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ABSTRACT

Pesticides are chemicals used to control unwanted organisms in agriculture; however, their use can have negative impacts on the environment. In this context, the aim of this study was to survey and identify the main pesticides used on agricultural crops in the municipality of Morretes, Paraná, between 2015 and 2021, and to assess the potential environmental impacts of the active ingredients employed. To this end, data on the sale and use of pesticides provided by ADAPAR via the Pesticide Trade and Use Monitoring System (SIAGRO) were analysed, alongside information from IPARDES on the municipality's agricultural crops. The results demonstrated widespread use of herbicides, fungicides and insecticides in seasonal crops, such as sugarcane, cassava, beans, maize and tomatoes, and perennial crops, such as bananas, passion fruit, ginger and oranges. The eleven most commonly used pesticides totalled 33,604.49 kg or litres, accounting for 64.89% of the total analysed. Among the main active ingredients, Glyphosate (20.04%), Paraquat (16.06%) and Mancozeb (15.08%) stood out, highlighting the predominance of herbicides and fungicides in local agricultural management. A reduction in the use of Paraquat was also observed after 2018, linked to regulatory restrictions due to its high toxicity. The majority of the products identified belong to toxicological classes II and III, being considered highly or moderately toxic and hazardous to the environment, reinforcing the need for monitoring and the adoption of more sustainable agricultural practices.

Keywords: Pesticides. Agricultural. Environmental Impacts.

RESUMO

Os agrotóxicos são produtos químicos utilizados para o controle de organismos indesejáveis na agricultura, porém seu uso pode causar impactos negativos ao meio ambiente. Nesse contexto, o presente estudo teve como objetivo levantar e identificar os principais agrotóxicos utilizados nas culturas agrícolas do município de Morretes-PR entre 2015 e 2021, avaliando os possíveis impactos ambientais dos princípios ativos empregados. Para isso, foram analisados dados de comercialização e uso de agrotóxicos disponibilizados pela ADAPAR, por meio do Sistema de Monitoramento do Comércio e Uso de Agrotóxicos (SIAGRO), além de informações do IPARDES sobre as culturas agrícolas do município. Os resultados demonstraram ampla utilização de herbicidas, fungicidas e inseticidas em culturas temporárias, como cana-de-açúcar, mandioca, feijão, milho e tomate, e permanentes, como banana, maracujá, gengibre e laranja. Os onze agrotóxicos mais utilizados totalizaram 33.604,49 kg ou litros, correspondendo a 64,89% do total analisado. Entre os principais princípios ativos destacaram-se o Glifosato (20,04%), Paraquate (16,06%) e Mancozebe (15,08%), evidenciando a predominância de herbicidas e fungicidas no manejo agrícola local. Observou-se ainda redução do uso de Paraquate após 2018, relacionada às restrições regulatórias devido à sua elevada toxicidade. A maioria dos produtos identificados pertence às classes toxicológicas II e III, sendo considerados altamente ou medianamente tóxicos e perigosos ao meio ambiente, reforçando a necessidade de monitoramento e adoção de práticas agrícolas mais sustentáveis.

Palavras-chave: Pesticidas. Agricultura. Impactos Ambientais.

INTRODUCTION

The use of pesticides in the city of Morretes, located on the coast of the state of Paraná, Brazil, requires particular attention given the risks these products pose to the conservation of the Atlantic Forest, especially in a region where approximately 80% of the coastal territory is occupied by conservation units (CUs). In this context, the Sagrado River Watershed, located in the rural area of the city and within the Guaratuba Environmental Protection Area (EPA), deserves special attention. This sustainable-use Conservation Unit is part of the Atlantic Forest Biosphere Reserve and is characterized by its high ecological relevance and the presence of traditional agricultural activities (Nowatzki et al., 2010); (Kleina et al., 2017). Morretes encompasses different categories of CUs, including both sustainable-use and strictly protected areas (Silva; Sezerino, 2021), coexisting with agricultural activities focused on the production of bananas, rice, cassava, and vegetables. Therefore, Morretes provides an important setting for examining the relationships among agriculture, use of pesticide, environmental conservation, and regional development, particularly given the fragility of coastal ecosystems and the need to reconcile economic production with biodiversity conservation.

However, studies have reported conflicts between land use and environmental conservation resulting from agricultural activities within the region. In this context, Silva et al. (2017) highlighted the use of agrochemicals and their potential risk to Atlantic Forest conservation, reporting several cases in which agricultural production occurs in close proximity to CUs. Similarly, Souza et al. (2012) found that “the relatively flat terrain of the plains allows large-scale cultivation using agricultural machinery, pesticides, and the production of bananas and, especially, vegetables,” demonstrating the occurrence of use of pesticides in areas located within CUs in the city of Morretes and the potential environmental risks associated with these practices. Furthermore, Morretes is crossed by several rivers, including the Sagrado River watershed, which is protected by the Serra do Mar mountain range (Alvarez, 2008). Consequently, there is potential for contamination of watercourses and soils resulting from use of pesticides and inadequate sanitation infrastructure (Cunico; Fiori, 2008). These authors also emphasized that important springs and rivers within the city are located near protected areas, such as Pico do Marumbi State Park and Pau-Oco State Park, including the Iporanga River, which supplies the city with drinking water through the Companhia de Saneamento do Paraná (Cunico; Fiori, 2008). Nevertheless, despite existing environmental legislation, there is still no clear definition regarding minimum distances for pesticide application in areas adjacent to CUs (Piasseta et al., 2021).

