BIOSCIENCE JOURNAL

LEACHING OF SAFLUFENACIL IN SOILS WITH DIFFERENT ORGANIC MATTER CONTENTS

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How to cite: BARCELLOS JÚNIOR, L.H., et al. Leaching of saflufenacil in soils with different organic matter contents. *Bioscience Journal*. 2022, **38**, e38071. https://doi.org/10.14393/BJ-v38n0a2022-54055

Abstract

Saflufenacil is a herbicide recommended for use in the main agricultural crops in Brazil to control eudicotyledonous weeds. However, the application of saflufenacil has been carried out without previous knowledge of this herbicide interactions with soil colloids, which may increase environmental contamination risks. In this study, the leaching of saflufenacil in soil samples was estimated with different organic matter contents. Therefore, PVC columns were filled with samples of Xanthic Ferralsol (XF) and Ferralsol (F), with different physical and chemical attributes. Twelve hours after herbicide (70 g i.a. ha^{-1}) application, the PVC columns were subjected to a rainfall of 60 mm. For the evaluation of saflufenacil leaching, the columns were sectioned in ten parts with 5-cm each. Saflufenacil leached up to 50 and 40 cm deep in the samples, with the lowest contents of organic matter of XF and F, respectively. The increase in organic matter content of Ferralsol and Xanthic Ferralsol samples reduced saflufenacil leaching and the symptoms of intoxication in the indicator species. There was an inverse relation between the content of organic matter and the leaching of the herbicide in both soils studied. It was observed that the application of saflufenacil in soils with low organic matter contents may represent a significant environmental contamination risk of soils and watercourses.

Keywords: Environmental pollution. Ferralsol. Herbicide mobility. Xanthic Ferralsol. Weed.

1. Introduction

Chemical weed control is efficient, has low cost and, for this reason, it is the method most used by small and large farmers (Fartyal et al. 2018). It is known that the dynamics of herbicides in the environment vary with soil attributes and climatic conditions (De Gerónimo et al. 2018; Jiang et al. 2018). Therefore, the application of many herbicides, as saflufenacil, without knowledge of their molecule interactions with the soil matrix, can result in serious environmental problems, such as contamination of soils and watercourses (Zhang et al. 2013; Van Stempvoort et al. 2014; Santos et al 2015; Silva et al. 2016).

Saflufenacil {2-chloro-4-fluoro-5- [3-methyl-2,6-dioxo-4- (trifluoromethyl) pyrimidin-1-yl] -N- [methyl (propane-2-yl) sulfamoylbenzamide} is a herbicide recommended for use in weed pre- or post-emergence in the main agricultural crops in Brazil to control eudicotyledonous species. As it is a herbicide derived from a weak acid (pKa = 4.4), the tendency is that the saflufenacil molecule in agricultural soils with pH values close to neutrality be in ionic form and, consequently, with greater availability in the soil solution (Ololade et al. 2015). However, other soil attributes, such as organic matter content, can also affect the sorption of saflufenacil in the soil, influencing its availability for plant absorption and its potential for movement in the soil profile (Ertli et al. 2004; Paszko et al. 2016).

Acidic herbicides can interact with –COOH and –COOR groups of soil organic matter by hydrogen bonding in non-ionic forms of the molecule (Senesi, 1992; Gevao et al., 2000). Saflufenacil has fluorine, nitrogen and oxygen atoms in its molecule, which increases the possibility of the molecule being adsorbed on organic matter in soils with pH values below its pKa. In addition, several factors can influence the binding of herbicides in the soil, such as the form of application, dose, time of contact of the molecule with the soil, use of organic and inorganic fertilizers, among others (Gevao et al. 2000). Frequently, the organic fraction is primarily responsible for the retention of herbicides in the soil but, due to the complex and heterogeneous nature of organic matter, it is difficult to elucidate the mechanism by which herbicides are incorporated into this fraction (Gevao et al. 2000).

