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ENVIRONMENTAL RISK INDEX OF THE MAIN HERBICIDES USED IN THE STATE OF MATO GROSSO

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ABSTRACT
In view of the concern with the contamination of the environment due to the intensive use of pesticides in Brazilian agriculture, such as in the state of Mato Grosso, it is necessary to analyze the particulERIties that the active ingredients (a.i.) exert on the environment to help reduce their impacts, and the Environmental Risk Index (ERI) is a means of knowing these damages. Thus, the objective of this study was to perform the IRA of the most used herbicides in Mato Grosso for weed control in soybean, corn and cotton crops. The survey was carried out by i.a., based on data from the Institute of Agricultural Defense of Mato Grosso, while the physicochemical characteristics of the herbicides, necessary for the IRA equations, were obtained from three databases (PPDB, PPD and IBAMA). The parameters used for the construction of the IRA were: soil persistence, leaching, volatility, dose and toxicological profile of the herbicides. The survey pointed out 42 herbicides used, but 11 compounds represent 98.2% of the total volume sold, with glyphosate being the first in the ranking with a total mass of 134,138,025 kg a.i. sold in the last three years in Mato Grosso. The result of the IRA of the largest mass traded in descending order was: atrazine, diuron, trifluralin, glyphosate, 2,4-D, clomazone, S-metolachlor, diquat, haloxifop-methyl, clethodim and glufosinate-amonium. The herbicides atrazine, MSMA, diuron, trifluralin and pendimethalin were the a.i. that presented the highest AKI. In general, all herbicides

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presented medium to very high levels of toxicity, resulting in a worrying factor for ecosystems when they reach non-target organisms.

Keywords: Risk analysis, Pesticides, Toxicology.

INTRODUCTION

Brazil is the largest consumer of pesticides in the world and, in 2021, it sold a total of 720.87 thousand tons of active ingredient (a.i.), which represents an increase of 5.03% compared to the previous year 2020. The state of Mato Grosso alone consumed 150,981.23 tons of a.i. in 2021 and, among the most traded are glyphosate, 2,4-D, mancozeb, atrazine, acephate, malathion, clethodim and S-metolachlor (IBAMA, 2022). Despite the important role of these compounds in protecting crops against pests, there are constant questions about the effect on the environment and human health (VIEIRA et al., 2020).

The effect on human health due to exposure does not depend only on the toxicity of the active ingredients, but also on the time of exposure and the amount of compound absorbed (MEDEIROSA et al., 2021). In Brazilian rural properties, the greater the intensity of pesticide use, the greater the impact on the health of these populations, considering an average investment of R$ 52.45 reais per hectare with these compounds, the index is 0.45% of Brazilian properties with poisoned people (RODRIGUES; FÉRES, 2021).

Some aspects of contamination in the field caused by pesticides may be related to their application. The physicochemical properties of these compounds can help predict their movements through air, water, and soil, because once applied, they can be degraded, volatilized, leached, or absorbed into the soil (GÓMEZ-BELTRÁN et al., 2021). Knowledge of the dynamics of pesticides in the environment helps to understand the relationships between them, as well as to assess the probability of adverse effects to agrosystems (REBELOA; CALDASB, 2014).

In this context, knowing the impacts that pesticides can cause to the environment, through a toxicological screening of herbicides, can help in decision-making, in order to minimize harmful effects. The Environmental Risk Index (ERI) is one of the ways to know the potential damage of these substances, as it allows the use of existing information in the literature on pesticide risk assessments individually, requiring only investigations, in order to establish the impact of these molecules on the environment.

According to Decree 4074/2002, No. 6,913/2009; and by the joint normative instructions Mapa/Anvisa/Ibama No. 1/2006; No. 3/2006; No. 6/2006 and No. 1/2010, IBAMA must carry out an environmental risk assessment, as an integral part of the regulation of the registration of new pesticides and reassessment of those already registered in Brazil (IBAMA, 2022). In general, pesticides are the most easily found contaminants in soil and their permanence is related to their physical, chemical, and biological properties. However, the technical and scientific information of its active substances is found in national and international databases, helping in the review process (KIMBROUGH et al., 2020).

In Brazil, Weis et al. (2021) evaluated the risk of water contamination by pesticides through a mathematical model, in a total of 60 a.i., and found that carbosulfan, together with paraquat, represent the greatest risks to the natural resources of the region studied. Onwona-Kwakye et al. (2020) identified several pesticides that may pose an acute risk to aquatic ecosystems, however, the herbicide butachlor presented a higher acute risk to the terrestrial ecosystem, as did glyphosate with a higher chronic risk.

Therefore, the study of the risk of herbicide behavior, within an integrated weed management, aims to mitigate damage to the ecosystem and improve the efficiency and longevity of the production system (ZALLER; BRÜHL, 2019). This information can be very useful for strategic planning in weed management, helping to define the AI to be used, especially for Mato Grosso, the largest producer of grains and fibers in the country (CONAB, 2023a).

Thus, knowledge that contributes to the development of management tools, which aim to minimize the impacts caused by herbicides, is of paramount importance for the maintenance of the productive environment. Therefore, the purpose of the IRA was to provide information on herbicides, which should be a priority in future studies, in addition to offering support regarding care and uses in agricultural systems in the state of Mato Grosso.

MATERIAL AND METHODS

PESTICIDE DATA COLLECTION

Data on the most commercialized herbicides for weed control in the grain and fiber production system in the state were collected from the Institute of Agricultural Defense of Mato Grosso (INDEA), for the years 2020, 2021 and 2022.

The physicochemical characteristics of the herbicides used in soybean, corn, and cotton crops were obtained during 2023, and extracted from the Pesticide Properties Database (PPDB) of the University of Hertfordshire in England, the Pesticide Properties Database (PPD) of the U.S. Department of Agriculture, and the IBAMA pesticide database (LEWIS et al., 2016; USDA, 2023; IBAMA, 2024).

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ENVIRONMENTAL RISK INDEX (ERI)

The vERIables considered to estimate the potential risk of herbicides were volatilization, water solubility, soil persistence, adsorption, organic solvent solubility and toxicological profile. Based on these values, it was possible to assess the environmental risk of each herbicide. For this, the simple linear equation of the Environmental Risk Index (ERI), described by Alister and Kogan (2006) (Chart 1), was used. Each parameter is presented in the following topics.

Table 1. Equations used to construct the Environmental Risk Index (ERI).

Parameter	Equation	Description
Persistence (P)	K = 0.693/DT50 (1)	K: Degradation rate per day. T50: half-life of dissipation, persistence (Table 1). 0.693: Constant of proportionality.
Leaching (L)	LIX = $e^{(- k. Koc)}$ (2)	K: Constant of proportionality (Equation 2). Koc: Sorption coefficient normalized in relation to the organic carbon content of the soil.
Volatilization (V)	V = 2.9 x 10-3 P M0.5 (3)	Q: Steam pressure. M: molecular weight of the pesticide.
Environmental Risk Index (IRA)	IRA = (P+L+V+PT) D (4)	Q: Persistence. L: Leaching. V: Volatilization. PT: Toxicological profile. D: Dose.
Toxicological Profile (PT)	*PT= Kow + Rfd + DL50 + TA* (5)	Kow: Octanol-water partition coefficient. Rfd: Reference dose. LD50: Acute lethal dose for humans. TA: Animal toxicology.

Source: Adapted from Alister and Kogan (2006).

Persistence

Persistence is characterized for each herbicide by its mean half-life (t1/2) of dissipation, i.e., the time required, in days, for 50% of the initial concentration of the pesticide to be degraded in the soil (SAMGHANI; HOSSEINFATEMI, 2016). The T50 of a herbicide in the soil can be influenced by factors such as soil moisture, precipitation, temperature, intrinsic characteristics of the soil, among others (BAUMGARTNER et al., 2017).

Leaching

Once applied to the atmosphere, herbicides can be moved over great distances and, among the vERIous forms of dispersion, it is possible that it is leached into groundwater and/or transported via runoff to other locations (SEVERO et al., 2020).

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To determine this parameter, the method proposed by Spadotto (2002), called the LIX index, was used, which was developed to provide clear information on the leaching potential of pesticides, on a scale ranging from 0 to 1, thus identifying the compounds that need greater attention in determining the leaching potential, in order to analyze their leaching characteristics more carefully. This index identifies non-leachable (LIX = 0) and leachable (LIX ≥ 0.1 - 1.0) herbicides (SPADOTTO, 2002).

Volatility

Volatilization is the process by which the pesticide is deposited in the desired area, but evaporates to the atmosphere in gaseous form, being transported out of the target of application (MUELLER, 2015). The volatility of a herbicide is associated with higher relative humidity of the air and soil, as well as its surface temperature (COSTA et al., 2016). The pesticide vapor pressure, chemical properties, structure, and molecular weight determine the distribution of the part that will be evaporated and/or deposited on soil, however, the higher its vapor pressure, the higher its volatility rate (PIRES et al., 2022).

Dose

The dose represents the amount of a.i. that is applied to a given target in the environment, which is an important factor, because the greater the amount of a.i. applied, the greater the chemical load of the pesticide and, consequently, the greater the potential for soil and water contamination (ALISTER; KOGAN, 2006). In addition, the dose will also have a multiplier effect on the other components of the IRA, because even if the LD50 is the same for two different herbicides, the one with the highest dose of a.i. to be applied will have a higher risk of leaching. For the ERI equation, the maximum dosages allowed by the herbicide package insert for weed control in cotton, soybean and corn crops were used, and scores were assigned according to the degree of severity (Table 1).

Table 1. Degree of severity, assigned values and intervals proposed by Alister and Kogan (2006) for each term of the Environmental Risk Index.

