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EFFECTS OF DECREE 10.833/21 ON THE PRODUCTIVITY OF SOYBEAN AND CORN CROPS IN THE MUNICIPALITIES OF MATO GROSSO

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Introdução
The release of pesticides caused an increase in sales, as well as inspection through control carried out by the government of Mato Grosso. The increasing consumption of pesticides can have a positive effect on the productivity and yield of extensively produced crops. Knowing the effects of using pesticides can help producers and governments in developing policies for the development of the soybean and corn production chain.
Problema de Pesquisa e Objetivo
Discussions about the approval, commercialization, and large-scale use of pesticides can raise questions and hypotheses about their effects on the productivity of soybean and corn crops, which rely heavily on pesticides for their variable costs in agricultural production. the objective of this study is to analyze the effects of the release and commercialization of pesticides on soybean and corn crops in the state of Mato Grosso.
Fundamentação Teórica
On October 8, 2021, the federal government published Decree 10.833/2021 in the Official Gazette, which simplifies the processes of research, analysis, and commercial registration of agricultural pesticides for use in Brazil. While it makes the analysis of new products faster and less bureaucratic, the legislation also strengthens oversight. The new decree includes additives specifically for certified organic crops and facilitates the production of generic pesticides.
Metodologia
To construct the data panel, annual data were collected from 141 municipalities over the years from 2019 to 2022, related to variables such as planted area, production value, prices, productivity per hectare, quantity produced, and population. These data were made available by the Matogrossense Institute of Agropecuarian Economics - IMEA. Data from the annual Agrochemical Trade Report consolidated by INDEA-MT were also used. The estimator used in this study is the differences-in-differences model. According to BERTRAND, DUFLO, and MULLAINATHAN (2004).
Análise dos Resultados
The results presented show that after the approval of decree 10,833/21, releasing pesticides, there was an increase in average productivity, that is, the yield in kg/hectare, considering the two crops of soybean and corn by 10.94% in municipalities that produce both crops in Mato Grosso. When considering estimates per bag/hectare, the yield rises to 17%. This demonstrates that the decree provided greater commercialization and, consequently, greater application of pesticides, considerably improving the productivity of soybean and corn crops.
Conclusão
The hypothesis of the study was based on the argument that the release and commercialization of pesticides would lead to increased productivity and profitability. This hypothesis was accepted and statistically proven. The results presented show that after the approval of Decree 10,833/21, which released pesticides, there was an increase in average productivity, i.e., yield in kg/hectare, considering both soybean and corn crops, by 10.94% in the municipalities that produce both crops in Mato Grosso.
Referências Bibliográficas
BRASIL. Decreto nº 10.833, de 8 de outubro de 2021. dispõe sobre a pesquisa, a experimentação, a produção, a embalagem e rotulagem, o transporte, o armazenamento, a comercialização, a propaganda comercial, a utilização, a importação, a exportação, o destino final dos resíduos e embalagens, o registro, a classificação, o controle, a inspeção e a fiscalização de agrotóxicos, seus componentes e afins. Disponível em: https://www.in.gov.br/en/web/dou/-/decreto-n-10.833-de-7-de-outubro-de-2021-351524955. Acesso em: 05.05.2022.

Palavras Chave
Pesticides, agribusiness, Differences-in-differences model

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ABSTRACT
The release of pesticides caused an increase in sales, as well as inspection through control carried out by the government of Mato Grosso. The increasing consumption of pesticides can have a positive effect on the productivity and yield of extensively produced crops. Knowing the effects of using pesticides can help producers and governments in developing policies for the development of the soybean and corn production chain. The objective of the work is to evaluate the effects of the commercialization of pesticides provided by decree 10,833/21 and the relationship with the productivity of soybean and corn crops in Mato Grosso. To carry out this research, data on quantity produced, planted and harvested area, production value and yield kg/hectare were consulted, provided by the Matogrossense Institute of Agricultural Economics - IMEA. Information on pesticide registration was obtained from the INDEA-MT trade report. The estimator used was the difference-in-differences model. The results presented show that after the approval of decree 10,833/21, releasing pesticides, there was an increase in average productivity, that is, the yield in kg/hectare, considering the two crops of soybean and corn by 10.94% in municipalities that produce both crops in Mato Grosso. When considering estimates per bag/hectare, the yield rises to 17%. This demonstrates that the decree provided greater commercialization and, consequently, greater application of pesticides, considerably improving the productivity of soybean and corn crops.

