Influence Of Pesticide Use On Agricultural Production In The Years 2006 And 2017 In Paraná

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ABSTRACT
Driven by the Green Revolution, the use of pesticides in Brazil has increased dramatically, transforming the rural complex into an agro-industrial complex, generating large-scale production of monocultures and strengthening agribusiness production chains. Despite the economic benefits, the intense use of pesticides leads to concerns, including a lack of training, technical difficulties and environmental and social vulnerabilities. The study focuses on analyzing the impact of these pesticides on production in the state of Paraná by comparing the census years between 2006 and 2017 and investigates the spatial dynamics of agricultural production using the Moran's I test. The results highlight the influence of neighboring communities on agricultural production values and highlight regional interdependence. The model underlines the importance of sustainable regional planning and highlights spatial lag as a key factor in promoting regional cooperation. Hence, expenditure was positive both in the local effect and for the effect caused in the neighborhoods. Still, the pesticide use variable itself became ambiguous for analyzing production due to its problems.

KEYWORDS: Pesticides, Spatial Dynamics, Sustainable Regional Planning, Agricultural Production.

ABBREVIATIONS: VBP: Gross Value of Production; SEAB: Secretary Of Agriculture And Supply.

1. INTRODUCTION

The use of pesticides in agricultural production in Brazil has significantly increased since the Green Revolution, a systematic event of adopting technological innovations in production that began in the second half of the 20th century.

The intensification of the technological model with intensive capital use in production, particularly in the chemical, mechanical, and biological realms, has led to a significant increase in the mass production of monocultures, resulting in a profound dependence on industrialized products and enhancing the inter-sectoral connections of agribusiness production chains [1]. In this context, rural complexes are becoming agro-industrial complexes that increasingly require favorable conditions for large-scale production, and consequently, Brazil's consumption of pesticides, agricultural pesticides, agrochemicals, agricultural defensives, or phytosanitary products [2] is rising.

As pointed out by Hybner [3], the agricultural production of the South region is one of the most important in Brazil, especially in the grain sector. In 2017, the agro-productive complex of the South totaled a VBP of R$133.09 billion, while the Paraná economy accounted for R$85.31 billion, approximately 64.1% of the total.

According to SEAB [4], the average annual growth of the VBP from 2008 to 2017 was 2.5%, while the overall real growth during this period was 28%, with agribusiness representing about 80% of the total VBP of the state. It is also noteworthy that summer grain production, such as soybeans, corn, beans, and rice, significantly contributes to the formation of Paraná's VBP, reaching 34% (with soybeans alone accounting for 24% of the 34% or 70% of the total) in 2017. This indicates that Paraná is among the top three agribusiness producers in Brazil, alongside Mato Grosso and São Paulo.

From an economic standpoint, Soares [5] states that the use of pesticides is based on three main points: increasing crop production, enhancing product quality, and reducing labor and energy costs. However, the intensive use of pesticides in countries with predominantly agricultural production characteristics overlooks certain needs and structural characteristics necessary for production, such as inadequate training for new workers, difficulties in implementing new technologies, and vulnerabilities in environmental and social protection, leading to certain “invisible” costs, or externalities.

As Lopes and Albuquerque [6] indicate, despite the significant productive development and improvement in cultivation conditions and agribusiness production practices, the increased application of pesticides does not necessarily translate into increased production. Even if fully passed through and leads to an optimal productive increase, it can also result in various impacts, such as generating multiple types of externalities, particularly in environmental and food safety.

For this reason, this work aims to analyze and discuss the behavior of agricultural production in Paraná with the introduction of pesticide use in the region, comparing the census years of 2006 and 2017. The study considers that the application of pesticides in a region can influence both the production of the city itself and that of neighboring municipalities while also considering that this application can impact the health of workers and consumers in that region, especially when regulation and oversight are not properly enforced [7].

Thus, the main objective of the work is to analyze how the behavior of pesticide use can influence the production of that region as a whole, considering both the city itself and its surroundings. With increased production, there is a tendency for pesticide use to rise, along with the quantity of pesticides, their residues, and the externalities they cause in the lives of the population.

2. LITERATURE REVIEW

2.1 DEFINITION AND USE OF PESTICIDES IN PARANÁ

The use of pesticides as a means of controlling pests and diseases affecting cultivated crops has drastically increased since the Green Revolution, and with it, the very definition and regulation of this use have also evolved.

Until the end of the 1990s, pesticides were associated with any chemical products applied in agricultural production until Law No. 7.802 was created on July 11, 1989, which established all necessary provisions and conditions for organizing the use of these products. In 2002, Decree No. 4074 was created, regulating the previous law, defining pesticides as:

> "IV - pesticides and related products - products and agents of physical, chemical or biological processes, intended for use in the production sectors, in the storage and processing of agricultural products, in pastures, in the protection of forests, both native and planted, and other ecosystems, and in urban, water and industrial environments, aimed at altering the composition of flora or fauna, to preserve them from the harmful actions of living beings considered harmful, as well as substances and products used as defoliants, desiccants, stimulators, and growth inhibitors..." (Brazil, 2002)

Pesticides can be used both in production and in the storage and improvement of marketed agricultural products, increasing productivity rates; however, the characteristics of intensive and non-intensive pesticide producers are not homogeneous. The application of these products is usually associated with the production of crops, especially temporary ones. This also correlates with the receipt of technical guidance from pesticide-intensive properties, where the receipt rate is approximately 40%, while non-intensive properties have nearly half this value, around 18.4%. This factor is further compounded by the education level of intensive producers, which is typically higher than that of non-intensive producers. Additionally, the provision of credit and funding from social programs and irrigated areas also influences the use of these products, with pesticide-intensive farms having greater funding and nearly double the irrigated area. Furthermore, it is noted that areas adopting technological innovations, such as the use of pesticides, typically have more than double the VBP of others, indicating an increase in productivity [8].