Degree of severity and values assigned		Sorting of intervals				
		Persistence (P) (DT50, days)	Dose (D)* (kg a.i. ha^{-1})	Leaching (L) LIX Index	Volatility (V) (mmHg)	Profile Toxicológico (PT)
Low	1	≤ 30	≤ 1	≤ 0.09	≤ 10-6	≤ 8
Medium	2	30 ≤ 60	1 ≤ 2	0.09 ≤ 0.25	10-6 ≤ 10-5	8 ≤ 14
High	3	60 < 90	2 < 3	0,25 < 0,5	$10^{-5} < 10^{-4}$	14 < 20

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Very high	4	≥ 90	≥ 4	≥ 0,5	≥ 10^{-4}	≥ 20

Source: Adapted from Alister and Kogan (2006). * Higher dose used for soybean, corn and cotton crops.

Toxicological profile

The toxicological profile (PT) is an estimate of the impact that a given pesticide presents when it reaches a living community of an ecosystem, taking into account important factors such as estimating the Kow, Rfd, LD50 and animal toxicology (TA), for this, values 1, 2, 3 or 4 were assigned, which represent low, medium, high and very high, respectively (Table 2). The values of the toxicological profile (TP) may be from 6 to a maximum value of 24, while the IRA is concentrated in the theoretical range of 4 to 64 (ALISTER; KOGAN, 2006).

Table 2. Degree of pesticide severity, assigned values and intervals for each Toxicological Profile term.

Degree of severity and values Assigned		Sorting of intervals					
		Kow Log Kow	Rfd mg kg^{-1} is ^{1}	DL50 mg kg^{-1}	CL50 Ave mg L^{-1}	DL50 Bee µg ab^{-1}	CL50 Peixe mg L^{-1}
Low	1	1 ≤	≥ 0,1	≥ 4000	≥ 5000	≥ 100	≥ 100
Medium	2	1 ≤ 2	0,1 ≥ 0,01	4000 ≥ 400	5000 ≥ 500	100 ≥ 50	100 ≥ 50
High	3	2 > 3	0,01 > 0,001	400 > 40	500 > 50	50 > 25	50 > 10
Very high	4	≥ 3	≤ 0.001	≤ 40 ≤	≤ 50 ≤	25 ≤	10 ≤

Fonte: Adaptado de Alister e Kogan. (2006). A Ave refere-se *Anas platyrhynchor / Colinus virginiaus*, abelha à *Apis* spp., peixe à *Oncorhynchus mykiss / Lepomis macrochirus*.

The octanol-water coefficient (Kow) is defined by the measure of the intensity of affinity that a molecule has for the nonpolar (1 octanol) and polar phase (represented by water), being a measure of the lipophilicity of the molecule, allowing the quantification of the potential impact of pesticides in relation to the accumulation in fatty acids (OLIVEIRA; BRIGHENTI, 2011).

Octanol represents a substitute for biotic lipid and polERIty, the presence of alkaline atoms and the asymmetry of molecules present a greater contribution to solubility in water, while elements heavier than carbon and lipophobic characteristics, a lower solubility, therefore, gives an approximation to a biotic lipid-water partition coefficient (FIORESSIA et al., 2019).

While the reference dose (Rfd) is a risk indicator, represented by the estimate of acceptable daily exposure that a human can ingest without causing a health risk (MARTINAZZO et al., 2011). The lethal dose (LD50), on the other hand, refers to the time required for the concentration of the chemical substance under controlled laboratory

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conditions to reduce by 50% the number of individuals to whom the pesticide was administered (LOUREIRO et al., 2021). As a reference to LD50, the present study used the dermal lethal dose to be included in the TST equation.

For Apis spp. bees, the acute contact LD50, expressed in mg bee-1, we considered the worst values for 24, 48 and 72 hours. For birds, the acute LD50 is expressed in mg kg-1 of body weight, and the choice of data was for the species Colinus virginianus, in the last case, when no data was available for this species, the LD50 used was for Anas platyrhynchos. The 96-hour acute lethal concentration (LC50) for fish is expressed in mg L-1, and the species used was Onchorynchus mykiss, when the value was not found in the selected databases, the value for the species Lepomis macrochirus was used.

Characterization of Precipitation and Temperature in Mato Grosso

The Cerrado has a strong climatic seasonality, with some peculiERIties, configuring a rainy period, during spring and summer, followed by a dry period, throughout autumn and winter (NASCIMENTO; NOVAIS, 2020). Climatic data related to monthly rainfall and average temperature were collected from the National Institute of Meteorology (INMET), using information from eleven meteorological stations distributed throughout the state of Mato Grosso (Table 3).

Table 3. Meteorological stations used for precipitation and temperature analysis in Mato Grosso.

Name	Code	Latitude	Longitude	Altitude
Cuiabá	A901	15th 33' 33"	56º 3' 46"	241
Nova Xavantina	83319	14th 42' 00"	52º 9' 45"	440
Primavera do Leste	A923	15th 48' 00"	54º 22' 51"	680
Canarana	83270	13th 42' 00"	52º 16' 12"	406
Tangará a Serra	A902	14th 30' 00"	57º 25' 54"	440
Diamantino	83309	14th 24' 36"	56º 27' 00"	448
Querência	A916	12th 36' 16"	52º 9' 45"	355
São José do Rio Claro	A903	13th 27' 14"	56º 40' 37"	339
Vila Bela da Santíssima Trindade	A922	15th 3' 46"	59º 52' 23"	213
Smile	A904	12th 33' 18"	55º 43' 22"	379
Sapezal	DT7917	13th 18' 14"	58º 45' 47"	710

Fonte: INMET, 2023.

The process of constructing the IRA of herbicides involves, therefore, the multidisciplinary survey of data, through parameters that indicate and form information about their behavior in the environment. In this sense, the study presents quantitative and qualitative data of the main herbicides used in Mato Grosso, being compared through tables, ordered according to their use and risk presented to the environment.

RESULTS AND DISCUSSION

The most widely used herbicides during the period from 2020 to 2022 in the state of Mato Grosso included 42 a.i., 26 chemical groups and 13 mechanisms of action, with total commercialized represented in Table 4. Glyphosate, atrazine, 2,4-D, S-metolachlor, clethodim and diquat were responsible for the highest numbers, with the sum during the three years, exceeding a total mass of 187.8 million kg across the state (INDEA, 2023).

The amount of herbicides discriminated by INDEA, for the three crops, soybean, corn and cotton that have the largest extension of area and economic importance in Mato Grosso were grouped, with a total area of 16,625.7 thousand ha-1, 17,325.3 thousand ha-1 and 18,796.0 thousand ha-1 for the 2020, 2021 and 2022 harvests, respectively (CONAB, 2023b).

Of the total a.i. evaluated, 54.7% (atrazine, S-metolachlor, trifluralin, glufosinate-amonium, clomazone, diuron, fomesafen, sulfentrazone, carfetrazone-ethyl, triclopyr, chlorasulam-methyl, flumiclorac-penthyl, diclosulam, quizalofop-ethyl, lactofen, fenoxaprop-p-ethyl, pendimethalin, fluazifop-p-buthyl, metribuzin, dicamba, isoxaflutol, fenoxaprop-p-ethyl and amicarbazone) have environmental classification II, a very dangerous product, with a high degree of toxicity to algae, animals aquatic animals, bees, among others (AGROFIT, 2023).

While 45.3% (glyphosate, 2,4-D, clethodim, diquat, haloxifop-methyl, flumioxazin, imazethapyr, mesotrione, chlorimuron-ethyl, MSMA, pyroxasulfone, pyrithiobac-sodium, nicosulfuron, fluroxypyr, saflufenacil, metsulfuron-methyl, trifloxysulfuron-sodium, imazapic, simazine, and imazaquin) are in class III (Table 4), being dangerous and highly toxic to micro crustaceans, fish, and bees (AGROFIT, 2023).

The physicochemical properties of the herbicides for the realization of the ERI are represented in Table 5. The highest degradation rate (T50) was for the a.i. quizalofop-ethyl, with 0.4 days, while the lowest degradation rate was for imazethapyr with T50 of 513 days. According to Carvalho (2013), the T50 <30 days classifies pesticides as non-persistent, between 30-100 moderately persistent, 100-365 days persistent, and the T50 > 365 days very persistent.

Dessa forma, 59,52% dos herbicidas analisados (glyphosate, clomazone, S-metolachlor, glufosinate-amonnium, 2,4-D, clethodim, piroxasulfone, carfentrazone-ethyl, diquat, flumioxazin, quizalofop-ethyl, nicosulfuron, haloxifop-methyl, lactofen, metsulfuron-methyl, mesotrione, triclopyr, fluroxypyr, fluazifop-p-buthyl, dicamba, saflufenacil, isoxaflutol, fenoxaprop-p-ethyl, metribuzin e cloransulam-methyl) não são persistentes (DT50 <30 dias).

Pyrithiobac-sodium, fomesafen, atrazine, trifloxysulfuron-sodium, chlorimuron-ethyl, diclosulam, flumiclorac-penthyl, amicarbazone and simazine formed 21.42% and are medium-persistent (T50 >30 and <100 days). While trifluralin, diuron, pendimethalin, MSMA, imazaquin and imazapic, accounted for 14.28% and are persistent in the soil, with a T50 of more than 100 days. In the case of sulfentrazone and imazethapyr, it takes 400 and 513 days, respectively, for half of the initial concentration to be degraded.

Regarding the sorption coefficient to the organic carbon content - CO (Koc), it indicates the relative sorption of the pesticide in the soil, and when this value is high, the sorption will be high, so pesticides with high Koc are poorly soluble in water and can be transported by sediments other than water (GUARDA et al., 2020).

The herbicide information was tabulated according to the Chemical Database of Existing Pesticides prepared by Lewis et al. (2016), in which they classify Koc <15 as very mobile, 15-75 mobile, 75-500 moderately mobile, 500-4000 slightly mobile and >4000 non-mobile, based on the retention potential of the pesticide normalized to the organic carbon present in the soil. Thus, 36.58% of the herbicides studied were identified as mobile in the soil, 31.70% moderately mobile, 17.07% slightly mobile and, finally, 14.63% of the herbicides classified as non-mobile (Table 5).