Keywords: Pesticides. agribusiness. Lei 10.833/21. Differences-in-differences model. Mato Grosso

1 Introduction

A Brazilian law establishes guidelines regarding the import, export, production, commercialization, and use of pesticides. There are bills that foresee the relaxation of rules regarding pesticides, highlighting that in recent years, there has been an increase in the registration and commercialization of pesticides in Brazil (MAPA 2021).

Such pesticides (some prefer the term agrochemicals) have proven to be an important factor in the evolution of agricultural productivity as they reduce losses caused by pests and diseases that attack plants, despite knowing that the improper use of pesticides is harmful to the environment and human health. The reason for their use is that the benefits of preserving agricultural productivity outweigh the costs and negative external factors caused by pesticides. Currently, Brazil is one of the countries that use the most pesticides in the world, highlighting the growing use of this product since the 1970s. This increase in pesticide consumption in Brazil, along with other inputs, has enabled agricultural productivity to rise.

Agribusiness is closely tied to the Brazilian economy, with agriculture being the primary beneficiary of public investment, encouraging the expansion of the monoculture technology

market. However, the exploitation of this sector has been accompanied by growing concerns about the impact of agriculture and livestock on the environment. This is especially evident in the use of pesticides and fertilizers, methane emissions, deforestation, and the burning of indigenous plants to expand agribusiness.

The use of different pesticides depends on the regulations in force in a given country. In Brazil, the control of pesticide use is simultaneously carried out by three agencies: the Ministry of Agriculture, Livestock, and Supply (MAPA), the National Health Surveillance Agency (ANVISA), and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), which establish guidelines for the use of pesticides.

Annual pesticide consumption in Brazil has exceeded 300,000 tons of commercial products. In terms of active ingredient quantity, approximately 130,000 tons are consumed annually in the country. This represents a 700% increase in pesticide consumption over the past forty years, while the agricultural area has increased by 78% during the same period.

On October 8, 2021, the federal government published Decree 10.833/2021 in the Official Gazette, which simplifies the processes of research, analysis, and commercial registration of agricultural pesticides for use in Brazil. While it makes the analysis of new products faster and less bureaucratic, the legislation also strengthens oversight. The new decree includes additives specifically for certified organic crops and facilitates the production of generic pesticides.

Discussions about the approval, commercialization, and large-scale use of pesticides can raise questions and hypotheses about their effects on the productivity of soybean and corn crops, which rely heavily on pesticides for their variable costs in agricultural production. The question arises: what are the effects of Decree 10.833/2021 on the commercialization of pesticides and its relationship with the productivity of soybean and corn crops in the state of Mato Grosso from 2019 to 2022? In light of this justification, the objective of this study is to analyze the effects of the release and commercialization of pesticides on soybean and corn crops in the state of Mato Grosso.

The literature on the effects of pesticides can be found in the following works:

Veiga (2007) analyzed the relationship between economic efficiency and socio-environmental justice regarding the use of pesticides, focusing on the idea of maximizing economic efficiency through productivity gains. Additionally, the study evaluated the impact of regulatory instruments on the control of pesticide use and management. Restrictions on pesticide use in productive systems that rely on these raw materials to sustain their economy could be highly detrimental. Regarding the need for state intervention to regulate pesticide use,

this study concluded that the question should not be whether legislation is needed but rather how this intervention should take place.