In summary, the results found by Reyna *et al*. [8] indicate that the efficiency of intensive farms in pesticide use is 17.5% higher than that of non-intensive farms, on average; this means that the distinct characteristics of producers using pesticides directly influence the technical efficiency of production, not only altering the final production outcome but also contributing to the explanation of different practices/production itself.

Pólippo [9] and Schneiders [10] present an overview of pesticide use in the state of Paraná based on official data from the Paraná Agricultural Defense Agency, indicating that the state's climate, with greater frequency of rains and favorable planting temperatures, along with much of its so-called "terra roxa," or technically basalt-derived soils, which are formed through the decomposition of basaltic rocks, having a good structure, high mineral content, and is fertile, has high agricultural production potential in crops while also being more prone to pests, fungi, bacteria, and weeds. It is in this sense that there is a higher propensity for pesticide application.

In this context, agricultural production in Paraná has been increasingly growing, with its VBP in Agriculture representing approximately 50%. This can be seen in Graph 1, which shows the total VBP in billions of reais, along with the participation of this VBP by area.

In this scenario, it is essential to understand the quantity of pesticides marketed in Paraná, which has been growing each year, as shown in Graph 2.[1]

Furthermore, when observing the behavior of the agricultural VBP of the state, particularly focusing on agricultural production and noting the amount of pesticides used in crops, it is also important to consider the distribution of this quantity across mesoregions (Table 1).

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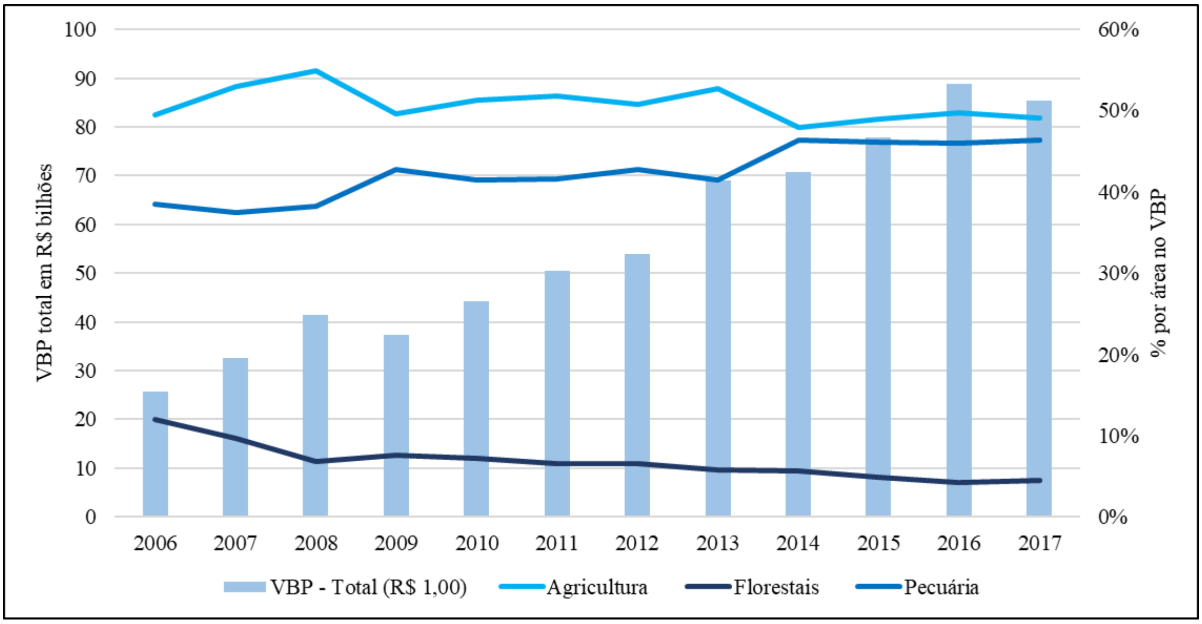
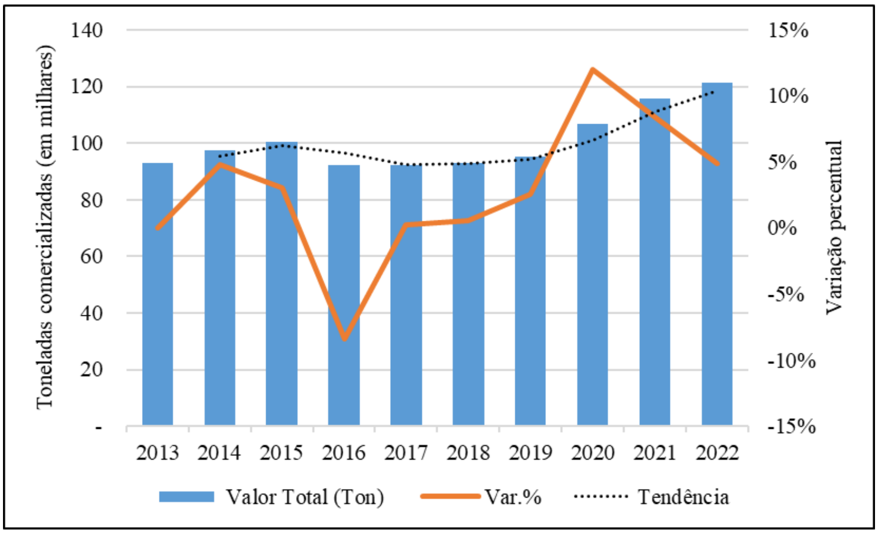
[1] Since 2019, with the occurrence of the Covid-19 Pandemic, the cost of some assets has increased significantly, especially those most used in Brazil, causing the composition of these assets in total to decrease overall, which is observed in the change in the composition of the portfolio of the "Top 10" most used assets, with the decrease in the use (in total participation) of Glyphosate, for example, while some new assets appear in this composition since that year, such as Potassium Salt, Clethodim, Glufosinate, Diquat and Lambda Cyhalothrin.