The Koc, therefore, is an indicator of the mobility of herbicides in the soil and is directly related to the organic carbon content in it, thus, the higher the content, the greater the surface area and porous structures, resulting in greater sorption capacity of herbicides. In this sense, small vERIations in the concentration of organic carbon in the profile can influence the dynamics of pesticides (CHITOLINA et al., 2020).

When analyzing the sorption coefficient together with the half-life, we have herbicides that are persistent in the soil, such as imazaquin, MSMA, pendimethalin and trifluralin, and very persistent, as is the case of sulfentrazone and imazethapyr, but Koc differentiates them, being trifluralin, MSMA and pendimenthalin non-motile, while sulfentrazone, imazethapyr and imazaquin are motile in the soil. Thus, the herbicides trifluralin, MSMA and pendimethalin have a greater potential to suffer surface runoff than sulfentrazone, imazethapyr and imazaquin, which would have a higher vertical leaching potential in the soil profile.

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According to Inoue et al. (2002), the leaching of imazaquin is influenced by the increase in soil pH, being higher the closer it is to neutrality. For Nunes and Vidal (2017), imazaquin presents low leaching, because after 25 days of application, more than 60% of the a.i. was biodetected at a depth of 2-8 cm. Regarding sulfentrazone, Melo et al. (2010) observed greater leaching with increased dose, being more pronounced in sandy soils.

Regarding the ionization of the herbicides analyzed, only fenoxaprop-p-etlyl is very strong acid, and most of it is 35.71% weak acids, 19.04% strong acids, 4.76% very weak bases and 26.16% non-ionizable (Table 5). For herbicides that dissociate as weak acids and weak bases, the higher the pH value, the lower the herbicide sorption in the soil, which can influence the leaching process (OLIVEIRA Jr et al., 2022).

Thus, according to Oliveira Jr. et al. (2022), acidic herbicides can be considered strong if the pKa is less than 3.0; weak if the pKa is between 3.0 and 9.0; and very weak if the pKa is greater than 9.0. Regarding bases, they are considered strong if pKa greater than 9.0; weak between 3.0 and 9.0 and very weak pKa less than 3.0 (Table 5).

Table 4. Main herbicides used in the state of Mato Grosso in 2020, 2021 and 2022 for weed control.

Active Ingredient (a.i.)	Mechanism of Action [1]	Chemical Group	Environmental Rating*	2020	2021	2022	Total
				Total Mass**	Total Mass**	Total Mass**	Total Mass**
				Kg a.i.	Kg a.i.	Kg i.a.	Kg i.a.
Glyphosate	EPSPs	Glycine substituted	III	44.141.701	46.836.859	43.159.465	134.138.025
Atrazine	FS II	Triazine	II	8.321.304	8.356.818	7.964.860	24.642.982
2,4-D	Auxins	Carboxylic phenoxy acid	III	5.164.068	5.198.853	5.394.934	15.757.855
S-metolachlor	Mitosis	Chloroacetanilide	II	1.372.963	1.815.254	1.827.983	5.016.200
Clethodim	ACCase	Ciclohexanoclean	III	980.583	1.273.868	1.358.024	3.612.475
Diquat	FS I	Bipyridylum	III	873.054	1.251.975	2.564.299	4.689.328
Trifluralin	Microtubules	Powered by Dinitroanide	II	549.877	722.868	1.007.430	2.280.175
Glufosinate-amonnium	Inib. Yes Glutamine	Homoalanine replaced	II	305.227	645.847	1.009.636	1.960.710
Clomazone	Carotenoids	Isoxazolidinona	II	127.393	263.038	537.661	928.092
Haloxyfop-methyl	ACCase	Aryloxyfenoxipropionate	III	154.643	269.227	405.471	829.341
Diuron	FS II	Phenylureia	II	185.613	169.417	265.581	620.611
Flumioxazine	PROTOX	Cyclohegenodicarboxymide	III	121.822	155.685	189.911	467.418
Fomesafen	PROTOX	Diphenyl ether	II	215.220	108.192	91.686	415.098
Imazethapyr	THAN	Imidazolinona	III	163.873	145.347	176.745	485.965
Mesotrione	Cathotenoids	Come on, let's go	III	81.921	86.684	103.199	271.804
Sulfentrazone	PROTOX	Triazolone	II	64.492	67.390	113.233	245.115
Chlorimuron-ethyl	THAN	Sulfoniluréia	III	70.439	78.756	94.230	243.425
Carfentrazone-ethyl	PROTOX	Triazolone	II	35.250	62.233	98.313	195.796
Triclopyr	Auxins	Pridiniloxialcanoico	II	37.030	17.351	56.787	111.168
Cloransulam-methyl	THAN	Sulfonanilida triazolopirimidina	II	9.778	22.614	73.290	105.682

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Flumiclorac-penthyl	THAN	Cyclohegenodicarboxymide	II	716	43.862	31.055	75.633
Diclosulam	THAN	Sulfonanilida triazolopirimidina	II	18.502	25.353	31.080	74.935
Quizalofop-P-tefuryl	ACCase	Aryloxyfenoxipropionate	II	8.592	24.464	24.015	57.071
MSMA	Unknown	Organoarsênic	III	7.222	35.529	12.049	54.800
Lactofen	PROTOX	Diphenyl Ether	II	28.380	20.429	5.922	54.731
Pyroxasulfone	Mitosis	Oxazole	III	1.179	16.346	33.720	51.245
Pyrithiobac-sodium	THAN	Pirimidiniloxibenzóico	III	11.710	16.393	8.163	36.266
Nicosulfuron	THAN	Sulfoniluréia	III	11.082	11.545	13.486	36.113
Fenoxaprop-p-ethyl	ACCase	Aryloxyfenoxipropionate	II	15.382	10.169	6.041	31.592
Fluroxypyr	Auxins	Pridiniloxialcanoico	III	3.279	5.508	21.948	30.735
Saflufenacil	PROTOX	Pyramids	III	6.492	7.778	14.280	28.550
Metsulfuron-methyl	THAN	Sulfoniluréia	III	686	278	13.697	14.661
Pendimethalin	Microtubules	Powered by Dinitroanide	II	4.904	3.836	5.609	14.349
Fluazifop-buthyl	ACCase	Aryloxyfenoxipropionate	II	5.437	2.379	554	8.370
Metribuzin	FS II	Triazinone	II	1.384	2.913	469	4.766
Dicamba	Auxins	Benzoic acid	II	75	979	2.493	3.547
Isoxaflutole	Cathotenoids	Oxazole	II	623	261	2.254	3.138
Amicarbazone	FS II	Triazinolinona	II	-	812	2.082	2.894
Trifloxysulfuron-sodium	THAN	Sulfoniluréia	III	791	1.367	241	2.399
Imazapic	THAN	Imidazolinona	II	536	929	211	1.676
Simazine	FS II	Triazine	III	450	-	230	680
Imazaquin	THAN	Imidazolinona	III	-	150	3	153
Total				63.103.673	67.779.556	66.722.340	197.605.569

* Data obtained from the Institute of Agricultural Defense of Mato Grosso – INDEA. ** Environmental classification according to the registration of formulated products (Agrofit – MAPA). ACCase = inhibition of aceti – CoA carboxylase; carotenoids = inhibition of carotenoid biosynthesis; microtubules = inhibition of microtubule formation; FS I = inhibition of photosynthesis in photosyntem. FS II = inhibition of photosynthesis in photosynthema II; PROTOX = inhibition of protoporphyrinogen oxidase; lipids = inhibition of lipid synthesis; mitosis = inhibition of mitosis; ALS = inhibition of acetolactate synthase; auxins = auxin mimics; cellulose = inhibition of cellulose biosynthesis; EPSPs = glycine replaced;

Table 5. Physicochemical properties of herbicides used to calculate the Environmental Risk Index - IRA.

Herbicide	*DT50a*	Husband	Kb	Vapor Pressure	Indicec	Dosed	*Sw**	Classification	pKa / pKb	Ionization
(i.a.)	(days)	(L Kg^{-1})	(1 day)	(mmHg)	LIX	(kg a.i./ha)	(mg L^{-1})	of *Sw**		
Trifluralin	133,7	15800	0,00518	1,47 x 10^{-2}	0,0000	1,07	0,221	Low	-	Non-ionizable
Glyphosate	16,11	1424	0,04302	2,45 x 10^{-8}	0,0000	2,40	100000	Loud	2,34	Weak acid
Clomazone	22,6	300	0,03066	1,92 x 10^{-2}	0,0000	1,00	1212	Loud	-	Non-ionizable
Diuron	146,6	680	0,00473	9,2 x 10^{-6}	0,0000	3,20	35,6	Low	-	Non-ionizable
S-metolachlor	15	120	0,04620	1,73 x 10^{-3}	0,0000	1,00	530	Loud	-	Non-ionizable
Glufosinate-amonnium	7,4	600	0,09365	1,0 x 10^{-4}	0,0000	0,70	500000	Loud	9,15	Weak acid
2,4-D	4,4	39,3	0,15750	1,5 x 10^{-5}	0,0024	1,34	24300	Loud	2,8	Strong acid