Herbicide leaching is directly related to the efficiency of weed control, whose seeds are distributed in subsurface layers of the soil, and to the environmental contamination risk (Pereira et al. 2017). Thus, moderate mobility of herbicides in the soil profile is necessary for an efficient control of the weed seed bank (Inoue et al. 2015). On the other hand, excessive herbicide leaching can contaminate groundwater (Pereira et al. 2017). Herbicides applied to soils with high levels of organic matter tend to leach less (López-Piñeiro et al. 2013; Tejada and Benítez 2017; Marín-Benito et al. 2018, Mendes et al. 2018). The application of higher doses of saflufenacil was necessary to inhibit the development of canola since the increase in the organic matter content of the soil decreases the bioavailability and leaching of this herbicide in the soil (Gannon et al. 2014). Little is known about the behavior of saflufenacil in soils of tropical regions. Our hypothesis is that the addition of organic matter in tropical soils limits saflufenacil leaching due to the increase in chemical interactions between the herbicidal molecule and soil loads. To clarify this issue, this study was conducted to know the influence of organic matter in the leaching of saflufenacil in Ferralsol profile, a widely cultivated soil in tropical areas.

2. Material and Methods

The soils used in this work were a Xanthic Ferralsol (XF) and Ferralsol (F) from the Brazilian cities of Três Marias and Viçosa, Minas Gerais state, respectively. Both soils came from fallow areas for more than five years. The soil samples were collected to a 0–20 cm. Both sample of soils were mixture with bovine manure in the following proportions (manure:soil, v:v): 0: 1; 0.25: 1; 0.5: 1; 0.75: 1 and 1: 1 L L^{-1}, and incubated for 30 days. After the incubation period, the substrates were air dried and sieved through a 4-mm-screen sieve. Thus, the treatments consisted of XF and F with five different organic matter contents (Table 1). The physical and chemical analysis of these treatments were showed in table 1.

The soil samples were placed in PVC (Polyvinyl chloride) columns (10.0-cm diameter and 50.0-cm height) that the internal walls were previously coated with paraffin in order to avoid water preferential flow. The bottom of the columns was covered by a "clarite" type screen fixed in a perforated PVC cap, which allowed the upward flow of water, the drainage of excess water, and prevented soil loss. After filling with soil samples, the columns remained for 18 hours in a box containing a water layer 80% of the height of the columns, in order to saturate the soil. This method allows soil moistening occurs from the bottom up, avoiding the formation of air bubbles trapped in the pores. Subsequently, the columns were left in an upright position for 72 hours to drain excess water until the soil reached field capacity.

A CO_2 pressurized sprayer equipped with two TT 11002 tips, spaced 0.50 m, maintained at a pressure of 35.5 lb pol^{-2} and a spray volume of 180 L ha^{-1} was used to applied the commercial dose 100 g ha^{-1} of saflufenacil (Heat®) on top of the columns. The dose used corresponds to the maximum recommended for the application in pre-emergence in the control of weeds in the registered cultures (MAPA, 2020).

Table 1. Chemical and physical properties of the treatments: Xanthic Ferralsol (XF) and Ferralsol (F) after incubation with different amounts of manure.

Soils	Treatment	Manure:Soil (v:v)	OM dag kg^{-1}	pH (H_2O)	P --mg dm^{-3}--	K^+	Ca^{2+} --------cmol$_c$ dm^{-3}--------	Mg^{2+}	Al^{3+}	H+Al
Xanthic Ferralsol	XF1	0: 1	0.65	4.98	0.3	9.0	0.13	0.04	0.20	2.1
	XF2	0.25: 1	1.43	6.16	46.8	408.0	1.84	1.15	0.00	1.1
	XF3	0.5: 1	3.00	6.8	161.2	887.0	3.26	2.11	0.00	0.5
	XF4	0.75: 1	5.09	7.21	348.9	1386.0	4.45	3.36	0.00	0.3
	XF5	1: 1	7.43	7.33	612.3	2292.0	4.65	3.80	0.00	0.5
Ferralsol	F1	0: 1	1.43	4.97	8.9	21.0	0.52	0.13	0.99	4.1
	F2	0.25: 1	2.87	5.47	59.2	448.0	2.78	1.57	0.00	2.9
	F3	0.5: 1	5.09	6.09	171.6	967.0	4.73	2.91	0.00	1.8
	F4	0.75: 1	6.65	6.55	297.1	1625.0	6.29	4.10	0.00	1.3
	F5	1: 1	8.87	6.95	434.5	2173.0	6.89	4.92	0.00	0.5