For monitoring and management purposes, the state of Paraná operates the Pesticide Trade and Use Monitoring System (SIAGRO), regulated by State Decree No. 6,107/2010. This system compiles information on the commercialization and use of pesticides and is populated by companies and professionals responsible for issuing agronomic prescriptions (Gaboardi et al., 2019). Accordingly, Agência de Defesa Agropecuária do Paraná (ADAPAR), which manages the system, currently constitutes one of the principal databases for quantifying the use of pesticides in the state of Paraná, together with data provided by Instituto Paranaense de Desenvolvimento Econômico e Social (IPARDES).

Accordingly, the present study aimed to survey and identify the main pesticides used in agricultural crops in Morretes, Paraná, Brazil, as well as to assess the potential environmental impacts associated with the active ingredients applied between 2015 and 2021.

THEORETICAL REVIEW

PESTICIDES AND THE REGIONAL CONTEXT

The historical process of global capitalist expansion transformed agriculture into one of the main pillars supporting the economic reproduction of industries located in the Global North, consolidating modern agricultural production as part of an accumulation logic based on production intensification and technological dependence. Within this context, the production and commercialization of pesticides have assumed a strategic role in the contemporary economic system, becoming central elements of capitalist agriculture (Bombardi, 2023). Agricultural modernization, particularly following the so-called Green Revolution, promoted the expansion of mechanization, chemical fertilizers, improved seeds, and pesticides, together with the implementation of rural credit policies and technological incentives (Sousa et al., 2022). According to Pol et al. (2021), this production model established an agricultural system that is highly dependent on chemical inputs, increasing the use of pesticides as a strategy to enhance agricultural productivity. However, classical scholars of development theory, such as Furtado (1974), Valverde (1989), and Andrade (2004), had already argued that processes of territorial and regional development cannot be dissociated from environmental issues, particularly in light of the impacts generated by the intensive exploitation of natural resources.

In Brazil, the intensive use of pesticides has generated considerable debate regarding their environmental, social, and economic impacts, particularly in environmentally fragile regions, such as areas influenced by CUs and protected ecosystems. According to Law No. 7,802/1989, regulated by Decree No. 4,074/2002, pesticides are defined as physical, chemical, or biological products and agents intended for use in agricultural production, storage, and ecosystem protection, with the purpose of controlling organisms considered harmful (Brasil, 2002). These products include herbicides, fungicides, insecticides, bactericides, fumigants, and plant growth regulators (Ribeiro; Pereira, 2016). In the state of Paraná, State Decree No. 3,876/1983 regulates the distribution and commercialization of these products and prohibits the use of organochlorine compounds (Paraná, 1983). Despite these regulatory advances, several studies have shown that the indiscriminate use of pesticides results in soil and water contamination, human intoxication, mutations in animal and plant species, and the occurrence of severe diseases associated with chemical exposure (Mattei;

Michelon, 2021; Hess, 2024). Steffen et al. (2011) further emphasized that a substantial proportion of pesticides applied to crops reaches the soil directly, compromising its ecological functions and its capacity to sustain biodiversity.

Environmental vulnerability and use of pesticides in conservation areas

Soil performs essential functions for both ecosystems and agricultural production, serving as the physical support for plants and as a reservoir of nutrients indispensable for plant development (Lepsch, 2010). However, a significant proportion of the pesticides used in agriculture is dispersed by rainfall and wind, reaching soils, groundwater, and surface water bodies, particularly in the case of environmentally persistent compounds (Pignati, 2007). In Morretes, located on the coast of the state of Paraná, this issue becomes even more relevant due to the region's environmental characteristics. According to Silva et al. (2013), the predominant soil types in the city are Fluvent Entisols, Inceptisols, and Gleysols, each exhibiting different levels of vulnerability to chemical contamination and therefore considered environmentally fragile soils. Fluvent Entisols, found along riverbanks, have a low capacity to retain chemical compounds, whereas Inceptisols predominate in agricultural areas used for banana cultivation on the slopes of the Serra do Mar and are characterized as shallow and environmentally fragile soils. Gleysols, which are common in wetlands, exhibit a high susceptibility to contamination of both groundwater and surface waters (Silva et al., 2013). Thus, the interaction between environmental fragility, agricultural land use, and pesticide application increases environmental and public health risks throughout the coastal region of Paraná.