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Clethodim	0,55	22,17	1,26000	$1,33 \times 10^{-5}$	-	0,11	5450	Loud	4,47	Weak acid
Pyroxasulfone	22	223	0,03150	$3,0 \times 10^{-06}$	0,0009	0,15	3,49	Low	-	Non-ionizable
Carfentrazone-ethyl	12,4	750	0,05589	$1,6 \times 10^{-5}$	0,0000	0,06	29,3	Low	-	Non-ionizable
Diquat	30	210	0,02310	$3,04 \times 10^{-3}$	0,0000	0,50	260	Moderate	-	Non-ionizable
Pyrithiobac-sodium	60	-	0,01155	$1,33 \times 10^{-3}$	-	0,14	728000	Loud	2,34	Strong acid
Flumioxazine	21,9	889	0,03164	$3,21 \times 10^{-4}$	0,0000	0,05	0,786	Low	-	Non-ionizable
Pendimethalin	182,3	17491	0,00380	$1,33 \times 10^{-5}$	0,0000	1,60	0,33	Low	2,8	Strong acid
Quizalofop-ethyl	0,4	510	1,73250	$4,0 \times 10^{-5}$	0,0000	0,08	0,61	Low	1,25	Strong acid
Nicosulfuron	16,4	30	0,04226	$4,8 \times 10^{-8}$	0,2815	0,06	7500	Loud	4,78	Weak acid
Fomesafen	86	50	0,00806	$1,33 \times 10^{-5}$	0,0000	0,38	50	Moderate	2,83	Strong acid
MSMA	200	7000	0,00347	$1,5 \times 10^{-3}$	0,0000	2,88	580000	Loud	9,02	Weak acid
Haloxifop-methyl	0,5	47	1,38600	$1,7 \times 10^{-5}$	0,0000	0,06	7,9	Low	-	Non-ionizable
Atrazine	66	100	0,01050	$3,87 \times 10^{-5}$	0,3490	2,50	35	Low	1,7	Very weak base
Sulfentrazone	400	43	0,00173	$1,07 \times 10^{-7}$	0,9280	0,60	780	Loud	6,56	Weak acid
Trifloxysulfuron-sodium	70	306	0,00990	$1,0 \times 10^{-5}$	0,0483	0,0075	25700	Loud	4,76	Weak acid
Lactofen	4	10000	0,17325	$2,4 \times 10^{-6}$	0,0000	0,18	0,5	Low	-	Non-ionizable
Metsulfuron-methyl	23,2	35	0,02987	$3,3 \times 10^{-10}$	0,3515	0,0018	2790	Loud	3,75	Weak acid
Chlorimuron-ethyl	40	106	0,01733	5×10^{10}	0,0000	0,02	1200	Loud	4,2	Weak acid
Imazaquin	106,6	20	0,00650	$1,9 \times 10^{-5}$	0,8781	0,15	102000	Loud	3,8	Weak acid
Mesotrione	19,6	122	0,03536	$5,69 \times 10^{-6}$	0,0134	0,19	1500	Loud	3,12	Weak acid
Triclopyr	1,5	20	0,46200	$1,6 \times 10^{-4}$	0,0001	0,96	5,75	Low	3,97	Weak acid
Imazethapyr	513	52	0,00135	$1,3 \times 10^{-5}$	0,9322	0,4	1400	Loud	2,1	Weak acid
Diclosulam	49	90	0,01414	$6,58 \times 10^{-8}$	0,2801	0,04	6,32	Low	4,09	Weak acid
Fluroxypyr	1	19550	0,69300	5×10^{-5}	0,0000	0,43	0,136	Low	-	Non-ionizable
Flumiclorac-penthyl	45	30	0,01540	$1,6 \times 10^{-14}$	0,0000	0,06	0,189	Low	-	-
Fluazifop-p-buthyl	15	3000	0,04620	$5,3 \times 10^{-7}$	0,0000	0,19	1	Low	-	-
Dicamba	9,62	233	0,07204	$4,5 \times 10^{-3}$	0,8656	0,72	250000	Loud	1,87	Strong acid
Saflufenacil	20	20	0,03465	$2,0 \times 10^{-14}$	0,5474	0,14	2100	Loud	4,41	Weak acid
Isoxaflutole	0,9	145	0,77000	$3,2 \times 10^{-7}$	0,0000	0,105	6,2	Low	-	Non-ionizable
Amicarbazone	50	30	0,01386	$3,0 \times 10^{-6}$	0,6598	0,28	4600	Loud	-	Non-ionizable
Fenoxaprop-p-ethyl	0,36	11354	1,92500	$5,4 \times 10^{-5}$	0,0000	0,16	0,43	Low	0,18	Very strong acid
Metribuzin	7,03	60	0,09858	$1,6 \times 10^{-5}$	0,0027	0,72	10700	Loud	1,3	Strong acid

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Simazine	90	130	0,00770	8,1 x 10^{-7}	0,3675	2,00	5	Low	1,6	Very weak base
Imazapic	232	137	0,00299	1,3 x 10^{-5}	0,9783	0,052	2230	Loud	2	Strong acid
Cloransulam-methyl	15	30	0,04620	1,3 x 10^{-5}	0,2501	0,04	184	Moderate	4,81	Weak acid

Legend: [a] - Average values obtained from the *Pesticide Properties DataBase* (PPDB) of the *University of Hertfordshire* and the *Pesticide Properties Data base* of the US Department of Agriculture (ARS). [b] - Values calculated from the T50 according to Equation (1) [*K = 0.693/T50]*. [c] - Leaching index calculated according to Equation (2) [$LIX = e^{(- k. Koc)}$]. [d] - Maximum dose used for weed control. * Solubility classification according to the *Pesticide Properties Database* (PPDB) of the University of Hertfordshire, where ≤ 50 mg *L-1* = low; 50 – 500 mg $^{L-1}$ = moderate; > 500 = high solubility.

As for the values of the daily degradation rate (K), these are inversely proportional to the T50, i.e., the lower the T50, the greater the K and vice versa. Thus, the lowest degradation rates are related to the most persistent herbicides in the soil, such as imazethapyr and sulfentrazone, followed by imazapic, MSMA, pendimethalin, diuron and trifluralin (Table 5).

In sequence, the vapor pressure (PV) (mmHg) of the herbicides was obtained, which vERIed between the orders of magnitude of 10-2 (for trifluralin and clomazone) and 10-14 (for flumiclorac-penthyl and saflufenacil) (Table 5). PV expresses the ease that herbicides have to volatilize, being influenced by temperature, thus determining whether the herbicides, after being applied, will remain on a certain surface, or will volatilize to the environment (OLIVEIRA et al., 2018). According to Alves (2008), the products that have PVr >10-2 are very volatile, between 10-4 to 10-3, moderately volatile, 10-7 to 10-5 slightly volatile and the non-volatile <10-8. Of the total herbicides used in the state of Mato Grosso, only 25% are classified as very volatile and medium-volatile molecules.

Therefore, the lower the value of the magnitude, the lower the probability of the herbicide suffering volatilization, however, if a herbicide is classified as non-volatile and the temperature is unfavorable (>30 ºC), it may volatilize, but in smaller quantities than a more volatile product. In this case, most of the a.i. studied and used in the state have a low possibility of volatilization, according to the data available in the literature that addressed PV at 20º C (PAULA et al., 2021).

In Mato Grosso, the average monthly temperature is always above 20º C and very close to 30º C, in the periods of April, March, August, September and October (Figure 1), which can influence the PV of the herbicides evaluated in this study. Pires et al. (2022) report that the volatility of herbicides was influenced by the relative humidity of the air, and the herbicide dicamba, for example, can volatilize in a period of 12 hours, when the

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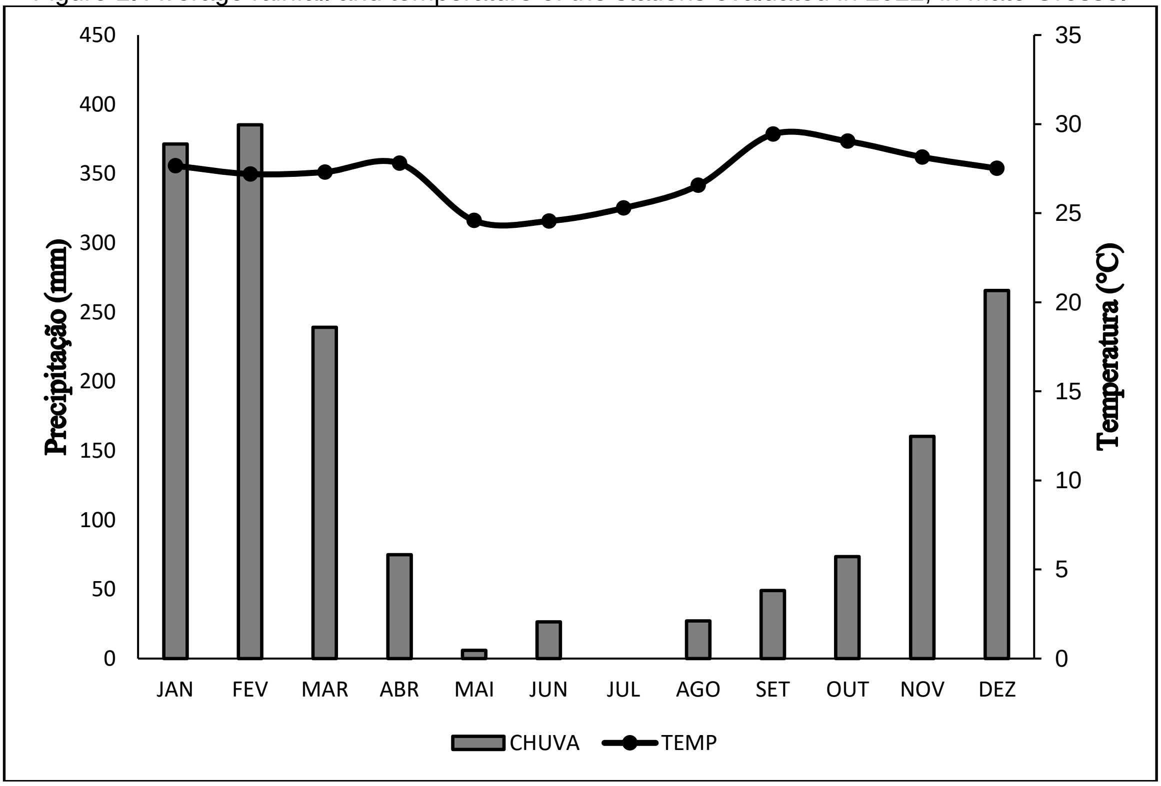
temperature rises from 20ºC to 30ºC, while glyphosate volatilizes 36% in a period of three hours after deposition. However, these authors found that the herbicide haloxyfop-methyl was the one that presented the highest volatility (80%), two hours after its deposition.