Lopes and Albuquerque (2018) conducted a systematic review from 2011 to 2017 on the subject using scientific databases. They included 116 studies that demonstrated the negative impact on human and environmental health. It is essential to conduct studies on the effects of chronic and simultaneous exposure to various pesticides, as well as studies on the structural determinants of pesticide use and its consequences. There is an important gap in uncovering the links between processes at the individual, specific, and structural levels of reality in determining health and diseases related to pesticide use. Analyzing only individual and specific processes of health determination is insufficient for effective prevention of harm and health promotion.

Ogino (2021) aimed to analyze, in econometric terms, the behavior of pesticide consumption in three regions and, specifically for Brazil, the relationship between pesticide consumption and Brazilian agricultural productivity from 1990 to 2016. Johansen cointegration analyses indicated long-term relationships between pesticide consumption per hectare of crops among Brazil, the USA, and the European Union, as well as between pesticide consumption and crop productivity in Brazil. Regarding the latter relationship, the SVEC model estimates generally showed a direct relationship between these two variables in the Brazilian case.

Meyer et al (2022) emphasized the need for food security and food sovereignty. The right to food is enshrined in Article 6 of the Brazilian Federal Constitution of 1988 and is in conflict with the approval of pesticide use in the country. There has been a significant increase in pesticide use authorizations, despite the well-established harmful consequences to the environment. The Agrochemical-Free Zone of Florianópolis reinforces the legal framework historically established in ensuring the fundamental right to food. Although the state has shown a lack of coherence and demonstrated inconsistencies in its agricultural policies, approving pesticides and environmental setbacks while also promoting organic production in the country, this initiative is significant.

Da Silva Dantas (2021) aimed to analyze the main Brazilian environmental laws, highlighting their interface with the Sustainable Development Goals proposed by the United Nations and their objectives. There is an important gap in uncovering the links between processes at the individual, specific, and structural levels of reality in determining health and diseases related to pesticide use.

Waichman (2012) discussed some obstacles that need to be overcome to contribute to the construction of an integrated research strategy that goes beyond the academic multidisciplinary approach. This new paradigm involves the engagement of all social actors

(agrochemical industry, government, producers, rural workers, researchers, civil society) in understanding the perception of these actors regarding the issue and comprehending the underlying rationale behind pesticide use in Brazil, incorporating multiple perspectives into the development of a common language and vision. Thus, two economic incentive strategies, one negative and one positive, should be considered: taxing these inputs (the polluter-pays principle) and providing subsidies to producers who use integrated pest management and adopt agroecological practices (the beneficiary-receiver principle). Obviously, both strategies are fraught with weaknesses due to industry resistance and opposing pressures regarding overtaxation and the government's rather timid support for agroecology.

Pignati et al (2014) conducted a study on the strategy of worker, population, and environmental health surveillance, analyzing the quantities, types, and toxicity of pesticides used per hectare in Mato Grosso's crops to support municipal surveillance efforts in Brazil. They also observed, through an agricultural production and pesticide consumption matrix, that some health issues are correlated with the regions with higher production. Based on pesticide consumption data, agricultural production, and the toxicity of these agricultural chemicals, it is possible to infer their harms and damages in Brazilian municipalities and establish prevention and health surveillance strategies for workers, the environment, and exposed populations.

The next section will highlight the theoretical foundation of the study and relevant legislation, followed by the methodology and results. Finally, the study's conclusions will be presented. This research contributes to the literature by elucidating the relationship between pesticide commercialization and soybean and corn productivity in the state of Mato Grosso, utilizing panel data econometric analysis for the period 2019-2022 and employing a differences-in-differences model.