Due to this environmental vulnerability, a substantial portion of the coast of the state of Paraná is protected by environmental legislation and different categories of protected areas. CUs, regulated by the Brazilian National System of Nature Conservation Units, established by Law No. 9,985/2000 and regulated by Decree No. 4,340/2002, are intended to protect biodiversity, water resources, and natural ecosystems (Brasil, 2000). These units are classified into two categories: strictly protected areas and sustainable-use areas, with EPAs standing out as a category that allows human occupation while promoting environmental conservation and the sustainable use of natural resources. Besides CUs, permanent preservation areas, established under Law No. 12,651/2012, play an important role in protecting rivers, hillsides, biodiversity, and geological stability (Brasil, 2012). Furthermore, the

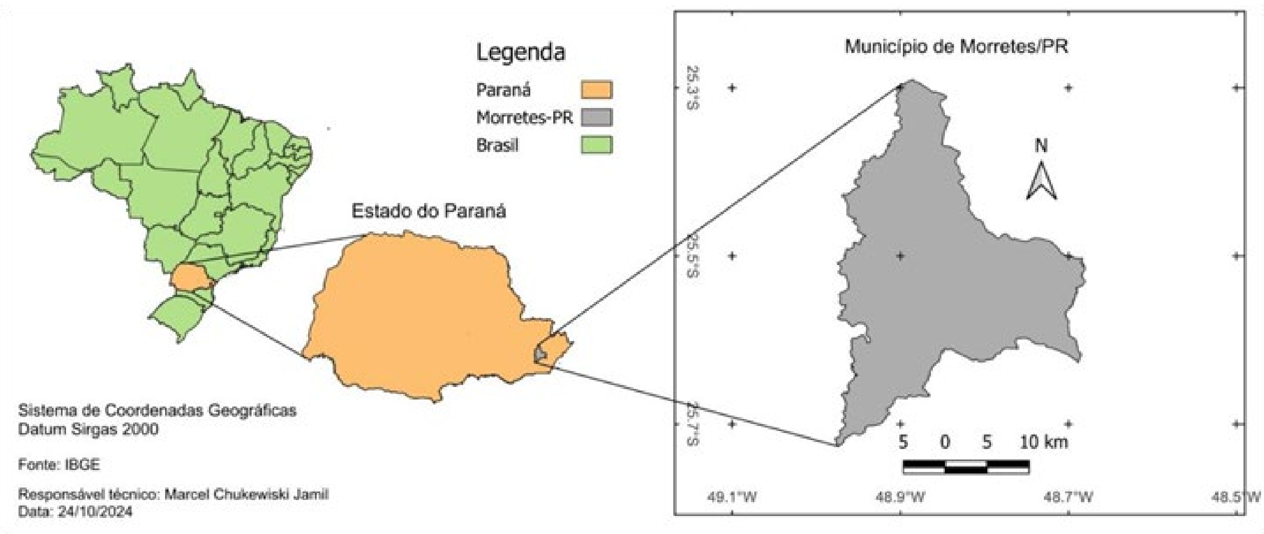
National Strategic Plan for Protected Areas, established by Decree No. 5,758/2006, aims to strengthen the management and conservation of these protected areas (Brasil, 2006). Within this context, CUs play a pivotal role in discussions on territorial planning and regional development, particularly in regions such as the coast of the state of Paraná, where agricultural activities conducted in close proximity to protected ecosystems require public policies and management strategies capable of reconciling economic production, environmental conservation, and the maintenance of ecosystem services provided to society.

MATERIALS AND METHODS

STUDY AREA

The city of Morretes, located in the state of Paraná, Brazil, has a territorial area of 688.473 km^2 according to IPARDES (2022) and is situated in the coastal plain region within the Atlantic Forest biome. Its geographical coordinates are 25° 28′ 44″ S latitude and 48° 49′ 54″ W longitude (Vanhoni; Mendonça, 2008). As one of the best-preserved remnants of the Atlantic Forest in Brazil, the biome is characterized by tropical humid montane forests, forming a heterogeneous ecosystem with exceptionally high species richness. The map below, obtained from the cartographic database of Instituto de Terras, Cartografia e Geociências (ITCG, 2000), shows the boundaries of the city of Morretes.