Thus, it is observed that the main a.i. herbicides used in Mato Grosso, which presented higher LW value, such as trifluralin, clomazone, S-metolachlor, diquat, pyrithiobac-sodium and MSMA, may have a higher LW value, different from that found in the consulted literature, which is generated under controlled conditions, in the laboratory.

Among the herbicides with the highest chemical load of application per hectare, i.e., the highest dose (D) in the environment for cotton, soybean and corn crops, are: diuron, MSMA, atrazine, glyphosate, simazine, pendimenthalin and 2,4-D, with (D) of 3,200, 2,880, 2,500, 2,400, 2,000, 1,600 and 1,340 kg of a.i., respectively (Table 5). As a consequence, some of these herbicides, such as glyphosate, 2,4-D and atrazine, are among the seven with the highest cumulative value of use in Mato Grosso (Table 4).

Figure 1. Average rainfall and temperature of the stations evaluated in 2022, in Mato Grosso.



Font: INMET (2023).

The rest of the herbicides showed D between 0.100 kg a.i. ha-1 (clomazone and S-metolachlor) to 0.0075 and 0.0018 kg a.i. ha-1 (trifloxysulfuron-sodium and metsulfuron-methyl), respectively. However, despite the lower recommended amount of metsulfuron-

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methyl and trifloxysulfuron-sodium per application, this does not mean less environmental deposition, since these herbicides have a volume, with more than 17,060 thousand kg a.i. marketed in the last three years (Table 4). S-metolachlor, on the other hand, does not present itself with a molecule of greater (D) 0.100 kg. A.I. ha-1, however, in the last three years, occupies the 4th position in the ranking with a traded volume of 5,016,200 million kg a.i. in the state (Table 4).

As for the herbicides with leaching potential (L) by the LIX index, there are imazapic (0.9783), imazethapyr (0.9322), sulfentrazone (0.9280), imazaquin (0.8781), dicamba (0.8656), amicarbazone (0.6598), saflufenacil (0.5474), simazine (0.3675), atrazine (0.3490), metsulfuron-methyl (0.3515), nicosulfuron (0.2815), diclosulam (0.2801) and chloransulam-methyl (0.2501), but the other a.i. have values equal to or close to zero, representing the minimum potential of L (Table 5).

Thus, it is important to note that the 13 herbicides with leaching potential show some level of mobility when analyzed the Koc alone. However, soil transport also depends on other attributes and interactions linked to the physicochemical properties of herbicides, such as water solubility (Sw), octonal-water partition coefficient (Kow), and vapor pressure (P), in addition to environmental conditions related to climate, such as precipitation, average temperature, soil type, terrain topography, and soil management practices (TEIXEIRA et al., 2017; SILVA et al., 2022).

Precipitation (Figure 1) has a direct correlation with soil moisture, while the physical characteristics of the soil strongly influence water retention in the soil profile, therefore, the increase in moisture to close to the field capacity contributes to its microbial activity, better aiding biodegradation (MATOS et al., 2022). In this sense, Mato Grosso, in the months of December, January, February and March are the rainiest of the year, which represents in the 2022 harvest, 75.11% of the precipitated volume.

Regarding water solubility (Sw), this parameter determines the maximum amount that a herbicide can be dissolved before the product precipitates, and the higher the Sw index, the lower the tendency of volatilization of the herbicide (CHRISTOFFOLETI et al., 2008). On the other hand, the higher the Sw value of the herbicide combined with the low Koc value, the more easily the compounds move in the soil profile (SABIK et al., 2000).

Thus, Table 5 presents the classification of the solubility of the herbicides evaluated, with emphasis on 2,4-D (Koc 39.3 L Kg-1), imazaquin (Koc 20 L Kg-1), and metribuzin (Koc 60 L Kg-1), which showed high Sw and low Koc, indicating potential for groundwater contamination. However, of these three a.i., only imazaquin (LIX = 0.8781) was classified as having a high risk of L, reinforcing its danger to the environment, and 2,4-D (LIX = 0.0024) and metribuzin (LIX = 0.0027) were classified as having a low possibility of L, due to its high daily degradation rate (K).

So, even though 2,4-D is moderately mobile and highly soluble in water, along with metribuzin have some barriers to leaching. Gaultiera et al. (2008), observed that the dynamics of auxin herbicides are influenced by the organic matter content in the soil, increasing the solvent potential and reducing the risk of leaching.

In a study carried out by Silva Jr. et al. (2015), metribuzin, under normal rainfall in clay soil, was shown to be susceptible to being carried to groundwater, especially if the accumulation of precipitation occurs soon after the application of the herbicide, but seven days after sowing, with an accumulation of precipitation of 31 to 114 mm, The leaching of metribuzin reached a depth of 9-12 cm.

In addition to the physicochemical properties, the toxicological parameters of the herbicides were also collected, which includes Kow, reference dose (Rfd), lethal dose (LD50) and animal toxicology (TA), and the data of each a.i. are presented in Table 6. From this set of information, it was possible to construct the toxicological profile (TP) (Table 7).

Haloxyfop-methyl (20), trifluralin (19), triclopyr (19), quizalofop-ethyl (19), isoxaflutole (19), flumioxazin (19), fluroxypyr (19), fluazifop-p-ethyl (19) and fenoxaprop-p-ethyl (19) showed the highest values in the TP (Table 7), being considered the most toxic herbicides to animals. Among the factors that influenced this score are Log Kow, with a very high risk of bioaccumulation (4), with the exception of isoxaflutole and flumioxazin with high risk (3), accompanied by Animal Toxicology for fish and bees (4), for birds (2) with the exception of fluazifop-p-buthyl (1), generally indicating among the herbicides, a very high impact, if these herbicides reach the fauna (Table 6).

Bioaccumulation is governed by the Log Kow of the a.i., therefore, herbicides that have a lower Log Kow have a greater affinity for water, therefore more soluble (greater hydrophobicity), unlike pesticides that have a higher Log Kow (lower hydrophobicity), being more easily accumulated in the environment (MERCADO-BORRAYO et al., 2015). For the same authors, compounds with Log Kow values ≥ 3 indicate that they are highly hydrophobic, that is, there is a tendency for the molecules to avoid water.

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This characteristic is confirmed in 18 a.i. of the main herbicides used in Mato Grosso, which have low solubility in water (Table 5). However, of these herbicides, ten compounds, haloxifop-methyl, trifluralin, triclopyr, quizalofop-ethyl, fluroxypyr, fluazifop-p-buthyl, fenoxaprop-p-ethyl, pendimethalin, flumiclorac and carfentrazone-ethyl, represent a total volume of 1.83% traded in the analyzed crops (Table 4). Herbicides with high lipophilicity can be easily absorbed by animals, or even become bioaccumulated in the physicochemical structures of the soil (DUCHOWICZ, 2020).

In an aquatic environment, a study conducted by Gómez-Beltrán et al. (2021) demonstrated that glyphosate (log Kow = - 1.6) is highly toxic to amphibians when subjected to sublethal doses and showed a decrease in the survival rate, prolongation of the time in which it reaches metamorphosis and hepatic lipidosis. In fish, Silva et al. (2017) observed significant changes in the index of gonadosomatics in Danio rerio ovERIes exposed for a period of 15 days to a concentration of 65 mg L-1 of glyphosate.

Table 6. Ecotoxicological parameters* of the main herbicides used in the state of MT.

				Animal Toxicology		
Ingredient	Log*	*DL50**	*Rfd**	Have	Beeb	Fishfish
(i.a.)	*Kow*	mg kg^{-1}	Dermal	*DL50**	*CL50**	*DL50**
		Day-1	mg kg^{-1}	mg kg^{-1}	µg AB-1	mg $^{L-1}$
Trifluralin	5,27	2000	0,02	2250	100	0,088
Glyphosate	-1,6	2000	0,50	2000	100	100
Clomazone	2,58	2000	0,13	2224	89,5	14,4
Diuron	2,87	5000	0,016	1104	101,7	6,7
S-metolachlor	2,75	5050	0,1000	2000	110	3,9
Glufosinate-amonnium	-4,01	2000	0,0210	2000	345	710
2,4-D	-0,82	2000	0,3000	500	100	100
Clethodim	4,14	4167	0,1600	1640	51	25
Pyroxasulfone	2,39	2000	-	2250	105	2,2
Carfentrazone-ethyl	3,7	4000	0,0300	2250	200	99,2
Diquat	2,17	225	0,0240	30000	2432	97
Pyrithiobac-sodium	-0,84	2000	-	1500	24	930
Flumioxazine	2,55	2000	0,0500	2250	200	2,3
Pendimethalin	5,4	5000	0,3000	1421	196	0,196
Quizalofop-P-tefuryl	4,61	5000	0,1000	2000	100	0,21
Nicosulfuron	0,61	2000	2,0000	2000	25	65,7
Fomesafen	-1,2	1000	-	5000	50	170
MSMA	-3,1	2000	0,1000	3269	100	100
Haloxifop-methyl	4	2000	0,0750	1159	100	0,088
Atrazine	2,7	3100	0,1000	4237	100	4,5
Sulfentrazone	0,991	2000	-	2250	25,1	93,8
Trifloxysulfuron-sodium	-0,42	2000	0,0600	2000	25	103
Lactofen	-	2000	0,0015	2150	100	0,1
Metsulfuron-methyl	-1,87	2000	0,2500	2510	50	110
Chlorimuron-ethyl	0,11	2000	-	5620	12,5	8,4
Imazaquin	-1,09	5000	0,2500	2150	36,4	100
Mesotrione	0,11	2000	0,0200	3779	100	120

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Triclopyr	4,62	5000	0,3000	735	100	1,3
Imazethapyr	1,49	2000	-	2150	100	340
Diclosulam	0,85	2000	0,0500	2250	100	110
Fluroxypyr	5,054	2000	0,8000	2000	25	0,225
Flumiclorac-penthyl	4,99	2000	-	2250	100	1,1
Fluazifop-p-buthyl	4,5	2420	0,0170	17000	76	0,53
Dicamba	-1,8	2000	0,3000	188	160	98,85
Saflufenacil	2,6	2000	-	2000	100	98
Isoxaflutole	2,34	2000	0,0500	2150	100	1,7
Amicarbazona	1,23	2000	-	1965	24,4	120
Fenoxaprop-p-ethyl	4,58	2000	0,1000	2000	63	0,19
Metribuzin	1,75	5000	0,0200	164	100	74,6
Simazine	2,3	2000	0,1000	4640	97	90
Imazapic	2,47	2000	-	2150	100000	100
Cloransulam-methyl	-0,365	2000	-	5620	100	86

*Figures were obtained from the *University of Hertfordshire's* Pesticide Properties DataBase (PPDB) and the *U.S. Department of Agriculture's* Pesticide Properties Database (PPD).[a] - Refers to *Colinus virginiaus* / *Anas platyrhynchor*; [b] - refers to *Oncorhynchus mykiss* / *Lepomis macrochirus*; [c] - refers to *Apis* spp.