Graph 1: Total VBP and by Area in Paraná from 2006 to 2017.



Source: Elaborated by the authors based on IPARDES data.

Graph 2: Quantity and Variation of Pesticides Marketed in Paraná from 2013 to 2022.



Source: Elaborated by the authors based on SEAB data.

As can be observed in Table 1, there is a concentration of the number of pesticides marketed in the year 2017 by mesoregion, with only four mesoregions representing 57.1% of the total, mainly concentrated in the region highlighted in red in Figure 1, which presents the number of pesticides marketed in 2017 by the cities in the state, organized by mesoregions, highlighting the four largest: Centro Ocidental, Norte Central, Oeste, and Sudoeste, according to information from the State of Paraná's Pesticide Commerce and Use Control System, under the responsibility of Paraná Agricultural Defense Agency.

Analyzing the composition of this marketed quantity by culture, classification, and use of active ingredients, based on SEAB data for the year 2017, it can be observed that there is also concentration in its use by culture, with four crops (all grains) accounting for 83.32% of the total: Soybeans (52.27%), Corn (18.35%), Wheat (8.03%), and Genetically Modified Soybeans (4.67%); this structure has remained stable for almost all years since 2013. Regarding classification, there is also concentration, as herbicides, fungicides, and insecticides account for 80% of the market, with the first consistently maintaining its position, while the second and third may vary by year, a trend that follows the global tendency. For 2017, the representation was as follows: 60.58%, 12.12%, and 10.96%, respectively. Finally, analyzing the organization of active ingredient participation, despite there being over 200 active ingredients, the top ten accounted for 54.52% of the total in 2017, a percentage that has remained stable over the years. In this year, the relation of active ingredients was: Glyphosate

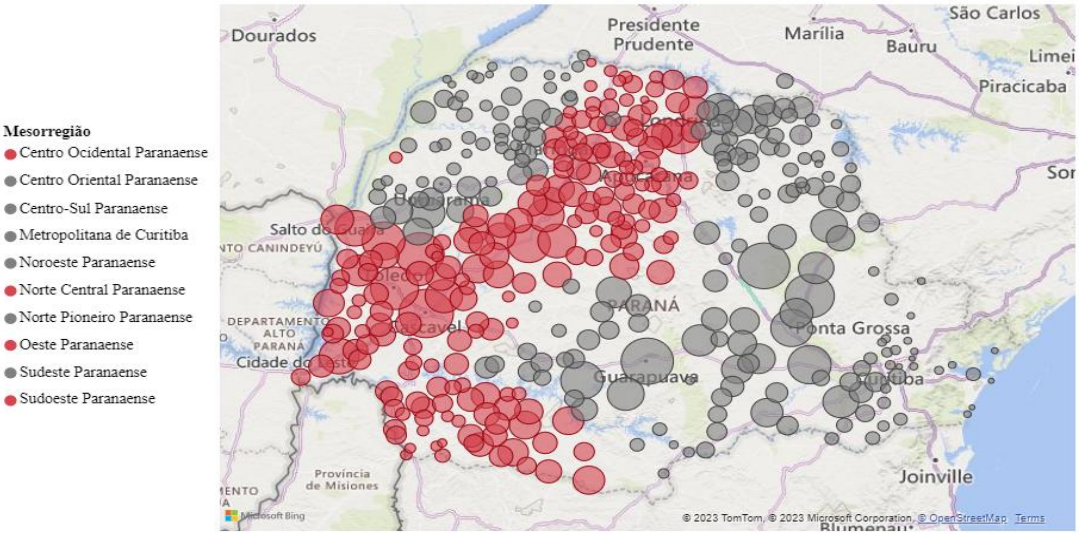
Acid Equivalent (13.96%), Paraquat (7.43%), Potassium Glyphosate (6.93%), Glyphosate (6.92%), Atrazine (5.02%), 2,4-D (3.35%), Mineral Oil (3.2%), Mancozeb (2.68%), Acephate (2.53%), and Imidacloprid (2.5%).

Table 1: Quantity of Pesticides Marketed by Paraná Mesoregion in 2017.

Mesorregião	Toneladas	Percentual
Oeste Paranaense	18.409,67	19,9%
Norte Central Paranaense	14.710,38	15,9%
Centro Ocidental Paranaense	10.471,53	11,3%
Sudoeste Paranaense	9.243,23	10,0%
Centro Oriental Paranaense	9.143,28	9,9%
Norte Pioneiro Paranaense	7.670,51	8,3%
Centro-Sul Paranaense	7.512,60	8,1%
Noroeste Paranaense	7.365,75	8,0%
Sudeste Paranaense	5.314,56	5,8%
Metropolitana de Curitiba	2.556,48	2,8%
Total	92.398,00	100,0%

Source: Elaborated by the authors based on SEAB data.

Figure 1: Map of Quantity Marketed (tons) of Pesticides in 2017 by Cities in Paraná.



Source: Elaborated by the authors based on SEAB data.

2.2 ENVIRONMENTAL IMPACTS OF PESTICIDE USE

Environmental concerns regarding agriculture are historical, particularly when it comes to issues such as deforestation and global warming. However, following the Green Revolution, a new necessity and concern arose regarding the contamination of the environment by the application of pesticides, primarily caused by inadequate dosage application [11].

In general, four types of environmental impacts from pesticide use can be identified: contamination of water and soil, volatility, and reactions in non-target organisms.