2. Theoretical Framework

The term pesticide has various denominations, including agricultural defense, pesticide, pesticide, biocide, among others. These names are used depending on the image one wants to convey about the product. According to the Agrochemicals Law No. 7,802 of July 11, 1989, along with the decrees that regulate it - Decree No. 4,074 of January 4, 2002, and Decree No. 5,981 of December 6, 2006 - they determine that agrochemicals and related products are "*Products and agents of physical, chemical, or biological processes, intended for use in the sectors of production, storage, and processing of agricultural products, in pastures, in the protection of forests, whether native or planted, as well as in other ecosystems and also in urban, aquatic, and industrial environments, whose purpose is to alter the composition of flora*

or fauna in order to preserve them from the harmful action of living beings considered harmful, as well as substances and products used as defoliants, desiccants, growth stimulants, and growth inhibitors." (BRASIL, 2006)

In the 1970s, global agricultural modernization emerged, driven by the incorporation of technological advancements into production. This development led to the expansion of economically-driven agriculture, subsequently bringing about significant changes in agricultural productivity, especially in monoculture-based systems heavily reliant on agrochemicals. Taking note of the increased economic development in the agricultural sector in recent decades, it is essential to address the indiscriminate use of pesticides and natural resources, which have resulted in irreversible impacts on the environment and society (WAICHMAN, 2012).

Pesticide consumption varies across diferente braziliam regions, where a mix of intensive and traditional agricultural activities coexist, with the latter not widely adopting the use of chemical products. Pesticides have been more extensively used in the Southeast (approximately 38%), South (31%), and Central-West (23%) regions. In the Northern region, pesticide consumption is comparatively very low, accounting for just over 1%, while in the Northeast region (around 6%), a significant amount is concentrated mainly in irrigated agriculture areas. Pesticide consumption in the Central-West region increased in the 1970s and 1980s due to the expansion of Cerrado land occupation and continues to rise due to the increased cultivation of soybeans and cotton in that region.

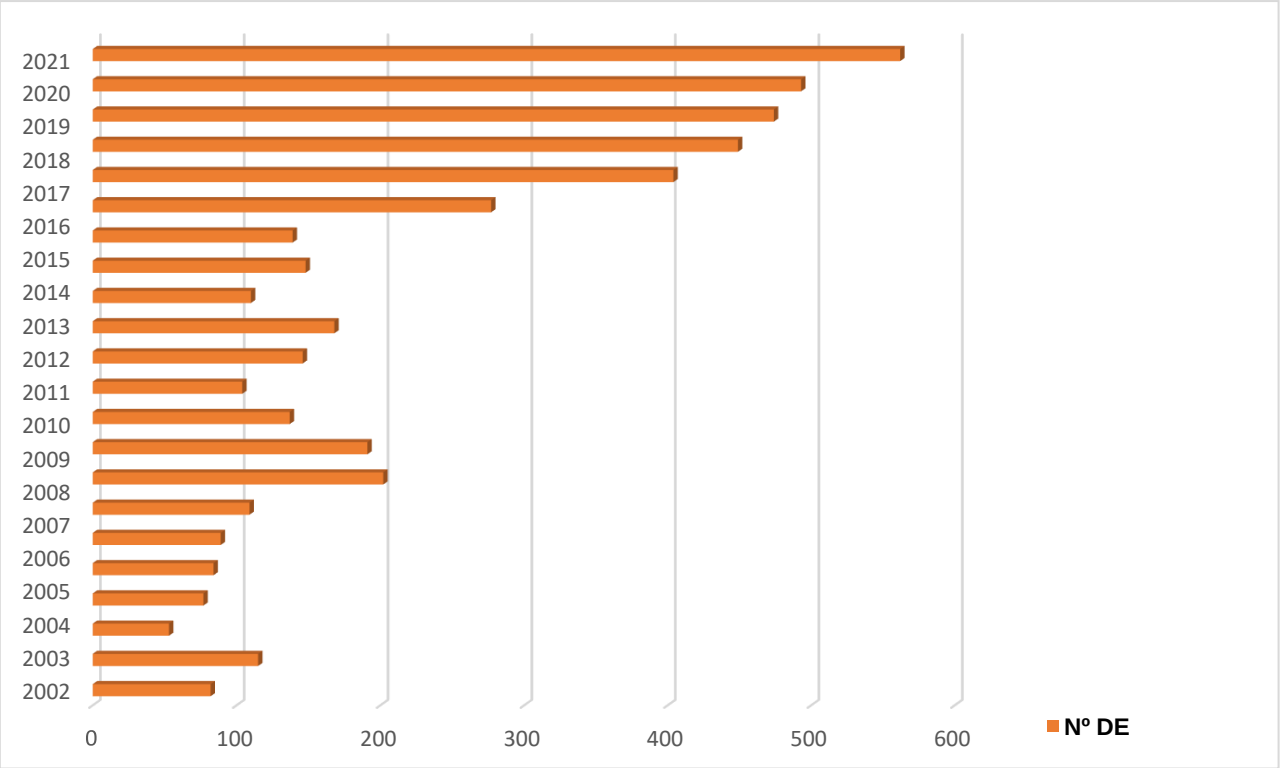
The braziliam states that stand out the most in terms of pesticide use are São Paulo (25%), Paraná (16%), Minas Gerais (12%), Rio Grande do Sul (12%), Mato Grosso (9%), Goiás (8%), and Mato Grosso do Sul (5%). Regarding pesticide consumption per unit of cultivated area, the overall average in Brazil increased from 0.8 kg a.i. ha-1 in 1970 to 7.0 kg a.i. ha-1 in 1998 (MINISTÉRIO DA AGRICULTURA, BRASIL, 2021).