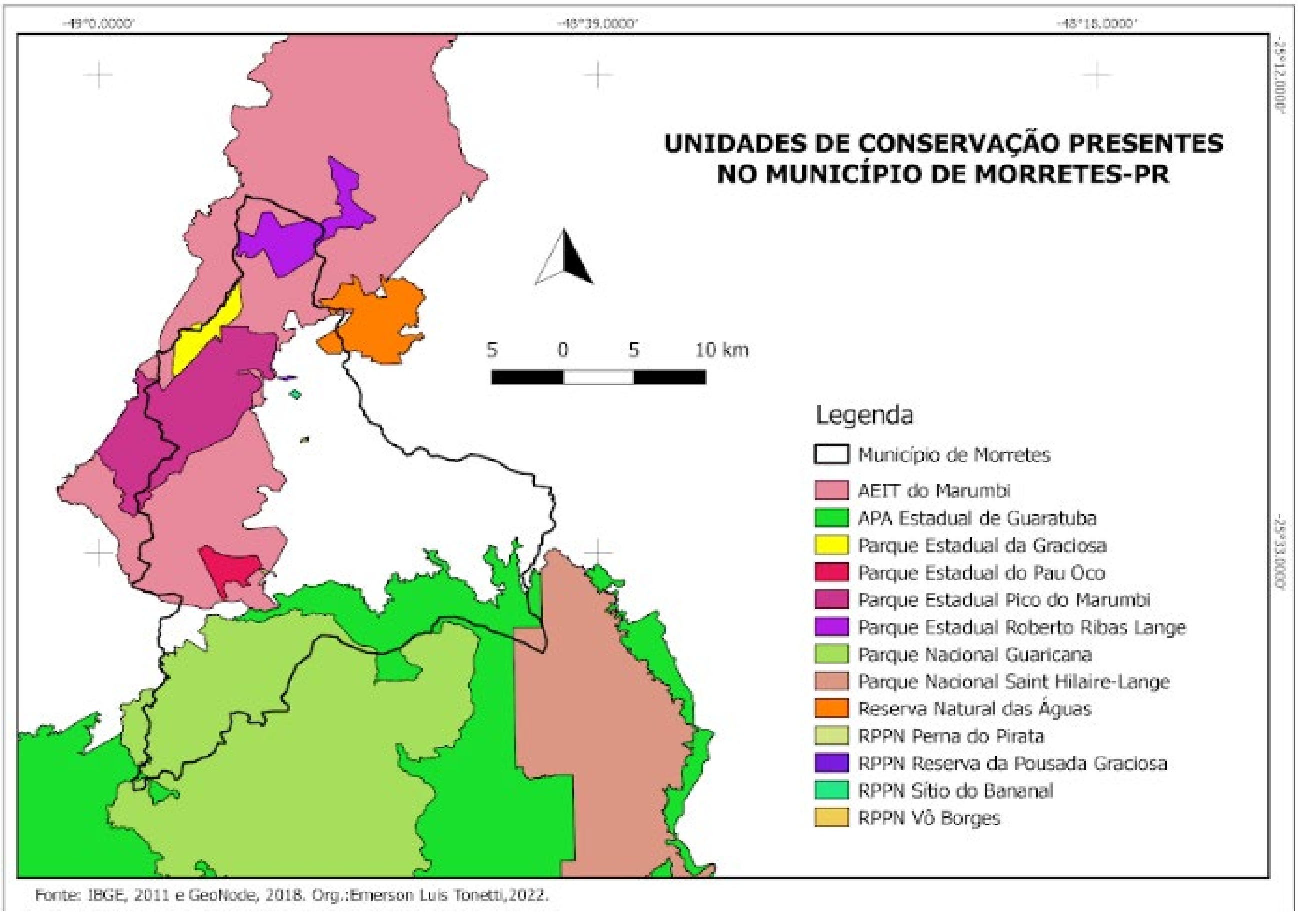
Figure 1 | Location of the study area: city of Morretes, Paraná, Brazil



Source: authors (2025).

The survey of the use of pesticides was conducted to investigate pesticide application on rural properties located either partially within the EPA or in areas adjacent to other categories of CUs, including State Parks, National Parks, Private Natural Heritage Reserves, and Natural Reserves (Figure 2).

Figure 2 | Conservation units in the city of Morretes, Paraná, Brazil



Source: IBGE, 2011 and GeoNode, 2018. Prepared by Emerson Luiz Tonetti, 2022.

The methodology consisted of a quantitative and exploratory study based on the collection of secondary data provided by ADAPAR, which operates SIAGRO. Data referring to the use of pesticides in Morretes were obtained following an adaptation of the methodology proposed by Wolfram et al. (2023). Statistical reports from IPARDES were also consulted to identify the city's main seasonal and temporary agricultural crops. ADAPAR provided monthly datasets covering the period from 2015 to 2021, which were analyzed to calculate the quantities (kg or liters) and percentages of pesticide active ingredients used in the city's agricultural areas. Subsequently, the most frequently used pesticides were organized and classified according to the toxicological criteria established by Embrapa (2018) and the environmental hazard classification proposed by IBAMA (2017).

Following this survey, the toxicological classification of pesticides was determined according to Embrapa (2018).

The toxicological classification of chemical products is based on the hazard potential of each predominant active ingredient:

a) Class I – Extremely toxic (red band);

b) Class II – Highly toxic (yellow band);

c) Class III – Moderately toxic (blue band);

d) Class IV – Slightly toxic (green band).

Additionally, the methodology proposed by IBAMA (2017) was adopted to classify the environmental hazard potential of pesticides according to Box 1, allowing the assessment and understanding of their transport potential among different environmental compartments, specifically air, soil, and water (IBAMA, 2017).

Accordingly, all pesticides registered in Brazil are assigned to one of these four environmental hazard classes. This classification is displayed in the central column of the product label and package insert, together with the toxicological classification. Therefore, the pesticides identified in this study were classified according to Box 1.

Box 1 | Environmental hazard potential of pesticides according to IBAMA (2017).

Class	Environmental hazard potential
I	Product highly hazardous to the environment
II	Product very hazardous to the environment
III	Product hazardous to the environment
IV	Product slightly hazardous to the environment

Source: Adapted from IBAMA, 2017.