Soils	Coarse sand	Thin sand	Silt	Clay
	-----------------	%	-----------------	
Xanthic Ferralsol	20.1	54.7	4.9	20.3
Ferralsol	18.6	9.2	13.3	58.9

OM: Organic matter, v:v: volume:volume, pH: potential of hydrogen, P: phosphorus, K^+: potassium, Ca^{2+}: calcium, Mg^{2+}: magnesium, Al^{3+}: aluminum, H+Al (hydrogen + aluminum). Soil analysis was made according to describe for Teixeira et al. (2017).

Twelve hours after spraying the herbicide, rain simulation was performed with the application of a 60 mm of water. The volume of water applied was measured using rain gauges attached to the side wall of the columns. The columns remained upright for 48 hours to drain the remaining excess water. Then, the columns were sectioned in ten parts with 5-cm each one. Substrate samples contained in each column section were transferred to pots of 0.3 dm^3. Five beet (*Beta vulgaris*) seeds, indicator species of saflufenacil presence in the soil (Barcellos Júnior et al., 2019), were sown per pot. After seed germination, seedlings were thinned to three per pot.

Two experiments were carried out, one for XF and one for F. The experiments were installed in a greenhouse in a completely randomized design with a factorial 5 × 10 scheme with three replications, i.e., soils with five different organic matter contents (mixture of soil and manure described in Table 1) ten depths of soil sample collections in PVC columns (0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45 e 45-50 cm). Additionally, some columns, for both soils, without herbicide application, were kept as control.

The leaching of the herbicide in the soil columns was determined by evaluating the index of intoxication of the indicator plant at 21 days after seedling emergence (DAE). The intoxication index of the plants was evaluated according to the European Weed Research Council scale (1964), modified for grades varying from 0 (absence of intoxication) to 100 (death of the plant).

The intoxication values at 21 DAE were calculated as a percentage of the control (without herbicide application). Results were expressed as treatment means ± standard deviation.

3. Results

Intoxication symptoms were observed in beet plants grown in Xanthic Ferralsol samples with a lower content of organic matter (XF1) collected up to a depth of 45-50 cm from the column (Figure 1). The increase in the organic matter content retained the herbicide in the first layers of the soil profile. Plants grown in soil samples XF2 and XF3 showed symptoms around 10% and 40% intoxication at depths of 25-30 cm and 20-25 cm, respectively (Figure 1). On the other hand, the percentage of intoxication in beet plants was lower than 5% in samples collected at depths of 20-25 cm for XF4 and 30-40 cm for XF5 (Figure 1).

The increase in the organic matter content of Ferralsol samples (F) reduced saflufenacil leaching and intoxication symptoms in the indicator species (Figure 1). The percentage of intoxication in beet by saflufenacil was greater than 80% in the cultivation of F1 soil samples collected to a depth of 30-35 cm (Figure 1). Saflufenacil leached to a depth of 25-30 cm in F2, causing about 20% intoxication in beet plants at this depth (Figure 1). Plants grown in F3 show the greatest intoxication symptoms, about 60%, when planted in samples taken at a depth of 15-20 cm (Figure 1). In treatments F4 and F5, low saflufenacil leaching was observed. In these soils, the intoxication symptoms of the indicator species were lower than 5% (Figure 1).