The registration of pesticides is continually growing in Brazil. From 2020 to 2022, there was an increase of 14%. Approvals for these registrations became more frequent starting in 2016. A significant increase of 200% in pesticide registrations can be observed from 2016 to 2021. In 2021, Brazil set a record with 562 pesticides approved, including 33 that were previously unregistered, marking the highest number in the historical series that began in the 2000s by the Ministry of Agriculture (MINISTÉRIO DA AGRICULTURA, BRASIL, 2021).

The registration of pesticides over the past twenty-one years in Brazil can be observed in Figure 1. It is noticeable that the increase in registrations has been occurring since 2016;

however, in 2021, there is a predominance in the quantity of pesticide registrations.

Figure 1: registration of pesticides in Brazil – 2002-2021



Source: Ministério da Agricultura (2022)

2.1 The decree No. 10,833/21 for agricultural pesticides.

The legislation covers issues related to research, production, packaging, transportation, storage, marketing, importation, exportation, registration, classification, control, and inspection of pesticides, among other topics. The need to harmonize the criteria and guidelines adopted by other countries, which are reference points in the field of pesticides, and to keep pace with scientific advancements led to the issuance of decree 10,833/2021. This decree aims to enhance the existing legislation provided by decree 4,074/2002 and harmonize it internationally.

To achieve the harmonization of these criteria and guidelines, decree 10,833/2021 introduced the Global Harmonized System of Classification and Labelling of Chemicals (GHS). By adopting this system in our country, Brazil aligns itself with various other countries, such as those in the European Union, ensuring international conformity.

The advantage of implementing decree 10,833/2021 was the streamlining of the pesticide registration analysis process, which in Brazil is carried out by three agencies - Anvisa,

the Ministry of Agriculture, Livestock, and Supply (Mapa), and the Brazilian Institute of Environment and Renewable Natural Resources (Ibama). The rationalization of the work of these agencies aims to prevent redundancy among the mentioned agencies, establishing specific competencies for each of them and thereby enhancing the effectiveness of their work.

The decree also aimed to establish deadlines that can be met within the specified time, but it is a fact that it will face challenges in terms of reviewing registration requests within the currently regulated 120-day timeframe. This deadline is not compatible with the complexity and inherent specifics of the process, resulting in legal actions against the agencies responsible for pesticide registration in Brazil. For comparative purposes, Anvisa highlights some average timeframes practiced by other countries for completing registration: European Union - 4 years; Japan - 3.3 years; United States - 2.6 years; and in South America, Chile - 2.6 years and Argentina - 1.7 years.