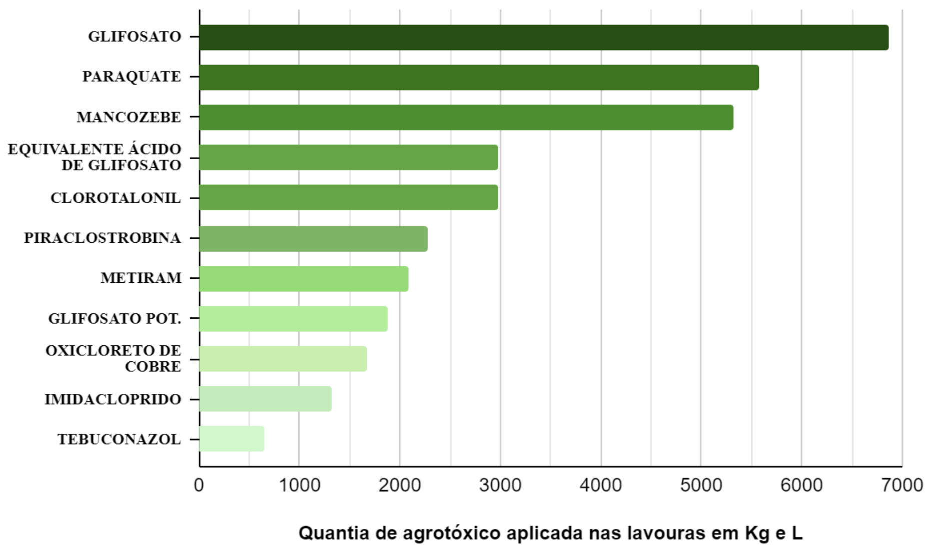
RESULTS AND DISCUSSION

Based on this survey, we found that different types of pesticides are used in agricultural production in Morretes to prevent and control pests, diseases, and weeds in both temporary and permanent crops. In this regard, data provided by ADAPAR showed that, between 2015 and 2021, different herbicides, insecticides, fungicides, and bactericides were used in Morretes' agricultural production.

Based on the ADAPAR dataset and the subsequent analysis of the pesticides most frequently used in agricultural crops, 11 products were identified as the most prominent (Figure 3). To obtain these results, the six most frequently used pesticides were first identified for each month of every year between January and December. After compiling these data, variations in the use of different active ingredients were observed over the study period. As shown in Figure 3, Glyphosate was the most widely used pesticide, totaling 6,871.40 L, followed by Paraquat (5,578 L), Mancozeb (5,319.55 kg), Glyphosate Acid Equivalent (2,971.50 L), Chlorothalonil (2,970.15 L), Pyraclostrobin (2,278.68 L), Metiram (2,087.18 L), Potassium Glyphosate (1,878.34 L), Copper Oxychloride (1,674 L), Imidacloprid (1,321.69 L), and Tebuconazole (654 L).

The prominent use of Glyphosate and Paraquat highlights the predominance of herbicides in local agricultural management, reflecting a production model that is highly dependent on the chemical control of weeds. This scenario follows the national trend observed in Brazil, which is considered one of the world's largest consumers of pesticides, particularly in high-productivity agricultural systems (Bombardi, 2023). The recurrent use of these active ingredients is associated with the expansion of monoculture farming and the intensification of agricultural practices, factors that contribute to increasing chemical dependence in crop production. Moreover, the pattern observed in Morretes is consistent with that reported for the state of Paraná (Ruths et al., 2024). Another noteworthy finding is the extensive use of fungicides, including Mancozeb, Chlorothalonil, Pyraclostrobin, Metiram, and Tebuconazole. The widespread use of these products is associated with the climatic conditions of the coastal region of Paraná, which is characterized by high humidity that favors the occurrence of fungal diseases in agricultural crops. As reported by Pignati et al. (2017), the frequent use of fungicides in intensive agricultural systems increases the potential for environmental contamination and occupational exposure, particularly in regions where these products are applied continuously throughout the year. Furthermore, copper-based products, such as Copper Oxychloride, although widely used for phytosanitary control, may lead to the accumulation of metals in the soil and cause alterations in agricultural ecosystems when applied over prolonged periods.