Atrazine (log Kow = 2.7) in an aquatic environment presents changes in the structure and size of the larynx of amphibians (Xenopus laevis), even when exposed to low concentration, while for fish (Prochilodus lineatus) it led to oxidative stress of the gills (CARMO et al., 2013). Studies carried out by Loro et al. (2015), detected concentrations of atrazine in the two aquatic environments and times evaluated, being above the maximum concentration allowed by the National Council for the Environment. Atrazine was the second most used herbicide in the last three harvests in Mato Grosso, with a total accumulation of 24,642.9 thousand kg a.i. (Table 4), indicating the possibility of being present in the state's groundwater.

In birds, the effects of pesticides are vERIable, for example, migrating birds use contaminated agricultural areas for food, especially insectivorous, which are negatively impacted by consuming contaminated grains and insects, affecting their survival, body mass and fat, and their reproductive capacity (STANTON et al., 2018). For poultry, the degree of severity of the herbicides analyzed is higher for diquat, dicamba and metribuzin, the others with medium to low levels (Table 7).

In the general analysis, the PT ranged from 7 to 20 points (Table 7), with 53.33% of the herbicides having high or very high toxicity, among the most used in Mato Grosso, atrazine (18) and S-metolachlor (18) and the other 46.66% with medium potential, including glyphosate (10), 2,4-D (10), clethodim (18) and diquat (13). Atrazine's high score is mainly due to Log Kow (3) and LD50 (3). Although atrazine has low solubility (Table 5), its degradation depends on the soil matrix, having a high capacity to interfere with the human nervous and endocrine system and wild biota (CARMO et al., 2013).

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S-metolachlor, like atrazine, is considered highly toxic to fish and bees (4) with an extremely high LD50 (Tables 6 and 7). Glyphosate has a low degree of severity (1) for Apis mellifera bees, however, Herbert et al. (2014) observed that this molecule interferes with the taste capacity and learning of individuals, but does not interfere with their locomotor activities. Balbuena et al. (2015) observed that bees fed a 10 mg L-1 solution of glyphosate had difficulties returning to the hive, impairing their cognitive abilities.

In the case of the herbicide clethodim (18), there is a high toxicological profile, when compared to the other herbicides used in Mato Grosso, and its lethality for both bees and fish is extremely high (4). On the other hand, the a.i. diquat (13) has a moderate solubility in water and a medium degree of severity for both bees and fish (2) (Table 7). Henares et al. (2007), in a study carried out with L. macrocephalus, found that diquat was low toxic, and the changes that occurred in the gills and liver of fish submitted to an LC50 (96 h) of 34.7 mg L-1 are reversible.

After analyzing the parameters inherent to pesticides (e.g. persistence, leaching, volatility and dose) and animal toxicology (e.g. toxicological profile), the Environmental Risk Index (ERI) was constructed. Table 8 presents the IRA of the 42 herbicides evaluated, which are classified from the highest value (33) to the lowest (5).

Table 7. Toxicological profile (PT)* constructed from ecotoxicological parameters.

Ingredient Ativo (i.a.)	Mechanism Share	Log *kow*	*Rfd*	*DL50*	Ave	Fish	Bee	PT
Haloxifop-methyl	ACCase	4	2	4	2	4	4	20
Trifluralin	Microtubules	4	2	3	2	4	4	19
Triclopyr	Auxins	4	1	4	2	4	4	19
Quizalofop-P-tefuryl	ACCase	4	1	4	2	4	4	19
Isoxaflutole	Carotenoids	3	2	4	2	4	4	19
Flumioxazine	PROTOX	3	2	4	2	4	4	19
Fluroxypyr	Auxins	4	1	4	2	4	4	19
Fluazifop-p-buthyl	ACCase	4	2	4	1	4	4	19
Fenoxaprop-p-ethyl	ACCase	4	1	4	2	4	4	19
S-metolachlor	ACCase	3	1	4	2	4	4	18
Pendimethalin	Microtubules	4	1	3	2	4	4	18
Diuron	FS II	3	2	3	2	4	4	18
Clethodim	ACCase	4	1	4	2	3	4	18
Atrazine	FS II	3	2	3	2	4	4	18
Pyroxasulfone	Myths	3	-	4	2	4	4	17
Lactofen	PROTOX	-	3	4	2	4	4	17
Flumiclorac-penthyl	THAN	4	-	3	2	4	4	17
Clomazone	Carotenoids	3	1	4	2	3	4	17
Carfentrazone-ethyl	PROTOX	4	2	4	2	2	2	16
Diquat	FS I	3	2	3	3	2	2	15
Metribuzin	FS II	2	2	4	3	2	2	15
Mesotrione	Carotenoids	1	2	4	2	1	4	14
Simazine	FS II	3	1	3	2	2	2	13

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Dicamba	Auxins	1	1	4	3	2	2	13
Chlorimuron-ethyl	THAN	1	-	3	1	4	4	13
Saflufenacil	PROTOX	3	-	3	2	2	2	12
Nicosulfuron	THAN	1	1	4	2	2	2	12
Glufosinate-amonnium	Glutamine	1	2	4	2	1	1	11
Cloransulam-methyl	THAN	1	1	4	1	2	2	11
Trifloxysulfuron-sodium	THAN	1	2	3	2	1	1	10
Metsulfuron-methyl	THAN	1	1	4	2	1	1	10
Imazapic	THAN	3	-	3	2	1	1	10
Glyphosate	EPSPs	1	1	4	2	1	1	10
Diclosulam	THAN	1	2	3	2	1	1	10
2,4-D	Auxins	1	1	4	2	1	1	10
Sulfentrazone	PROTOX	1	-	2	2	2	2	9
MSMA	Unknown	1	1	3	2	1	1	9
Imazaquin	THAN	1	1	3	2	1	1	9
Amicarbazone	FS II	2	-	3	2	1	1	9
Pyrithiobac-sodium	THAN	1	-	3	2	1	1	8
Imazethapyr	THAN	2	-	2	2	1	1	8
Fomesafen	PROTOX	1	-	3	1	1	1	7

*PT - toxicological profile calculated according to the Equation: *PT = Kow + Rfd + LD50 + AT.* The values were assigned according to table 02 of the degree of severity. ACCase = inhibition of aceti – CoA carboxylase; carotenoids = inhibition of carotenoid biosynthesis; microtubules = inhibition of microtubule formation; FS I = inhibition of photosynthesis in photosyntem. FS II = inhibition of photosynthesis in photosynthema II; PROTOX = inhibition of protoporphyrinogen oxidase; lipids = inhibition of lipid synthesis; mitosis = inhibition of mitosis; ALS = inhibition of acetolactate synthase; auxins = auxin mimics; cellulose = inhibition of cellulose biosynthesis; EPSPs = glycine replaced.

In general, most of the a.i. presented low risk per application. However, it is possible to identify the critical points of each herbicide and compare them with each other, so that technical field professionals have a subsidy to propose a planning that is less harmful to the environment, through decision-making based on the degree of risk that the herbicide represents.

Table 8. Environmental Risk Index (ERI)* of the main herbicides used in the state of Mato Grosso, placed in descending order.

Ingredient Ativo (i.a)	Mechanism Action1	P	L	V	PT	D	IRA*
Atrazine	FS II	3	3	2	3	3	33
MSMA	Unknown	4	1	4	2	3	33
Diuron	FS II	4	1	1	3	3	27
Trifluralin	Microtubules	4	1	4	3	2	24
Pendimethalin	Microtubules	4	1	2	3	2	20
Simazine	FS II	3	3	1	2	2	18
Glyphosate	EPSPs	1	1	1	2	3	15
2,4-D	Auxins	1	1	2	2	2	12
Imazapic	THAN	4	4	2	2	1	12
Imazaquin	THAN	4	4	2	2	1	12
Imazethapyr	THAN	4	4	2	1	1	11
Sulfentrazone	PROTOX	4	4	1	2	1	11
Clomazone	Carotenoids	2	1	4	3	1	10
Amicarbazone	FS II	2	4	1	2	1	9
S-metolachlor	Mitosis	1	1	4	3	1	9

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Diquat	FS I	2	1	2	3	1	8
Diclosulam	THAN	2	3	1	2	1	8
Dicamba	Auxins	1	1	4	2	1	8
Flumioxazine	PROTOX	1	1	3	3	1	8
Flumiclorac - Penthyl	THAN	2	1	2	3	1	8
Haloxifop-methyl	ACCase	1	1	2	4	1	8
Saflufenacil	PROTOX	1	4	1	2	1	8
Pyrithiobac - sodium	THAN	3	-	4	1	1	8
Triclopyr	Auxins	1	1	3	3	1	8
Carfentrazone-ethyl	PROTOX	1	1	2	3	1	7
Cloransulam-methyl	THAN	1	3	1	2	1	7
Fenoxaprop-p-ethyl	ACCase	1	1	2	3	1	7
Fluazifop-p-buthyl	ACCase	1	1	2	3	1	7
Fluroxypyr	Auxins	1	1	2	3	1	7
Fomesafen	PROTOX	3	1	2	1	1	7
Metribuzin	FS II	1	1	2	3	1	7
Metsulfuron-methyl	THAN	1	3	1	2	1	7
Nicosulfuron	THAN	1	3	1	2	1	7
Quizalofop-P-tefuryl	ACCase	1	1	2	3	1	7
Trifloxysulfuron-sodium	THAN	2	1	2	2	1	7
Clethodim	ACCase	1	-	2	3	1	6
Glufosinate-amonnium	Glutamine	1	1	2	2	1	6
Isoxaflutole	Carotenoids	1	1	1	3	1	6
Lactofen	PROTOX	1	1	1	3	1	6
Pyroxasulfone	Mitosis	1	1	1	3	1	6
Chlorimuron-ethyl	THAN	1	1	1	2	1	5
Mesotrione	Carotenoids	1	1	1	2	1	5

P - Persistence; L - leaching; V - volatility; PT - toxicological profile; D - dose. *IRA - environmental risk index calculated for herbicides according to the equation: *IRA = [(P+L+V+TP) x D]*. The values were based on the properties of the pesticides (Tables 05 and 06) and on the toxicological profile (Table 07).