According to Carneiro *et al*. [12], contamination of soil and groundwater is the most likely to occur, as the application of pesticides is directly related to the plant, and the actions of rain and irrigation can wash the leaves and direct part of the products applied into the water, which is then filtered by the soil and can later enter the subsequent watercourses. The consequences of this contamination lead to residues in food and water pollution, with one-third of the food consumed by Brazilians being contaminated by pesticides [13]. The authors also point out that the average contamination level from samples in Brazilian states is primarily found in the following crops: bell pepper (91.8%), strawberry (63.4%), cucumber (57.4%), lettuce (54.2%), carrot (49.6%), pineapple (32.8%), beetroot (32.6%), and papaya (30.4%).

According to Santos [14], understanding the physicochemical properties of pesticides, structure, and molecular mass is essential to controlling their behavior in the soil, with water solubility parameters indicating the tendency of the compound to be carried by surface water or leaching. He concludes that for the Paraná III basin, there is a high risk of contamination of surface and groundwater.

Contaminations by volatility relate to distant sprays, typically done by agricultural planes or spray machines, but can also be done by drones and tractors. When applying the active ingredient, part of it dissipates into the air and can be carried to other regions by the wind, increasing the concentration applied in other areas and increasing the pressure on the local ecosystem. Reactions in non-target organisms concern populations that are not the target of the application of the active ingredients but still suffer from its application; the two main affected agents are bees and humans [15].

Soares [5] presents an estimate of the social cost of acute poisonings caused by pesticide use in Paraná, utilizing data from the summer harvest of 1998/99 by crop type. The author reports that 7.64% of properties had at least one case of poisoning, with 77.8% of these cases involving treatment by a doctor or hospital. He also indicates that the crop with the highest proportion of poisoning was cotton, followed by corn, soybeans, and cassava. Notably, these include the crops that produce the most in the state. Furthermore, he shows that considering medium and long-term scenarios in a model where pesticide poisoning is endogenous, the use of highly toxic active ingredients can increase the chance of poisoning by 58%, and increasing pesticide consumption by 100 kg raises the chances of poisoning by 7%. An important point is the presence of a professional agronomist as a protective factor, which can reduce the chances of poisoning by up to 42% (given that better application control generates fewer residues). On the other hand, the author compares the cost of acute poisoning in establishments with similar characteristics, showing that costs could vary for the state of Paraná, on average, between U$89,542 and 10,478, depending on the level of safety and planning for pesticide application, potentially reducing costs by up to 86% if well-organized. Furthermore, the author indicates that the social cost of acute poisoning could reach around 85% of the benefits of using insecticides and herbicides in the long term; however, if preventive measures were taken during this period, the gains would be considerable, about 6.5 times greater.

It is interesting to note that larger establishments with greater production tend to have a lower proportion of poisoning, as they proportionally employ fewer workers and also engage in more organized, planned planting under the guidance of professionals and agronomists, indicating the need for state guidance and support, especially for family farmers.

2.3 EXPOSURE TO PESTICIDES AND HEALTH EFFECTS

Despite being a very important input for agricultural production and not only being used in agriculture but also in forests and other ecosystems, pesticides generate externalities and adverse problems, primarily for public health, if not applied correctly within the legally established quantities, potentially causing poisonings.

Klaassen [16] highlights that the toxicological and harmful effects of pesticide use can manifest in acute and chronic symptoms. Acute effects arise rapidly through three channels: through the skin (such as irritation, burning, and allergies), through respiration (cough, runny nose, breathing difficulties), and through the mouth (heartburn, nausea, vomiting). On the other hand, according to the National Health Surveillance Agency [17], chronic symptoms develop over time and can be related to factors such as forgetfulness, abortion, impotence, respiratory problems, hormonal abnormalities, and some studies suggest a possible link to cancer development, a topic still under discussion in academic circles.

Carneiro *et al*. [12] point out that Brazil has been the largest consumer of pesticides since 2008, mainly due to the significant development of agribusiness in the country, and that since then, the problems generated by the use of these products have also increased. Consequently, there arises a need for greater control, better regulation, increased oversight, and, primarily, more studies on how the application of these products can influence the Brazilian economy. Thus, the classifications of active ingredients (the product itself) arise, which categorize and regulate each active ingredient by name, synonymy, CAS[2] number, chemical name, gross formula, structural formula, chemical group, class, technological classification, and, most importantly, their mode of use (both agricultural and non-agricultural) and establish, for monitoring and toxicological evaluation purposes, the limits of quantities and residues for that product. Additionally, they also highlight the acceptable daily intake (ADI) and Acute Reference Dose (ARfD), critical levels of intake or exposure to these products.

Aggregately, Anvisa organizes a total of 1,942 products into five categories: 1) extremely toxic, 2) highly toxic, 3) moderately toxic, 4) slightly toxic, and 5) unlikely to cause acute damage. The distribution of products is presented in Table 2.

Moreover, it is interesting to highlight some of the most commonly used pesticides in Brazil and their toxicity relationship, according to INCA [20]: 2,4-D - Class I; Acephate - Class III; Atrazine - Class III; Chlorpyrifos - Class II; Diazinone - Class II; Diuron - Class III; Glyphosate - Class IV; Malathion - Class III; Mancozeb - Class III; Methomyl - Class I. Therefore, observing that most of these products are Herbicides (4), Insecticides (5), and Fungicides (1) and that most are among the three most toxic classes, it is essential to study how pesticide application influences production, especially since Brazil, and specifically Paraná, represent significant agricultural producers.

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[2] The CAS Number is the registration number responsible for identifying chemical information about the product, which is adopted by the Chemical Abstract Service (CAS).

Table 2: Classification of Pesticides.