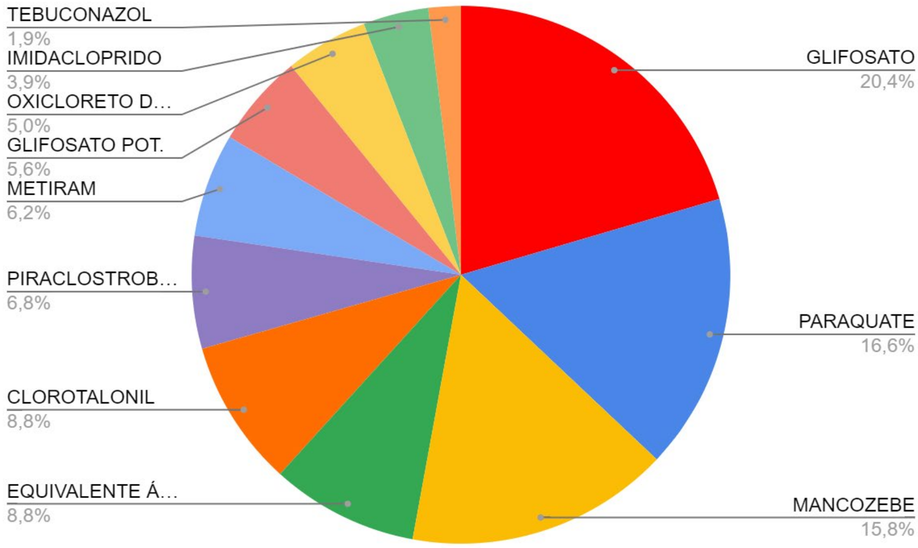
Figure 3 | Most frequently used pesticides during the study period (2015-2021).



Source: authors (2025).

The total amount of the active ingredients was 33,604.49 L or kg, representing 64.89% of the 11 most frequently used products. These were distributed as follows: Glyphosate (20.04%), Paraquat (16.06%), Mancozeb (15.08%), Glyphosate Acid Equivalent (8.08%), Chlorothalonil (8.08%), Pyraclostrobin (6.08%), Metiram (6.02%), Potassium Glyphosate (5.06%), Copper Oxychloride (5.00%), Imidacloprid (3.09%), and Tebuconazole (1.09%). These results are presented in Figure 4. The figure clearly demonstrates the predominance of herbicides among the most frequently used active ingredients in Morretes, particularly Glyphosate and Paraquat, which together account for more than 36% of the total analyzed. This finding highlights the strong dependence on chemical weed control in local agricultural management, particularly in temporary and permanent crops. According to Bombardi (2023), the intensive use of herbicides in Brazil is directly associated with an agricultural model based on high productivity and the expansion of agribusiness, contributing to increased environmental contamination and human exposure to pesticides.

Figure 4 | Percentage distribution of the most frequently used pesticides.



Source: authors (2025).

Glyphosate and Paraquat are herbicides used for weed control in agriculture. Oliveira-Filho (2013) states that herbicides are the most concerning class of pesticides from an environmental perspective. This is primarily due to their mobility in the soil, which frequently results in their detection in groundwater (Oliveira-Filho, 2013). Consequently, the use of herbicides is particularly complex from a toxicological standpoint.

Mancozeb, Chlorothalonil, Tebuconazole, Copper Oxychloride, Pyraclostrobin, and Metiram are described in the literature as fungicides used to control fungal diseases affecting plants, seeds, and other agricultural products. The chemical characteristics of these compounds are highly variable, and their application includes both protective and curative purposes (Oliveira-Filho, 2013). These products remain widely used and comprise several active ingredients. Nevertheless, many fungicides have been reassessed in several countries, with some products being withdrawn from the market because of their potential environmental impacts (Oliveira-Filho, 2013).

Imidacloprid is a systemic insecticide with translaminar activity (capable of penetrating leaf tissues) that acts through both contact and ingestion. It is rapidly absorbed and subsequently translocated from the upper to the lower parts of the plant, exhibiting effective systemic activity in the root system (ADAPAR, 2020).

Based on the data presented in Figure 4, the total quantity (kg or L) and percentage (%) of use were calculated for each active ingredient identified during the study. The cumulative amount of the most frequently used pesticides reached 33,604.49 kg or L, as presented in Table 1, considering the entire study period. It should be noted that the relative frequency was calculated exclusively for the eleven most frequently used products.

Table 1 | Pesticides with the highest usage between 2015 and 2021.

Pesticides	Amount (L or kg)								
	2015	2016	2017	2018	2019	2020	2021	Total	%
Glyphosate (H)	1,904.00	2,049.00	1,245.40	570.00	312.00	423.00	368.00	6,871.40	12.09%
Paraquat (H)	2,101.00	2,284.00	1,183.00	5.00	0.00	5.00	0.00	5,578.00	9.47%
Mancozeb (F)	901.60	836.45	525.50	680.10	936.70	746.00	693.20	5,319.55	8.94%
Glyphosate Acid Equivalent (H)	155.00	192.00	630.00	821.50	766.00	252.00	155.00	2,971.5	6.39%
Chlorothalonil (F)	489.65	311.40	267.25	378.50	763.60	412.75	347.00	2,970.15	5.04%
Pyraclostrobin (F)	54.00	81.00	167.18	213.00	456.00	717.00	590.00	2,278.68	4.57%
Metiram (F)	21.00	52.00	152.18	198.00	418.00	686.00	560.00	2,097.18	7.58%
Potassium Glyphosate (H)	180.00	193.34	198.00	325.00	308.00	463.00	211.00	1,878.34	4.00%
Copper Oxychloride (F)	235.00	235.00	196.00	273.00	310.00	203.00	222.00	1,674.00	2.98%
Imidacloprid (I)	148.21	291.62	190.06	166.74	208.70	191.33	125.03	1,321.69	2.56%
Tebuconazole (F)	204.00	117.00	77.00	84.00 L	86.00 L	45.00 L	41.00 L	654.00	1.26%
Total	6,393.46	6,642.81	4,831.57	3,714.84	4,565.00	4,144.08	3,312.73	33,604.49	64.89%

Source: authors (2026).