Glyphosate is the most used a.i. in the last three years in Mato Grosso crops, reaching an accumulated volume of 134,138,025 kg a.i. (Table 4). Glyphosate has IRA 15, being among the seven herbicides with the highest value, with high LD50 and solubility in water. Glyphosate has low mobility in the soil, as it has a high adsorption capacity to soil particles, being influenced by the content of organic matter, type of clay, temperature and pH (GONZÁLES ORTEGA; FUENTES PONCE, 2022). Thus, glyphosate has low persistence in the soil, however, in aquatic environments it is more persistent, and can be moderately toxic to aquatic organisms (LEWIS et al., 2016).

The most common degradation of glyphosate involves its conversion to aminimethylphosphonic acid (AMPA) as the main metabolite, by the action of enzymes such as oxidoreductases and transaminases and glyoxylic acid (ANDRIGHETTI et al., 2014). According to Dill et al. (2010), another form of degradation of glyphosate molecules in the soil is through the formation of sarcosine and inorganic phosphate and by the enzymes CP lyase, which are later oxidized to CO2, and it is estimated that 79 to 86% of glyphosate is converted to CO2 in six months. In an aquatic environment, glyphosate is complexed by the organic matter of rivers and lakes. which helps in the elimination of the herbicide, thus reducing the exposure of organisms in this environment (TAUHATA et al., 2020).

The i.a. com the largest AKI are atrazine and MSMA (33) (Table 8), belonging to the triazine and organoarsenic groups, respectively. Atrazine ranks second in the ranking of herbicides with the highest volume traded in Mato Grosso, totaling 24,642,982 kg a.i. in the last three harvests, representing 12.26% of the total (Table 4). Its main critical points are persistence (3), leaching (3), toxicological profile (3) and high dose (3). From the same chemical group as triazine, simazine also has an IRA 18, being among the herbicides that deserve attention in terms of use.

Atrazine can persist for decades in the soil, depending on the type of soil and its characteristics, such as environmental and climate conditions, especially precipitation, which can facilitate its leaching into groundwater, hindering its biodegradation process (CECILIA; MAGGI, 2016). In this context, atrazine has low solubility in water regardless of pH and high solubility in organic solvent (JAVARONI et al., 1999).

This characteristic of low affinity for water, combined with the Log Kow of 2.7 and the T50 of 66 days (Tables 5 and 6), indicates that atrazine is not easily adsorbed by the soil, being considered mobile. According to Neiverth (2015), atrazine is considered an herbicide with easy flow, slow hydrolysis and low adsorption in the soil and organic matter. This information corroborates the results found in this ERI, in addition to the LIX = 0.349 index signaling a greater potential for vertical leaching in the soil profile.

Thus, atrazine is presented with toxicological class II, which indicates a very dangerous product, with a high degree of toxicity for algae, aquatic animals, bees and other beneficial insects. Its high toxicological profile is due to its high LD50 (3) and high toxicology, especially for fish and bees (Table 7). Tillit et al. (2010) observed neurological lesions in fish when they were exposed to atrazine.

In this sense, with the large volume sold in Mato Grosso, combined with the time of application which coincides with the period of greatest rainfall, which is from January to April (Figure 1), the risks regarding the use of atrazine are high. An example of this was the finding of atrazine in river waters, in 4 of the 5 samples collected, in which the concentration ranged from 0.16 to 0.32 mg L-1, below the allowed by Brazilian legislation, which is 2.0 mg L-1, however, there may be a risk if the water is ingested (MACHADO et al., 2016).

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Simazine exhibits persistence and leaching similar to atrazine, differing in lower toxicology profile and dose. According to Azevedo et al. (2010), this a.i. has moderate adsorption to clay and organic matter, high soil persistence and high surface runoff potential. However, the volume sold in Mato Grosso is very low, and in 2021 no consumption was recorded.

The herbicide MSMA, on the other hand, has persistence (P) and volatility (V) as critical points, both criteria being considered very high. The 200-day persistence and volatility in the order of magnitude 10-3, combined with its dose (D) with a value considered high, make this i.a. com one of the highest IRAs evaluated (Alister and Kogan, 2006). However, the volume of MSMA traded in Mato Grosso does not exceed 0.3% of the total volume.

From the information available in the literature, it is possible to identify that MSMA presents some sources of exposure. Feng et al. (2005) analyzed different substrates and identified different species of arsenical compounds, and the type of substrate influenced their retention, and may also influence the percolated water compounds.

In this sense, soil and groundwater contamination can occur in areas where MSMA is applied. Plese et al. (2009), with herbicides used in cotton areas, found that the fugacity to the environment of MSMA is mostly due to water, with values greater than 82%, even though MSMA presents low leaching potential (Table 8).

Another herbicide widely used in cotton crops is diuron, being the 11th in the ranking of the most used products in the state, but with IRA 27, being among the top three. Its persistence in the environment, combined with its toxicological profile and dose, contribute to being a herbicide that presents a greater risk to the environment. The European Commission considers diuron to be a dangerous compound, responsible for water deterioration, being toxic to cyanobacteria, fish and mammals (SLAALAN et al., 2019).

The high persistence of diuron may be related to the half-life in the soil (T50) of 146.6 days (Table 5). According to Rocha et al. (2013), the persistence of diuron depends on the physical and chemical attributes of the soil, and the higher the organic matter content in the soil, the lower its dissipation, being favored in sandy soils, in which pH also exerts an influence. In clayey soil, Inoue et al. (2008) observed that, regardless of the irrigation depth applied, the movement of diuron was restricted to the superficial layers.

However, the main biodegradation product is (3,4-DCA), which exhibits greater toxicity than diuron, which is also quite persistent in soil and water (BERNARDES et al., 2011). In a study carried out by Britto et al. (2012), with waters from the Poxim-Mirim River, they identified two herbicides present in water intended for human consumption at levels above international standards, including diuron, finding that this a.i. has a high capacity to be transported in water.

The chemical group of dinitroanilines, composed in this study by trifluralin and pendimethalin, with IRA 24 and 20, respectively, show very high persistence, high toxicological profile and low leaching. Trifluralin differs by having very high volatility as a characteristic (Table 5). Roman et al. (2007) suggest the incorporation of herbicides when applied to the soil, as is the case of trifluralin, as they can cause losses due to volatilization. Trifluralin is among the seven herbicides most used in the crops in question, with a total volume traded in the three years of 2,280,175 kg a.i., representing 1.15% of the total, unlike pendimethalin, with a volume of 4,766 kg a.i. in the same cycle.

The low leaching of this a.i. is related to its low solubility in water, with Kow 5.27 for trifluralin and Kow 5.4 for pendimethalin, indicating its low lipophilicity. According to Santos et al. (2012), soil and climate conditions favor the persistence of trifluralin in the environment, combined with its low solubility. Therefore, despite presenting animal toxicity and low vertical leaching capacity (Lix = 0.00), these compounds present a more critical point, which is the persistence in the environment with a T50 of 133.7 and 182.3 days for trifluralin and pendimethalin, respectively.

Another pesticide of great importance and with a significant volume traded in the last three harvests is 2,4-D, representing 7.85% of the total volume, ranking third (Table 4). Among the auxin mimics of the phenoxycarboxylic acid group, in addition to 2,4-D that presents AKI (12), triclopyr (8) and fluroxypyr (7) were also used, but with smaller volumes. Both triclopyr and fluroxypyr have the same high PT (3) toxicological profile, differing in volatilization, being high for triclopyr and medium for fluroxypyr (Table 5).

2,4-D has low persistence in the environment with a half-life of (T50) of 4.4 days, combined with a low leaching index (Lix = 0.0024), with volatilization and an average toxicological profile. According to Franceschi et al. (2015), the 2,4-D can reach a depth of 32 cm in a dystrophic red-yellow Latosol. In this sense, this may be related to its high solubility in water (Sw 24,300 mg L-1) (Table 5).

Similarly, Neto et al. (2012), using a lysimeter, observed that 2,4-D, because it has high solubility in water, is easily transportable and very toxic to aquatic organisms, unlike soil organisms, birds and bees, and is not very toxic. In this context, due to the large volume of 2,4-D used in the state, its LIX=0.0024 index, its high solubility and very high LD50, it is evident that this a.i. needs care regarding its handling in the environment.

Still in the group of auxin-mimicking, dicamba is an a.i. that has an AKI (8) and toxicological profile similar to that of 2,4-D, but with volatility, very high LD50 and greater toxicity to fish, bees and birds (Table 7). According to Schaaf (2016), dicamba is a pesticide that has a low environmental risk value, corroborating the information observed in this work.