Classe toxicológica	Toxicidade	Faixa de rotulagem dos agrotóxicos	Quantidade de produtos	%	Classe de perigo		
					ORAL	DÉRMICA	INALATÓRIA
I	Extremante tóxico	Vermelho	43	2,2%	Fatal se ingerido	Fatal em contato com a pele	Fatal se inalado
II	Altamente tóxico	Vermelho	79	4,1%	Fatal se ingerido	Fatal em contato com a pele	Fatal se inalado
III	Moderadamente	Amarelo	136	7,0%	Tóxico se ingerido	Tóxico em contato com a pele	Tóxico se inalado
IV	Pouco tóxico	Azul	599	30,8%	Nocivo se ingerido	Nocivo em contato com a pele	Nocivo se inalado
V	Improvável de causar dano agudo.	Azul	899	46,3%	Pode ser perigoso se ingerido	Pode ser perigoso em contato com a pele	Pode ser perigoso se inalado

Source: Elaborated by the authors based on Anvisa [17] and INCA [20].

3. METHODOLOGY AND DATA

3.1 METHOD(S)

The period from 2006 to 2017 was chosen to demonstrate the increased use of pesticides alongside the technological advancements that promoted increased productivity. However, the main reason pertains to the economic and social advancements that the state of Paraná achieved during the first decade of the 21st century. To estimate the influence of pesticide use and expenditure on agricultural production in Paraná in the years 2006 and 2017, a spatial panel data methodology will be used. Through Breusch–Pagan's LM and Moran's I test, it was possible to detect the presence of spatial autocorrelation in the data used both in the panel model and year by year (the value was significant for both). The results of the Moran test can be observed in Figure 2, which illustrates the positive relationship of the dependent variable (value of production) over time via Moran's statistics. Additionally, it was possible, through Moran's I test, to select the neighborhood weights to be used in estimating the model, with the Torre type presenting the best statistics for both years. To determine the type of panel, the Hausman test for panel data was used, yielding results that the fixed effects panel is preferable to random effects. For greater robustness, another Hausman test was conducted for spatial panels, which obtained the same results as the first test (fixed effect is better). It is important to state that with the model running with fixed effects (without spatial effects yet), the residuals obtained were normal, according to the Jarque-Bera test. Thus, there was no need to use other estimation methods for the spatial model other than LM. To identify the spatial model to be used in the study, two tests were employed, Hausman for panel data and Locally robust LM, to verify if the model has a correlation with spatial errors or with spatial lag. From the first test, the spatial lag was significant, unlike the spatial error, which was not significant, providing strong indications that spatial lag is more suitable for the model. In the second test, both the LM test and the local robust test showed the best statistics for spatial lag, as can be seen in Table 3. It concludes that the best model is the SAR, as the spatial lag is more appropriate to be used.

Figure 2: Moran Statistics. **Source:** Elaborated by the authors (2023).

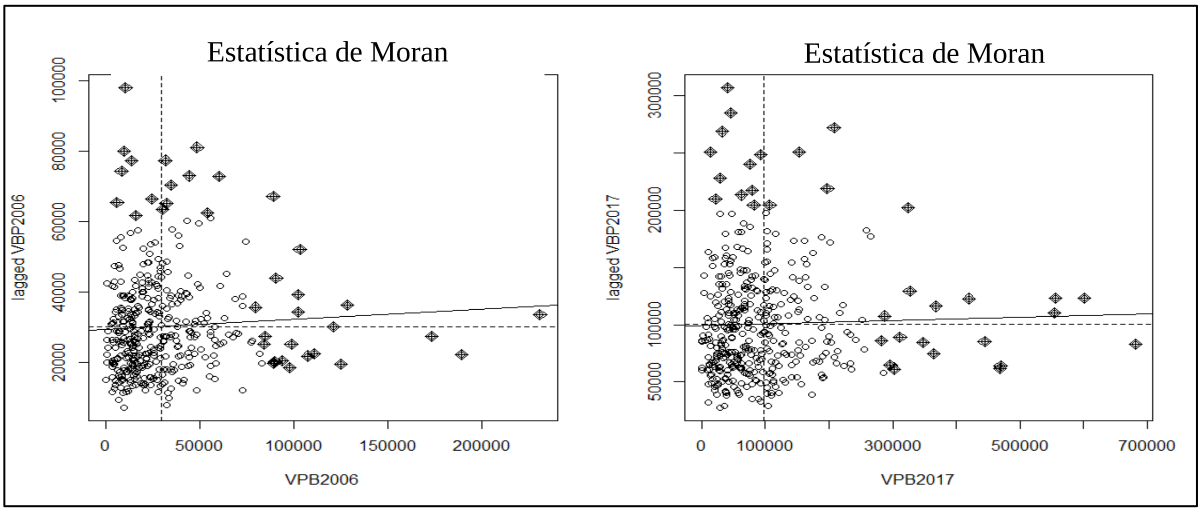

Table 3: LM Test and Robust LM.

	lml	*lme*	*rlml*	*rlme*
LM test	357.29	66.20	316.15	25.06
p-value	0.00	0.00	0.00	0.00

Source: Elaborated by the authors (2023).

Through the LR and Wald tests, it was possible to determine which model was more suitable for working on the SAR or the SDM. According to the test results, the SDM model proved to be the most efficient, while the SAR model will also be used for a better understanding of the results.