In accordance with Article 95, Section III of Decree 4,074/2002, the concept of risk assessment, an internationally recognized approach adopted in the toxicological evaluation process for pesticide registration, has been included. Since Law 7,802/1989 clearly links the need for updating the analyses performed to international scientific procedures and advancements, the concept of risk assessment, which is internationally recognized and employed in the toxicological evaluation process for pesticide registration, has been incorporated in accordance with Article 95, Section III of Decree 4,074/2002.

Risk assessment in the context of pesticides was defined as a systematic analysis of the possibility of side effects resulting from human exposure to pesticides, etc. The assessment process includes several phases, such as hazard identification, assessment of exposure to the product, and characterization of the risk arising from that exposure.

As already stipulated in Law 7,802/1989, which obligates technical updates in line with the latest discoveries in the scientific field, decree 10,833/2021 provides that updated procedures must involve the assessment of all aspects related to pesticides, from a thorough understanding of their toxicological properties to the forms of exposure that pose potential risks to human health.

Another essential aspect that remains unchanged is the requirement for the training of pesticide applicators, who must hold certification and be registered for the monitoring of their professional activities, thereby enhancing safety and protecting the health of rural producers and end consumers. Therefore, decree No. 10,833/2021 has brought improvements to the work processes of the agencies involved in pesticide registration in Brazil.

3. Materials and Methods

This research was conducted using a mixed approach, combining qualitative and quantitative methods. According to Knechtel (2014), the qualitative-quantitative research approach "interprets quantitative information through numerical symbols and qualitative data through observation, participatory interaction, and interpretation of subjects' discourse (semantics)." We will use the quantitative method because we will rely on an assessment based on quantified numerical data recorded in statistically presented numbers in order to quantitatively evaluate and analyze the use of pesticides in commodities in Brazil. It is qualitative because through literary studies, we will obtain descriptive data from a critical and interpretative perspective to present the meaning of facts and events. Gil (1999) states that qualitative research is subjective to the object of study, based on the dynamics and approach to the researched problem, aiming to describe and interpretively decode the components of a complex system of meanings, without concern for the measurement of phenomena, as it involves understanding the context in which the phenomenon occurs.

In order to understand the characteristics studied within the context of pesticide use in Brazil, the research will have a descriptive nature. Descriptive research requires that its investigator has a good understanding of various pieces of information related to the topic to be studied because it aims to identify information about a subject that is already known. This allows the researcher to gather and analyze information about the study (SANTOS, 2010).

To construct the data panel, annual data were collected from 141 municipalities over the years from 2019 to 2022, related to variables such as planted area, production value, prices, productivity per hectare, quantity produced, and population. These data were made available by the Matogrossense Institute of Agropecuarian Economics - IMEA. Data from the annual Agrochemical Trade Report consolidated by INDEA-MT were also used. The estimator used in this study is the differences-in-differences model. According to BERTRAND, DUFLO, and MULLAINATHAN (2004), this technique has been in use since the 1850s by John Snow and is also known as the "before-and-after control study" in social sciences. The construction of the model and the variables is described below:

$$logquant\_prod_{it} = \beta_0 + \beta_1 D10833_{it} + \theta X_{it} + \lambda_{it} + \varepsilon_{it}$$

Where $logQuant\_prodit$ represents the dependent variable, or the outcome of interest corresponding to the logarithm of the quantity produced of soy and corn in

municipality i and year (t). The impact variable $\beta_1 D10833_{it}$ consists of the impact variable that takes the value 1 for municipalities and soy and corn crops affected by the publication of decree 10.833/2021, and 0 otherwise. θX_{it} is a group of covariates or control variables described in the data section. λ_{it} it represents the fixed time and municipality effect. Finally, ε_{it} it is an error term.

The differences-in-differences model represents the most suitable method when used in conjunction with a fixed or random effects estimator. To determine the choice of estimator, the Hausman method was used. Furthermore, to statistically validate our results, we applied tests for heterogeneous responses for different crops, along with tests for heterogeneous responses by type of HDI (Human Development Index), high, medium, and low. Table 1 presents the descriptive statistics of the variables used for model estimation.

