 2.155 in red.

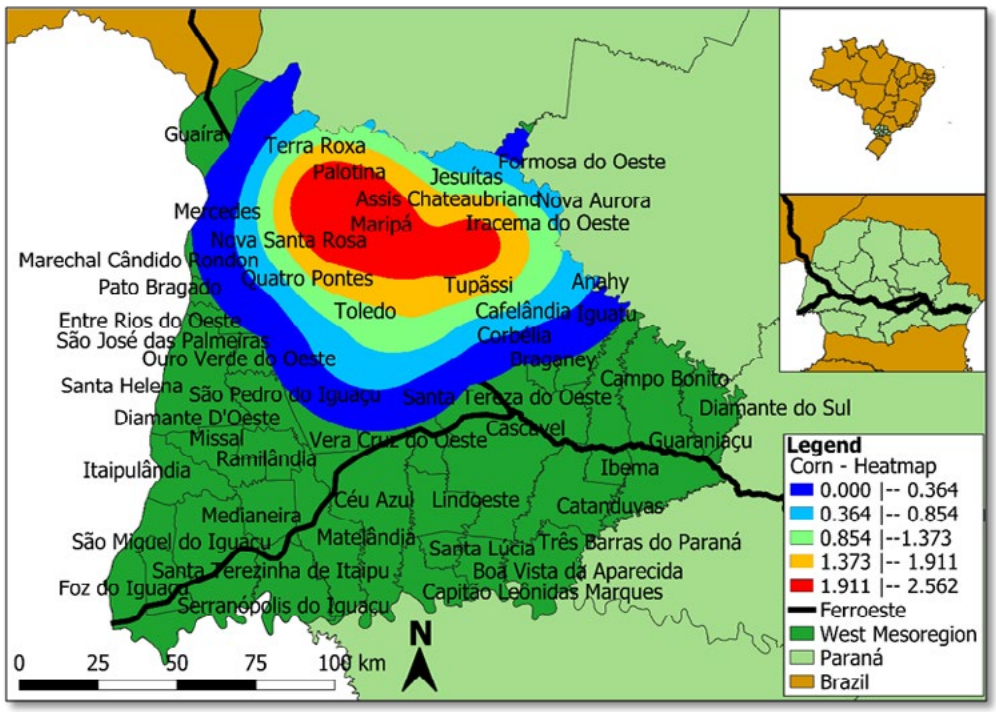
Figure 3 | Kernel density estimate map for the largest municipalities producing Mil (A) and Soybean (B) in the west region of Paraná-Brazil



Source: own research

For the heat map of corn production, it is possible to identify in Figure 4, which municipalities of Maripá, Toledo, and Assis Chateaubriand have values in class 5 of 1.911 and 2.562, in red. The corn production presents a behavior with expressive density, close to Maripá, and it is justified due to the presence of cooperatives and cerealists in the regions. These agro-industry chains is connected and integrated with the rural properties to contribute to inclusivity and sustainability.

Figure 4 | Kernel density estimate map for the largest municipalities producing Corn in the west region of Paraná-Brazil



Source: own research

Figure 3(B) shows a pattern similar to Figure 4, practically observing a high density of corn production in the same municipalities that have large concentrations of soybean production. The scenario presented in Figures 1 to 4 reflects the great vocation of agricultural production in the West Mesoregion of Paraná, thus boosting the different segments of markets that benefit from the agribusiness sector, favoring the generation of employment and development of the municipalities.

Similar studies were conducted in China according to Ji et al. (2022), in which the authors report that the Kernel density estimator is a useful technique for analyzing agricultural data,

considering the non-parametric approach.

Whereas, in Italy, Sophia et al. (2023) report that geotechnologies applied to agricultural data are important to identify possible problems in land use and occupation and suggest possible alternatives to minimize impacts on arable areas.

In this sense, the findings in this study highlight the importance of using Kernel density estimator in agricultural production data, as a way of adapting new methodologies that seek to reveal the relationship between the attributes of agricultural production with the strategic vision of growth and economic development of the regions under analysis. This approach corroborates the studies developed by Ščurková and Marčanová (2023) that deal with the use of strategic methodologies for economic and agricultural analysis.

CONCLUSION

The results showed that the municipalities that presented the highest agricultural production are well distributed in the West Mesoregion of Paraná, and the highest concentrations of production are located in the municipalities of Maripá, Toledo, Assis Chateaubriand Corbélia, Nova Aurora, Jesuítas and Tupãssi, supplying raw material and serving as a subsidiary to the processing agroindustry.

Higher production intensities were also identified in the municipalities of Ouro Verde do Oeste, Marechal Cândido do Rondon, Quatro Pontes, Anay, Vera Cruz and Cascavel. The other municipalities presented a low concentration of the productions. This can be explained by the strong presence of trade, industry, and children's clothing industry, as is the case in Terra Roxa, and industries that operate in other segments, such as the provision of services.

Through the *Kernel* density estimator, it was possible to analyze the behavior of agricultural and livestock productions, thus generating quantitative information about the regionalization of the productions in the studied period.

Therefore, the Kernel density estimator can be used as a systematic and periodic monitoring resource for the regions that presented higher concentrations of agricultural production. The effective monitoring of these regions makes it possible to outline the profile of the impacts that

these productions generate in municipalities in terms of economic and growth aspects. One of the benefits of using the kernel map for agricultural monitoring is the aid of visual analysis, which is a tool for quick analysis and serve as a basis for decision-making.

The study revealed that the great challenge was to understand, assimilate and adapt the database according to the methodologies used. The results found do not exhaust the subject, and new scientific academic research is necessary to understand the complexity that involves spatial analysis of the areas.

Therefore, studies of this nature favor the economic system as a whole and are suggestive of analysis in the decision-making of managers, whether in public or private institutions, thus contributing to the growth and development of the economy and promoting the dissemination of knowledge in the scientific community, economic sector, and agro-industrial sector.

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