The SAR model considers that the dependent variable y is affected by another endogenous variable y but from the neighbors of a location [18]. This relationship is represented by Wy, a nx1 vector of spatial lag and the spatial autoregressive coefficient p. It attempts to encompass the “neighborhood” effect and how it affects nearby regions. The equation expressing this model is shown below:

$$Y = pWy + \beta X + \epsilon$$

Following this, the SDM model is based on the SAR model but adds spatial lag to the exogenous variables. The variable WX is included in the model, which will analyze the “neighborhood” effect of the studied exogenous variables. Because the model includes sometimes insignificant variables, it is less efficient but gains greater consistency in estimating the coefficients than others [18]. This model can be algebraically expressed as follows:

$$Y = pWy + \beta X + \Omega WX + \epsilon$$

3.2 EMPIRICAL MODEL AND VARIABLE DESCRIPTION

The empirical model to be estimated is an aggregate production function of conventional agriculture with additional variables, pesticide use, and pesticide expenditure, in a Cobb-Douglas log-linear format, assuming the following equation:

$$\boldsymbol{ln y_{it} = \lambda W ln\, Y_{it} + \beta_1 ln\, Ah_{it} + \beta_2 ln\, Lt_{it} + \beta_3 lnK_{it} + \alpha_1 lnC_{it} + \alpha_2 ln\, DA_{it}}$$

Where *y* is the production value; *Ah* is the crop area in hectares; *Lt* is the number of workers; *K* is a proxy for capital in the municipalities' crops, represented by land lease, fertilizer, and corrective expenses, electricity, machinery, vehicles, and fuel and lubricants purchases; *C* is the number of establishments using pesticides (units); *DA* is pesticide expenditure; *Wlny* is the spatial lag of the dependent variable in logarithm; while *i* corresponds to the municipalities, and *t* to time.

The dataset used comprises 399 municipalities in the state of Paraná, covering the period from 2006 to 2017, consisting of data from both the agricultural census and the Municipal Agricultural Production. Data were collected only for the permanent and temporary crops of the municipalities.

Data were obtained from official sources such as the Brazilian Institute of Geography and Statistics (IBGE), specifically through the Municipal Agricultural Production and finally from the IBGE Automatic Recovery System (SIDRA).

Table 4: Description of the Econometric Model Variables.

Variable	Description	Source
y_{it}	Production value	IBGE
$\boldsymbol{\lambda W}$	Spatial lag of the SDM and SAR model	-
Ah_{it}	Crop area in hectares	SIDRA
Lt_{it}	Number of workers	SIDRA
K_{it}	K is the expenditure on land lease, fertilizer, and corrective expenses, electricity, machinery, vehicles, and fuel and lubricants	SIDRA
C_{it}	Number of establishments using pesticides	IBGE
DA_{it}	Pesticide expenditures	IBGE

Source: Elaborated by the authors (2023).

4. RESULTS AND DISCUSSION

Based on the results obtained from Moran's I test, it is identified that the value of production over time in the state of Paraná has a positive spatial relationship among municipalities. This significant relationship across both years of analysis defines that the production value of crops in the state of Paraná is geographically affected by producing municipalities.

Through Table 5, it can be seen that the spatial lag was significant and positive in both models, indicating that the production value of the municipalities' crops positively affects the production of neighbors over time. Additionally, along with the crop area in hectares, they are the variables that most affect the studied dependent variable.

The signs of the capital, area, and labor variables were consistent with the theory presented by Strassburg *et al*. [19], with the first two being positive and the last negative, all being significant. The fact that labor has a negative effect on production value arises from characteristics present in the agricultural sector, as labor substitution by machines is very intense. Thus, an increase in workers would be a "setback" from a theoretical standpoint, having a negative relationship with the endogenous variable.

Looking at the pesticide variables included in the production model in the SAR model, it is noted that pesticide expenditures were significant and had a positive effect on the value of production in Paraná's crops. Considering that this variable was separated from our capital proxy, the aim was to analyze whether increasing expenditure on this product was generating positive results for value addition in the municipalities' crops. It can be seen that, indeed, the increase in expenditures on pesticides has a positive effect; however, it is not as impactful as other variables, having the least impact on Y.

The number of establishments that used pesticides was not significant and showed a negative effect on production. It is important to emphasize that due to limitations in the dataset, particularly for 2006, there were no good proxies to study pesticide use in the municipalities' crops. This variable is quite problematic, as it does not specify the quantity used nor whether the use was continuous or simply occasional during the year. Thus, it should be used and analyzed with caution to avoid errors.

Table 5: SAR X SDM Model Results.

	log(VBP) (1)	log(VBP) (2)
λ	0.688*** (0.022)	0.592*** (0.033)
log(Ah)	0.725*** (0.035)	0.740*** (0.034)
log(K)	0.112*** (0.016)	0.050** (0.018)
log(L)	-0.107*** (0.022)	-0.053* (0.023)
log(DA)	0.035* (0.016)	0.007 (0.016)
log(C)	-0.005 (0.021)	0.012 (0.020)
log(lAh)		-0.234* (0.105)
log(lK)		0.078** (0.026)
log(lL)		-0.151*** (0.035)
log(lDA)		0.123*** (0.028)
log(lC)		-0.135+ (0.071)

Observations	399	399
Model	SAR	SDM

$+\ p < 0.1,\ {*}\ p < 0.05,\ {**}\ p < 0.01,\ {***}\ p < 0.001$

Source: Elaborated by the authors (2023).

In the SDM model, there are new important indications, such as the fact that the spatial lag of the dependent variable remains significant and more relevant in explaining the results. The other conventional variables remain significant with the same signs as before, but pesticide expenditure is no longer significant. The effect of spatial lag on independent variables removed the significance of this variable.

Discussing the spatial lag variables, all were significant (at least at 10% significance). The log(Ah) had a negative sign, indicating that an increase in the planted area of neighboring crops has a deteriorative effect on the production value of its neighbors. This occurs because the expansion of municipalities' areas limits the expansion of neighboring areas, hindering production. In some cases, certain areas expand excessively and end up using more pesticides than others, which negatively affects the development of neighboring regions precisely due to the greater quantity of pesticides used in some regions.

The labor and capital variables in spatial lag had the same signs as their “fixed” state, negative and positive, respectively. The result occurs because these variables, unlike hectares, do not have external effects; their effects are limited to the production value. Thus, their effect is more on λ than on the normal independent variable, as mentioned by Pólippo [9] in the literature review.