Table 1 - Descriptive statistics of the variables used for model estimation.

variables	Obs.	Mean	Std. Dev.	Mín.	Máx.
Planted area	1,692	81.7691	140.5839	0	977
Productivity kg/hectare	1,692	3,810356	2,199121	0	7,423
Production in tons	1,692	676.1619	441.5018	132	1486
Prices	1,692	9,142585	29.4808	0	172.25
Quantity produced	1,692	237811	397370.7	0	3190928
Productivity in sacks	1,692	63.53191	36.66341	0	124
Production value	1,692	7074.041	28902.68	0	246489.8
KgPa pesticides	1,692	208.8209	270.4758	0	837
Population	1,692	31.53371	97.58787	1.525	946
municipalities	1,692	71	40.7142	1	141
Idhm	1,692	.6842908	.0381529	.538	.785

Source: IMEA-MT (2022) e Indea/MT (2022) e dados estimados na pesquisa.

4. Discussions and results

The Table 2 presents the main results of the estimations or effects of Law 10.833/21 on the productivity of soybean and corn crops in the municipalities of Mato Grosso. It is possible to observe that as the volume of agrochemical use increases in the observed period

from 2019 to 2022, there is a positive and significant effect on the percentage increase in the quantity produced of soybean and corn crops combined. The results recorded an increase of 10% in yield in Kg/hectare, while similarly, there is a 17% increase in sacks per hectare. This fact demonstrates that the increased commercialization of agrochemicals provided by Law 10.833/21 led to a widespread increase in the productivity of soybean and corn crops

Table 2
Effects of Decree 10,833/21 on the productivity of soybean and corn crops in Mato Grosso

variable	Productivity kg/hectare	Productivity in sacks
Law 10833/21	0.1094***	0.1711***
Std. Dev.	(0.0310)	(0.0270)
Random effects	Yes	Yes
Covariates	Yes	Yes
N. Obs.	1.692	1.692

Note: Standard Errors are in parentheses. *** represents significance at p<1%; ** represents significance at p<5%; * represents significance at p<10%; fixed effects are estimated by year and municipalities. The covariates used in the estimations are area/hectares, production in tons, production value, prices, kg of active ingredients of pesticides, and population.

Source: Indea/MT (2022), e IMEA (2022) e dados estimados na pesquisa.

4.1 Heterogeneous Response Tests

Tables 3 and 4 present the robustness test estimates by type of crop. It is possible to observe that as the volume of pesticide use in kg increases during the observed period from 2019 to 2022, there is a positive and significant effect on the percentage increase in the quantity produced of soybean and corn crops, now analyzed separately, with a more significant result for the corn crop (Table 4). The results showed an increase of 10.9% in productivity in kg/hectare for the soybean crop, while similarly, there is an increase of 22.6% in sacks per hectare.

Table 3
Effects of Decree 10,833/21 on the productivity of soybean cultivation in Mato Grosso.

variable	Productivity kg/hectare	Productivity in sacks
Law 10833/21	0.1090***	0.2264***
Std. Dev.	(0.168)	(0.540)
Random effects	SIM	SIM
Covariates	SIM	SIM
N. Obs.	846	846

Note: Standard Errors are in parentheses. *** represents significance at p<1%; ** represents significance at

p<5%; * represents significance at p<10%; fixed effects are estimated by year and municipalities. The covariates used in the estimations are area/hectares, production in tons, production value, prices, kg of active ingredients of pesticides, and population.

Source: Indea/MT (2022), e IMEA (2022) e dados estimados na pesquisa.

Similarly, in the case of corn cultivation but on a larger scale, with a more significant increase, the results demonstrate a 17.8% increase in yield in Kg/hectare for corn cultivation, while the yield in sacks per hectare shows an increase of 43.76%. This concludes that the effects of pesticides are more significant in terms of increasing yield for second-crop cultivation, or corn cultivation.