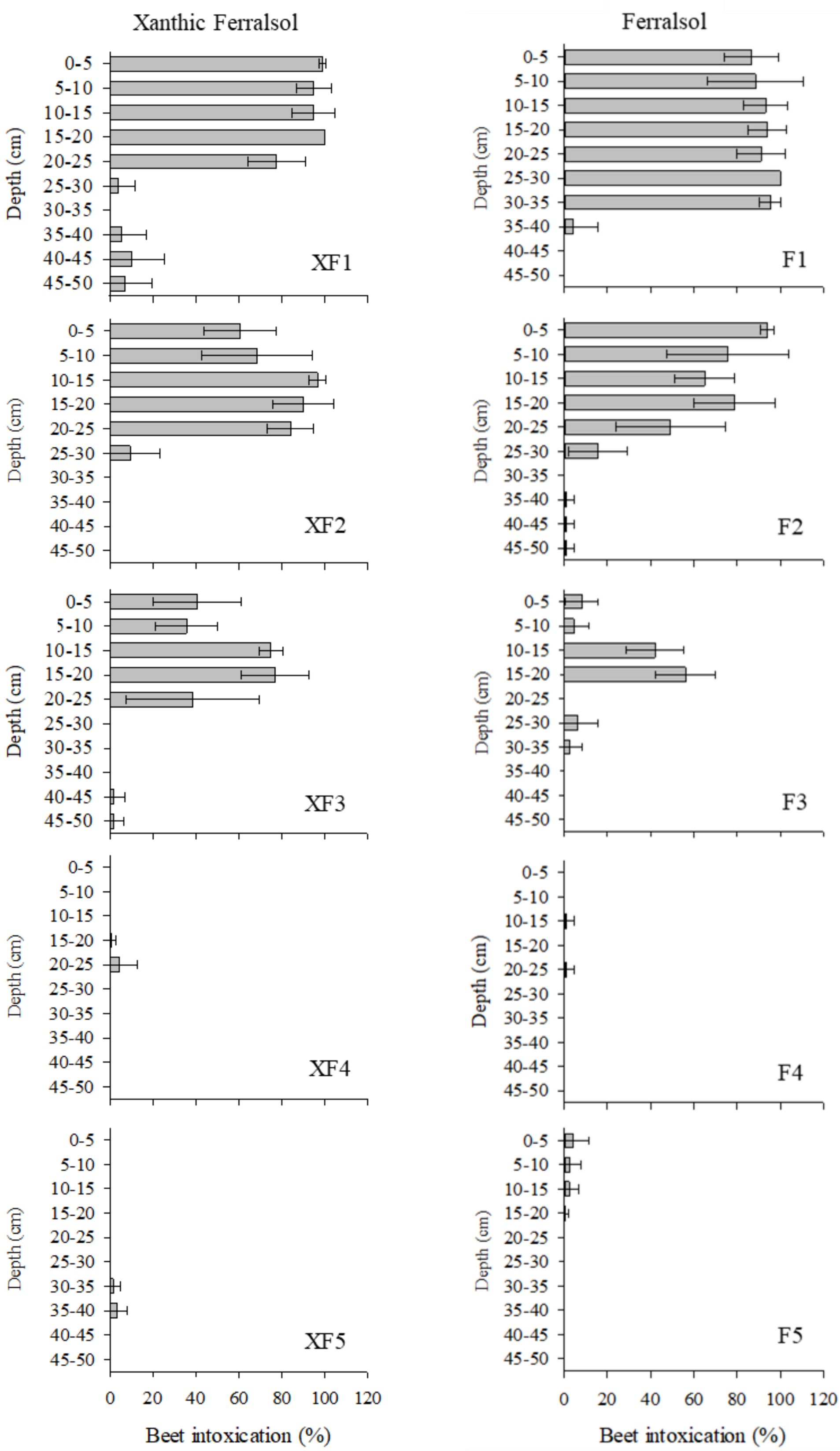

Figure 1. Leaching of saflufenacil in samples of Xanthic Ferralsol (XF) and Ferralsol (F) with different organic matter content: 0.65% (XF1), 1.43% (XF2), 3.00% (XF3), 5.09% (XF4) and 7.43% (XF5); 1.43% (F1), 2.87% (F2), 5.09% (F3), 6.65% (F4) and 8.87% (F5), after 60 mm simulated rain. Bars represent means ± standard deviations (n = 3) of the percentage of intoxication caused by the herbicide at 21 days after the emergence of beet (*Beta vulgaris*) grown in soil samples collected at different columns depths.