The spatial lags of the pesticide variables yielded interesting results, as this time, the use of pesticides in establishments was significant and had a negative effect. For pesticide expenditure, we can interpret the result as we did with labor and capital, while use can indicate the negative and external effects of pesticide use that are deteriorating the production value of neighbors. However, it is essential to clarify that due to the nature of this variable, we should make additional assumptions beyond this to explain this effect.

Some reasons for such a result may arise from natural problems caused by pesticide use, poor efficiency of use, and the variable being by a unit of establishments instead of the quantity of product used, causing this effect, in addition to not specifying whether the use was recurrent or momentary, leaving its relationship with the production value of neighbors “ambiguous.” This aligns with the argument presented by Soares [5] regarding the economic benefits of pesticide use, highlighting the needs of agricultural production and structural characteristics, thus emphasizing hidden externalities associated with the intensive use of pesticides, such as lack of training for new workers, difficulties in introducing new technologies, and deficiencies in environmental and social protection.

In turn, in Table 6, it is possible to analyze that all effects had the same signs as seen in the SDM model, with the indirect effect being greater than the direct one in all variables. This indicates that the spillover effect, or in this case, the effect caused by neighbors, has more impact on the production value of the municipalities' crops in Paraná than their local effects. This supports the importance of using spatial lag models to analyze this proposed model.

Table 6: Impacts of Pesticide Use on Each Variable.

	Direct	Indirect	Total
log(Ah)	0.8091649	1.1059503	1.8151152
log(K)	0.0544080	0.0676397	0.1220477
log(L)	-0.0576596	-0.0716822	-0.1293419
log(DA)	0.0072195	0.0089753	0.0161948
log(C)	0.0127432	0.0158422	0.0285854
log(lAh)	-0.2560363	-0.3183031	-0.5743394
log(lK)	0.0855248	0.1063240	0.1918488
log(lL)	-0.1655960	-0.2058682	-0.3714641
log(lC)	-0.1471761	-0.1829687	-0.3301448
log(lDA)	0.1339832	0.1665674	0.3005506

Source: Elaborated by the authors (2023).

In this final chapter, therefore, the implications and conclusions of pesticide use are discussed, along with recommendations for more sustainable practices in this area. The results from the Moran I test showed clear spatial relationships among municipalities and demonstrated that the value of Paraná's agricultural production is influenced by production from neighboring municipalities. Large spatial lags reinforce this interdependence and highlight the importance of public policies that consider regional dynamics in promoting agricultural development. Collaborative strategies and the sharing of best practices among communities may be considered to maximize the positive impact on production.

The analysis of traditional variables such as capital, area, and labor reveals consistency with economic theory, stating that capital and area positively impact product value while labor has a negative impact. The increase in pesticide expenditures is significant and positive, indicating that investment in this input, although of small magnitude compared to other variables, contributes to increased production value. However, a balanced and sustainable approach to pesticide use is recommended, considering potential environmental impacts.

5. CONCLUSIONS

This study thoroughly analyzed the impact of increased pesticide use on agricultural production in the state of Paraná, specifically in the years 2006 and 2017. The final section of this paper focuses on the main points that emerged from the overall research perspective, providing an in-depth understanding of the significance of this intensive practice within the context of agricultural production. The objective is to clarify the importance of these practices and offer suggestions for the evolution of the sector, considering the growing concerns about sustainability and environmental health.

Furthermore, this article goes beyond analyzing the immediate impacts of pesticide use, also reflecting on the long-term implications for agricultural sustainability and regional economies. The first part of the analysis highlights the importance of regional interdependence, showing that interurban dynamics play a crucial role in agricultural planning in the state of Paraná. The interaction between municipalities is essential for the success of agricultural policies and for increasing productivity in a sustainable manner. By understanding these relationships, it is possible to identify cooperation opportunities that strengthen production chains and promote more efficient use of available resources.

The impact of pesticide use was another focal point. The research revealed that while the use of pesticides increases crop yields, it also generates environmental and human health consequences that cannot be overlooked. The analysis showed that excessive pesticide use harms the soil, local fauna, and the health of farm workers who are in constant contact with these substances. These findings reinforce the need for stricter and more effective regulation of pesticide use, aiming to balance agricultural productivity with environmental preservation and public health protection.

Thus, the study suggests adopting more sustainable agricultural practices that prioritize the use of innovative and environmentally friendly technologies. For instance, organic farming models emerge as a viable alternative to reduce reliance on chemicals and improve soil and product quality. Additionally, implementing public policies that promote responsible pesticide use is crucial. Such policies should be based on solid scientific evidence and encourage farmers' education on proper chemical use while promoting safer, more effective alternative practices.

The importance of strengthening regional cooperation is also a central point of the study. The research highlights how the dissemination of sustainable agricultural practices and innovative technologies can be facilitated through cooperation among municipalities, fostering the exchange of knowledge and experiences. Collaboration between cities can result in the adoption of techniques that not only minimize environmental impacts but also increase agricultural production efficiency. Rural extension programs, promoting access to clean technologies and sustainable agricultural practices, are essential to ensure that the benefits of technological innovations reach all farmers, especially those still relying on traditional methods.

Furthermore, the study underscores the need for more research exploring spatial relationships in agricultural production. Understanding how agricultural practices in one municipality specifically affect neighboring municipalities over time can provide valuable insights for developing more effective policies. The analysis of spatial data can reveal how local agricultural policies impact neighboring areas, demonstrating that a policy error in one municipality can have negative consequences for the entire region. The lack of sustainable alternatives to pesticide use could lead to a food and financial crisis that would directly affect local economies and even global food security.

The recommendation for further research into sustainable agricultural practices is urgent. Alternatives to intensive pesticide use, such as biopesticides, biological pest control, and crop rotation practices, offer significant potential to reduce the negative impacts of conventional agriculture. However, it is crucial that new research focuses on assessing the economic feasibility of these alternatives, considering the costs involved and the long-term benefits to public health and the environment.