- H = Herbicide
- F = Fungicide
- I = Insecticide
- Temporary crops: sugarcane, cassava, common bean, maize, and tomato.
- Permanent crops: banana, passion fruit, ginger, and orange.

In 2015 and 2016, Paraquat was the most widely used pesticide, followed by Glyphosate, with only slight differences in the quantities applied to banana, sugarcane, common bean, cassava, passion fruit, maize, and tomato crops. However, a downward trend in Paraquat use was observed beginning in 2018 compared with previous years.

This reduction can be explained by Resolution No. 428 of October 7, 2020, which amended RDC No. 177 of September 21, 2017, and established the prohibition of the active ingredient Paraquat in Brazil following a 3-year transition period. During this period, Brazilian farmers were allowed to use only the remaining stocks of Paraquat-based products already in their possession for crop management. The prohibition was implemented because of the high acute toxicity of the herbicide Paraquat.

In 2017, Glyphosate reached its highest level of use, totaling 1,245.40 L of concentrated product. In the subsequent years, 2018 and 2019, Glyphosate was predominantly applied as the active ingredient Glyphosate Acid Equivalent. Overall, the trends in the use of pesticides clearly indicate that Paraquat and Glyphosate, together with its Glyphosate Acid Equivalent formulation, were the most widely used active ingredients throughout the study period.

Only after the prohibition of Paraquat and its formulations did its use decline in the years following 2018. Analysis of the use of pesticides in 2020 showed that Glyphosate Acid Equivalent became one of the least frequently used products, whereas the fungicide Pyraclostrobin exhibited a marked increase in use. Unlike previous years, the use of Glyphosate and its formulations declined, and Mancozeb became the most widely used pesticide in 2021.

Variations in the use of active ingredients were observed throughout the study period. These differences may be explained by variations in the cost of individual active ingredients, as well as by their effectiveness according to agronomic prescriptions for each crop and the agricultural calendar. Box 2 presents the toxicological class and toxicity of the eleven most frequently used pesticides during the study period. As shown, the herbicides Glyphosate, Glyphosate Acid Equivalent, and Potassium Glyphosate; the fungicides Mancozeb, Chlorothalonil, and Metiram; and the insecticide Imidacloprid are classified as Class III, indicating that they are moderately toxic and hazardous to the environment. Paraquat is classified as Class I, indicating that it is extremely toxic and highly hazardous to the environment. Tebuconazole, Copper Oxychloride, and Pyraclostrobin are classified as Class II, indicating that they are highly toxic and very hazardous to the environment. Elpo et al. (2008) had previously reported the indiscriminate introduction of pesticides in Morretes as well as their intensive use during the rainy season from January to April on small and medium-sized farms, involving products classified as highly toxic and moderately toxic.

Box 2 | Toxicological classification of the most frequently used pesticides in Morretes between 2015 and 2021

Pesticide	Type	EHP class
Glyphosate	Herbicide	III
Paraquat	Herbicide	I
Mancozeb	Fungicide	III
Glyphosate Acid Equivalent	Herbicide	III
Chlorothalonil	Fungicide	III
Pyraclostrobin	Fungicide	II
Metiram	Fungicide	III
Potassium Glyphosate	Herbicide	III
Copper Oxychloride	Fungicide	II
Imidacloprid	Insecticide	III
Tebuconazole	Fungicide	II

EHP: environmental hazard potential.

Source: Adapted from (IBAMA, 2017).

As shown, most of the pesticides identified as the most frequently used are classified as Class III, indicating that they are moderately toxic and hazardous to the environment. None of these products falls into Class IV (slightly toxic). The toxicity of a pesticide formulation depends on the specific active ingredient as well as on the presence of synergistic or inert compounds that may increase or modify its toxicity. Depending on the product classification, pesticides may have significant impacts on both the environment and human health (Ahmad et al., 2024). Despite the moderate toxicity classification of the pesticides most commonly used in Morretes, Schulz et al. (2021) emphasized the cumulative effects of different active ingredients within ecosystems, particularly in the present study area, where agricultural production using these products occurs within a mosaic of CUs.

Regarding agricultural crops, according to data from IPARDES (2022) presented in Box 3, Morretes has 111 temporary crop establishments covering 1,382 hectares, 121 horticulture and floriculture establishments occupying 1,688 hectares, 202 permanent crop establishments covering 5,193 hectares, and two establishments dedicated to seedling, nursery stock, and other plant propagation production (IPARDES, 2022).

Since the environmental importance of Morretes, particularly because of its diversity of CUs and abundant water resources, stricter control of the use of pesticides should be considered an essential criterion for water resource management (Anacleto; Silva, 2023). Wolfram et al. (2023) also highlighted the potential for contamination of water resources resulting from the use of pesticides in environmentally protected areas.