Table 4
Effects of Decree 10,833/21 on Corn Crop Productivity in Mato Grosso.

variable	Productivity kg/hectare	Productivity in sacks
Law 10833/21	0.1787***	0.4376***
Std. Dev.	(0.026)	(0.0443)
Random effects	SIM	SIM
Covariates	SIM	SIM
N. Obs.	846	846

Note: Standard Errors are in parentheses. *** represents significance at p<1%; ** represents significance at p<5%; * represents significance at p<10%; fixed effects are estimated by year and municipalities. The covariates used in the estimations are area/hectares, production in tons, production value, prices, kg of active ingredients of pesticides, and population.

Source: Indea/MT (2022), e IMEA (2022) e dados estimados na pesquisa.

Table 5 estimates the results by HDI level. The most significant results are observed in municipalities with a medium level of HDI, which make up the majority of observations, with a productivity increase rate of 13.33% for the analyzed period. Municipalities with a high level of HDI show a productivity increase rate of 5.4%.

Table 5
Effects of Decree 10.833/21 on the productivity (kg/ha) of soybean and corn crops in Mato Grosso by HDI level.

Variable	High HDI	Midle HDI	Low HDI
Law 10833/21	0.0541*	0.1333***	0.1158
Std. Dev.	(0.0324)	(0.0282)	(0.0872)
Random effects	SIM	SIM	SIM
Covariates	SIM	SIM	SIM
N. Obs.	588	1,068	36

Note: Standard Errors are in parentheses. *** represents significance at p<1%; ** represents significance at p<5%; * represents significance at p<10%; fixed effects are estimated by year and municipalities. The covariates used in the estimations are area/hectares, production in tons, production value, prices, kg of active ingredients of

pesticides, and population.

Source: Indea/MT (2022), e IMEA (2022) e dados estimados na pesquisa.

5. Conclusions

It is a fact that to produce food on a large scale, the conscious use of pesticides is essential as an additional tool to ensure protection against low yields or crop losses. However, chemical control should only be employed after all available control methods have been applied to avoid toxicological problems for both humans and the environment.

The relationship between pesticide sales per planted area in Brazil and the productivity of Brazilian crops also shows a long-term equilibrium, as evidenced by cointegration tests. Since the use of pesticides reduces agricultural production losses caused by pests and diseases, it allows the crop to express its productive potential, i.e., achieve its potential productivity for the technological package used.

This study aimed to present the estimates of the effects of Law 10,833/21, which released pesticides, on the productivity of soybean and corn crops in the producing municipalities of the state of Mato Grosso during the period from 2019 to 2022, using information from IMEA-MT, along with the report from INDEA-MT (Institute of Agricultural and Livestock Defense of the State of Mato Grosso). Through the difference-in-differences model with random effects, it was statistically demonstrated that the use of pesticides has positive effects on the productivity of soybean and corn crops.

The hypothesis of the study was based on the argument that the release and commercialization of pesticides would lead to increased productivity and profitability. This hypothesis was accepted and statistically proven. The results presented show that after the approval of Decree 10,833/21, which released pesticides, there was an increase in average productivity, i.e., yield in kg/hectare, considering both soybean and corn crops, by 10.94% in the municipalities that produce both crops in Mato Grosso. When considering estimates per bags/hectare, this yield increases to 17%. This demonstrates that the decree led to increased sales and, consequently, greater pesticide application, significantly improving the productivity of soybean and corn crops.

It was found that the justification for using pesticides in crops to increase production and profitability became relevant, as evidenced by the results obtained from 2019 to 2022 for soybean and corn crops. Since the increase in pesticide use represented 54% in both crops analyzed over the three-year period, it can be concluded that the increased use of pesticides allowed for significant increases in both crop quantity produced and yield per hectare.

Therefore, it is interesting for future research to relate these studies to other periods in the state to compare the evolution of pesticide use and analyze whether productivity continued to increase and whether profitability remained in decline or increased.

6. Authors contribution

Interpretation, econometric model design, translation, and writing of the paper: author 1; planning, analysis, and interpretation: author 2; both authors approved the final version submitted.

7. Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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