Most importantly, the research rejected the null hypothesis that no correlation exists between individual effects and explanatory variables, confirming the profound impact of local agricultural practices on regional outcomes. This finding highlights the importance of public policies that take into account the specifics of each municipality and region, promoting more responsible and sustainable agricultural practices. The study's conclusions not only enrich the scientific literature but also provide a solid foundation for the formulation of more effective public policies, considering the complex interactions between agriculture, the environment, and human health.

Thus, this study serves as a practical guide for policymakers, encouraging deeper reflection on agricultural practices and their regulation. It is a call to action for all stakeholders in agricultural systems, including governments, NGOs, researchers, and farmers, to promote more responsible and sustainable farming methods that ensure productivity without compromising natural resources and the health of future generations.

Finally, given the complexities and issues raised throughout the study, future research should focus on deepening the understanding of spatial relationships in agricultural production, considering additional variables such as water availability, soil quality, and climatic variability. Additionally, improving data collection methods is essential to ensure that public policies are based on accurate and up-to-date information. Research into the impact of sustainable agricultural practices and alternatives to intensive pesticide use offers valuable insights for promoting more balanced and resilient agricultural production models. It also highlights the complexities of challenges associated with pesticide use in modern agriculture, emphasizing the importance of a holistic approach that considers economic, environmental, and social impacts, aiming to achieve truly sustainable and responsible agricultural development.

Moreover, the authors should thoroughly discuss the risks of implementing public policies to regulate the use of fertilizers and pesticides, as suggested by the authors themselves, especially when no perfect substitute for traditional methods exists. Without effective alternatives, rigid regulation may not only be ineffective but could also result in an agricultural crisis with devastating impacts on production, exports, and global food security. This critical reflection is essential for developing more balanced public policies that ensure the continuity of agricultural production without compromising environmental health and social well-being.

CONFLICT OF INTEREST

None.

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REFERENCES

1. Parré JL, 2013. Interpreting rural space: Development, natural resources and infrastructure. In: ANPEC - National Association Of Graduate Centers In Economics. National Meeting of Economics. Foz do Iguaçu. p. 20. December 10 and 13.
2. Brazil: Ministry of Agriculture, Livestock and Food Supply – MAPA, 2012. Manual of procedures for pesticide registration. Brasília.
3. Hybner BR, *et al*., 2020. Convergence of total factor productivity in agriculture in Southern Brazil. Agricultural Policy Journal; 29(4), 47-64.
4. Secretary Of Agriculture And Supply (SEAB), 2017. Gross Value of Agricultural Production in Paraná in 2017.
5. Soares WL, 2010. Use of pesticides and their impacts on health and the environment: an integrated assessment between the economy, public health, ecology and agriculture. 163 p. Thesis (Doctorate) - Course of Sciences in the Area of Public Health and Environment, National School of Public Health Sergio Erouca Ensp, Rio de Janeiro, 2010.
6. Lopes CVA, Albuquerque GSC, 2018. Pesticides and their impacts on human and environmental health: a systematic review. Saúde em Debate, [S.L.]; 42(117), 518-534.
7. Bohner TOL, *et al*., 2013. The environmental impact of pesticide use on the environment and health of rural workers. Electronic Journal of the Law Course of the Federal University of São Paulo; 8, 335.
8. Reyna ED, *et al*., 2020. Chapter 12 - Impacts of the use of pesticides on technical efficiency in Brazilian agriculture. Book chapter in: Vieira Filho, José Eustáquio Ribeiro; Gasques, José Garcia (org.). A journey through the contrasts of Brazil: one hundred years of the agricultural census. Brasília: Institute of Applied Economic Research (Ipea); 2020, 173-187.
9. Pólippo D, 2018. Overview of the use of pesticides in the state of Paraná. 31 p. TCC (Undergraduate) - Agronomy Course, Agricultural Sciences, Federal University of Technology of Paraná, Pato Branco.
10. Schneiders S, 2018. Use of pesticides in the state of Paraná in 2016 and 2017. 44 p. TCC (Undergraduate) - Agronomy Course, Academic Department of Agricultural Sciences, Federal University of Technology of Paraná, Pato Branco.
11. Terra FHB, 2008. The pesticide industry in Brazil. 156 p. Dissertation (Masters in Economic Development). Department of Economics, Applied Social Sciences Sector, Federal University of Paraná. Curitiba.
12. Carneiro FF, *et al*., 2015. ABRASCO Dossier: a warning about the impacts of pesticides on health. Rio de Janeiro: EPSJV; São Paulo: Expressão Popular.
13. Lopes CVA, Albuquerque GSC, 2021. Challenges and advances in the control of pesticide residues in Brazil: 15 years of the program for the analysis of pesticide residues in food. Cadernos de Saúde Pública, [S.L.]; 37(2), 1-15.
14. Santos RAR, 2017. Assessment of the potential for contamination by pesticides: a case study in the Paraná III basin. 34 p. TCC (Undergraduate) - Environmental Management Technology Course, Federal Technological University of Paraná, Medianeira.
15. Bombardi LM, 2017. Geography of Pesticide Use in Brazil and Connections with the European Union. São Paulo: Fflch-Usp, 296 p.
16. Klaassen CD (ed.), 2013. Casarett and Doull’s toxicology: the basic science of poisons. 8th edn. New York: McGraw-Hill Education.
17. National Health Surveillance Agency (Brazil), 2018. Authorized monographs. Brasília, DF: ANVISA.

18. Almeida ES, 2012. Applied Spatial Econometrics. Campinas: Editora Alínea. Chap. 5, 183-150.
19. Strassburg U, *et al*., 2014. Notes on the aggregate agricultural production function of Paraná. Journal of Agricultural Policy; 23(3), 18-28.
20. National Cancer Institute, 2019. Exposure at work and in the environment. Pesticides. Rio de Janeiro: INCA.