Box 3 | Agricultural establishments and cultivated area according to economic activity in Morretes.

Economic activity	Establishments	Area (ha)
Temporary crops	111	1,382
Horticulture and floriculture	121	1,688
Permanent crops	202	5,193
Seedling and plant propagation production	2	—
TOTAL	436	8,263

Fonte: IPARDES (2022), adapted from IBGE – Municipal Agricultural Production (2022).

In Morretes, most agricultural establishments are dedicated to permanent crops, which remain productive for extended periods and do not require replanting after harvest. This type of cultivation can produce food for many years and, when properly managed without the use of pesticides, contributes to maintaining soil quality.

Regarding the agricultural establishments presented in Box 4, there are 413 landowners managing a total area of 10,905 hectares. The predominant agricultural production consists of temporary crops (Box 5), including rice (paddy), sweet potato, sugarcane, common bean, cassava, maize, and tomato. Permanent crops (Box 6) include banana, orange, passion fruit, and heart of palm (IPARDES, 2022). No information is available regarding the number of properties that used or did not use pesticides. However, the total area allocated to agricultural production is only 10,905 hectares (Box 4) within a city covering 688.473 km^2. These findings indicate that pesticides were used extensively and that products belonging to different toxicological classes were applied.

Box 4 | Agricultural establishments and cultivated area according to land ownership in Morretes

AGRICULTURAL ESTABLISHMENTS		
Producer status	Establishments	Area (ha)
Landowner	413	10,905

Source: IPARDES (2022), adapted from IBGE (2022).

Box 5 | Harvested area, production, and average yield of temporary crops in Morretes.

TEMPORARY CROP	HARVESTED AREA (ha)	PRODUCTION (t)	AVERAGE YIELD (kg/ha)
Rice (paddy)	133	889	6,684
Sweet potato	6	96	16,000
Sugarcane	148	6,186	41,797
Common bean	4	4	1,000
Cassava	265	4,770	18,000
Maize	9	30	3,333
Tomato	14	560	40,000
TOTAL	579	12,535	126,814

Source: IPARDES (2022), adapted from IBGE (2022)

Box 6 | Harvested area, production, and average yield of permanent crops in Morretes.

PERMANENT CROP	HARVESTED AREA (ha)	PRODUCTION (t)	AVERAGE YIELD (kg/ha)
Banana	215	3,225	15,000
Orange	3	60	20,000
Passion fruit	110	1,980	18,000
Heart of palm	660	2,310	3,500
TOTAL	988	7,575	56,500

Source: IPARDES (2022), adapted from IBGE (2022)

Specifically in agricultural activities, it is essential to identify the type of crop being cultivated, namely whether it is a permanent crop or a temporary crop.

> Temporary (seasonal) crops are those that require replanting after harvest. They generally have a short life cycle and are removed from the soil following harvest to allow for a new planting. Permanent crops, in contrast, remain established in the soil and produce more than one harvest or yield over time. In general, permanent crops are defined as those with a minimum productive lifespan of four years (Marion, 2005, p. 38).

Furthermore, the survey of the ADAPAR database regarding the agricultural crops in which pesticides were applied showed that, between 2015 and 2021, the predominant temporary crops were sugarcane, cassava, common bean, maize, and tomato, whereas the predominant permanent crops were banana, passion fruit, ginger, and orange. Regardless of the crops cultivated, agricultural producers in Morretes are predominantly family farmers operating small and medium-sized properties dedicated to diversified production. Nevertheless, these production systems also exhibit characteristics of an entrepreneurial model, including the hiring of employees and market-oriented production, making them susceptible to market influences, as described by Gomes et al. (2015). Furthermore, family farmers, under pressure from agricultural technical support companies, and a process intensified during the COVID-19 pandemic, increasingly adopted production practices traditionally associated with large-scale agriculture (Nepomoceno, 2021).

FINAL CONSIDERATIONS

The results demonstrated that agricultural production in Morretes, state of Paraná, Brazil, was highly dependent on the use of pesticides between 2015 and 2021, particularly herbicides and fungicides, with Glyphosate, Paraquat, and Mancozeb being the most frequently used active ingredients. The predominance of these compounds reflects an intensive agricultural model based on the chemical control of pests, diseases, and weeds, consistent with the pattern observed throughout the state of Paraná and Brazil. Furthermore, most of the products used were classified as moderately or highly toxic, representing potential risks to both the environment and human health.

Considering the environmental importance of Morretes, characterized by its abundant water resources and numerous CUs, it is essential to strengthen monitoring, regulatory enforcement, and incentives for more sustainable agricultural practices. The adoption of crop management strategies that are less dependent on pesticides may contribute to reducing environmental impacts, preserving local ecosystems, and promoting the health of both rural populations and consumers.

Finally, our findings highlight the need for stricter oversight of the use of pesticides, particularly in areas containing different categories of CUs, since some of these protected areas lack buffer zones that could mitigate the environmental impacts associated with pesticide application.

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