For the chemical group of imidazolinones, imazapic and imazaquin have the same IRA (12), followed by imazethapyr IRA (11). Two important points in this group, related to environmental risk, are persistence and leaching, considered very high, according to Alister and Kogan (2006). The persistence in the environment of imazapic, imazaquin and imazethapyr, is related to the very high values of the T50, being 232, 106.6 and 513 days, respectively.

For Monquero et al. (2010), the persistence in the soil of the imidazolinone group is influenced by pH, texture, organic matter and moisture. Working with bioindicators, these authors observed that imazapic, under conditions of higher rainfall, showed activity up to 40 cm deep, combined with the highest soil pH value, with persistence, even if with less activity, from 60 to 150 days after application.

The high vertical leaching of these compounds is related to their low Koc and high LIX index for imazapic (0.97), imazaquin (0.87) and imazethapyr (0.93) (Table 05). However, the commercialization of imazethapyr was low compared to other a.i., with no higher AKI due to its low LD50.

Sufentrazone has AKI 11, with characteristics in the environment very similar to imazapic, but lower volatility and higher toxicological profile for fish and bees. Its 50MWD is 400 days and the LIX index = 0.92. According to Monquero et al. (2010), the leaching of this herbicide increases with increases in the precipitated volume, and activity is identified in the soil up to 150 days after application. Sulfentrazone is influenced by the type of soil and in sandy soils, with low organic matter content, and can be leached into deep layers (FAUSTINO et al., 2015). In this sense, the risk of leaching into lakes and rivers, affecting the aquatic environment, becomes worrisome, due to the accumulated rainfall between the months of October and March in Mato Grosso (Figure 1).

Clamazone is a herbicide widely used in soybean and cotton cultivation areas and, in the last three harvests in Mato Grosso, the total volume sold was 928,092 kg a.y., 57.9% of which in the 2022 harvest. Clomazone has an AKI (10) with critical volatilization points V (4) and PT toxicological profile (3), as shown in Table 8. In the context related to the toxicological profile, Miron et al. (2005) found that the LD50 for clomazone in fish of the species Rhamdia quelen was 7.32 mg L-1, and this a.i. significantly inhibited the activity of the enzyme acetylcholinesterase in the brain and muscle tissue, affecting their behavior.

With large volumes sold in the last three years, the herbicides S-metolachlor (5,016,200 kg a.i.) and diquat (4,689,928 kg a.i.) (Table 4), have a very close environmental risk index, with ERI 9 and 8, respectively. The high toxicological profile value of S-metolachlor (PT =3) presents higher toxicities to bees and fish.

According to a study carried out by Fernandes Neto and Sarcinelli (2009), S-metolachlor was detected in most of the surface and groundwater samples collected in the regions of Primavera do Leste (MT), Lucas do Rio Verde (MT) and in the Pantanal of Mato Grosso. The high volume of this a.i. used in crops in Mato Grosso, combined with the fact that it has characteristics with lower water solubility and high Log Kow (Table 6), indicates that surface runoff can occur more easily, especially in the months of November to March, when the highest rainfall accumulations occur in the state (Figure 1).

Diquat has a median persistence in the environment due to its 30-day T50, but with a high toxicological profile, due to its high LD50 and Log Kow (Tables 5 and 6). In a study carried out by Peruzzolo et al. (2021), with the herbicide diquat in stingless bees of the species (Scaptotrigona bipunctata), they found that contamination by ingestion, at all concentrations tested, can affect the survival of bees.

In an aquatic environment, Gomes et al. (2008) observed a low risk of diquat poisoning for fish of the species Oreochromis niloticus, however, at high concentrations of this a.i., severe changes in the gills and liver can occur. In the soil, the activity of diquat can be immediately reduced, due to the exchange reactions of cations of the herbicide with the sites of negative charges in the soil, being greater according to its CEC (STEFFEN et al., 2011).

The high volume sold in the state of this a.i., combined with its high toxicological profile (PT=15), can cause greater damage to the environment. In this sense, with the prohibition of the commercialization of paraquat in 2017 and the impediment of its use from 2020, the consumption of diquat has been increasing linearly over the years, with an increase of more than 290%, when compared to the years 2020 and 2022 (Table 4).

Clethodim is sold in Mato Grosso, with a total mass of 3,612,475 kg a.i., representing 1.8% of the total volume of a.i. sold in the 2020, 2021 and 2022 harvests. Clethodim has one of the lowest ERI values (6) among the herbicides studied. The low persistence, dose, and volatility contribute to its low environmental risk index. According to Sousa et al. (2023), clethodim is a herbicide classified as unlikely to cause acute damage to health, but it is considered dangerous to the environment. Its LD50 of 4,167 mg kg-1 contributes to increased toxicity, being more lethal to fish and bees (Table 6).

With the advancement in genetic improvement and development of glufosinate-amonnium tolerant crops, the volume of the herbicide used increased significantly from 2021 to 2022, from 645,847 kg a.i. to 1,009,363 kg a.i., respectively (Table 4). Glufosinate-amonnium has AKI (6) due to its low persistence in the environment and leaching, combined with moderate volatility and toxicological profile.

The other a.i. sold in Mato Grosso, in smaller volume and with lower ERI, are presented in Table 8. With IRA 8, there are diclosulam, flumioxazin, flumiclorac-penthyl, haloxifop-methyl, saflufenacil and pyrithiobac-sodium. Among the a.i., saflufenacil has the highest leaching index (LIX = 0.54), followed by diclosulam (LIX = 0.28), while haloxyfop-methyl and flumiclorac-penthyl have the highest Log Kow index, 4 and 4.99, respectively. Pyrithiobac-sodium is the a.i. that has the highest volatilization potential among these herbicides. The toxicological profile of 19 and 20 is presented by flumioxazin and haloxifop-methyl, respectively (Table 7), with higher LD50 and toxicity to fish and bees.

With environmental risk index IRA 7, the following a.i. are found: Carfentrazone-ethyl, chlorasulam-methyl, fenoxaprop-p-ethyl, fluazifop-p-buthyl, fomesafen, metribuzin, metsulfuron-methyl, nicosulfuron, quizalofop-ethyl and trifloxysulfuron-sodium (Table 8). Nicosulfuron, metsulfuron-methyl and chlorasulam-methyl are the a.i. that present the highest leaching index with 0.28, 0.35 and 0.25, respectively.

The highest persistence was identified for the herbicide fomesafem (T50 = 86 days), followed by trifloxysulfuron-sodium (T50 = 70 days). The i.a. com the largest Log Kow are carfentrazone-ethyl (3.7), quizalofop-ethyl (4.6), fluazifop-p-buthyl (4.5) and fenoxaprop-p-ethyl (4.5), presenting high sorption to soil organic matter (Table 6). In the toxicological profile, the a.i. quizalofop-ethyl, fluazifop-p-buthyl and fenoxaprop-p-ethyl, of the chemical group aryloxyphenoxypropionates, present the highest value (PT = 19) (Table 7), with a high LD50 mainly for fish and bees.

The herbicides isoxaflutole, lactofen and pyroxasulfone have low values for ERI (6). On the other hand, the herbicides chlorimurom and mesotrione have AKI (5), lower values found. Despite having a low environmental risk index, the a.i. isoxaflutole, pyroxasulfone and lactofen have a high toxicological profile (Table 7). With everything, in addition to these a.i. already mentioned, mesotrione has a very high LD50, with a high risk, especially for fish and bees.

Thus, the herbicides with ERI in descending order, which represent 98.4% of the volume used in Mato Grosso, are presented as follows: Atrazine > diuron > trifluralin > glyphosate > 2,4-D > clomazone > S-metolachlor > diquat ≥ haloxifop > clethodim ≥ glufosinate-ammonium In this study, the final result of the IRA was affected by the multiplication factor "dose" of the a.i. recommended in the package insert, being considered the highest dose for soybean, corn and cotton crops, where 80% of the herbicides presented doses below 1 kg a.i. ha-1, resulting in classification 1 in this vERIable and, therefore, the final value of the ERI was low for most of the herbicides.

It should be noted that this index estimated the risk potential of a single application, and, in the production systems in the Brazilian Cerrado, successive applications are made, with the beginning of the use of herbicides in pre-emergence applications, lasting throughout the crop cycle with post-emergence applications, where herbicide associations are often made in the same application solution (PRESOTO et al., 2020).

Therefore, the analysis of this IRA served as a model to indicate the risk profile of an a.i.'s intended use, separately exposing the potential of each herbicide to cause damage to the environment. The lack of data on the physicochemical characteristics of the herbicides, appropriate to our local condition, may have affected the result, as several data were obtained from temperate climate regions. However, as some countries need to carry out this pesticide risk assessment study and do not have the information, it is common to use international databases such as the PPDB (LEWIS et al., 2016).

In Brazil, according to Law No. 7,802/89 and Decree No. 4,074/02, which regulates, IBAMA is responsible for carrying out the environmental assessment of these products, through the assessment of the environmental hazard potential (PPA) and the environmental risk assessment (ARA), the latter being implemented in 2011, through the assessment of exposure, considering doses, recommended application methods, interval between them, environmental conditions, chemical-physical characteristics of pesticides, with exposure values estimated with modeling, using the GNEEC2, T-REX, AgDrift models, being available on IBAMA's environmental profile list (IBAMA, 2024).

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CONCLUSION

The IRA of herbicides contributed to the provision of information, in order to avoid and prevent risks of contamination, and can assist in the environmental management of the active ingredients most used in Mato Grosso agricultural production systems, given the large amount of herbicides applied to the state's crops, generating concerns about the fate of these pesticides. In this sense, 99.3% of the volume of herbicides sold in Mato Grosso, for soybean, corn and cotton crops, are registered in 14 a.i., and of these, 92.9% have ERI between 10 and 33, with emphasis on the herbicides atrazine, diuron and trifluralin with the highest ERI, 33, 27 and 24, respectively, and an amount sold of 14.3% of the total.

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