4. Discussion

The greater saflufenacil leaching in soil without the addition of manure (XF1) shows that the increase in organic matter content reduces the movement of this herbicide in the soil profile (Figure 1). Similar results were observed for sulfentrazone, a weak acidic herbicide, belonging to the same mechanism of action as saflufenacil, which leached up to 50 cm, after a simulated 60-mm rain, in soils with low organic matter contents (Passos et al. 2015; Braga et al. 2016). This increase in herbicide leaching can be explained by the fact that the lower content of organic matter in the soil decreases the number of binding sites capable of interacting with the herbicide, facilitating the movement of the molecule in the soil profile (Vivian et al. 2007).

Organic matter content reduced saflufenacil leaching and intoxication symptoms in the indicator species grown in of Ferralsol samples (Figure 1). These results show that the addition of organic matter probably increased the sorption of the herbicide in the soil. In addition to organic matter, the clay content of the soil reduces saflufenacil leaching, as observed in Ferralsol samples (Monquero et al. 2012). Thus, soils with a higher clay content tend to retain the herbicide, reducing leaching. Interestingly, in this study, although Ferralsol (F) has a higher clay content than Xanthic Ferralsol (XF), observing a condition under which these soils showed a similar organic matter content (1.43% in F1 and XF2), saflufenacil leached more in F1 than in XF2. This result may be probably due to the greater potassium content in XF2 than F1 (Table 1). When present in the exchangeable soil complex, K+ can increase the contact surface by the double diffuse layer of clay (Parameswaran and Sivapullaiah 2017). Thus, saflufenacil may have been retained with greater intensity in XF2 and, therefore, leached less in the soil column. Not only can the transport of herbicides in the soil be influenced by the amount of clay, but also by the minerals present in it, which can influence the mobility of the herbicide (Mudhoo and Carg 2011).

The lower saflufenacil leaching in the XF2 treatment in relation to F1 may also be due to a higher soil: manure ratio of XF2 (Table 1). The addition of the highest manure volume may have increased the functional groups containing oxygen (–COOR, –C=O, –COR) after the incubation period, as observed for the addition of aged biochar to the soil (Ren et al. 2018). These functional groups can increase the formation of a hydrogen bond between organic matter and saflufenacil, reducing herbicide leaching.

It is important to know the physicochemical interactions between herbicides and soil organic matter in order to make the correct use of the chemical product, reducing environmental contamination and ensuring an efficient weed control (Stipičević et al. 2014; Faria et al. 2018; Martins et al. 2018). In this study, the increase in the organic matter content, both in XF and in F, reduced the intoxication of beet plants by saflufenacil and decreased the leaching of this product (Figure 1). These results can be explained once the addition of organic matter increases the sorption of saflufenacil in soils (Barcellos Júnior et al. 2021). It was observed that the recommendation of saflufenacil dose used in pre-emergence must be considered for soil organic matter content to reach a satisfactory weed control. Additionally, attention is necessary when using this herbicide, especially in sandy soils with low organic matter contents, due to the leaching propensity and the consequent risk of environmental contamination.

5. Conclusions

Soil organic matter content influences directly the dose of saflufenacil in pre-emergence, necessary for weed control. Additionally, the application of this herbicide in soils with low organic matter content may represent a significant environmental contamination risk of soil and watercourses.

Authors' Contributions: BARCELLOS JÚNIOR, L.H.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article; MATOS, C.C.: acquisition of data, analysis and interpretation of data, drafting the article; PEREIRA, G.A.M.: conception and design, drafting the article, acquisition of data, analysis and interpretation of data; PAULA, D.F.: acquisition of data, analysis and interpretation of data, drafting the article; CAPOBIANGO, N.P.: acquisition of data, analysis and interpretation of data, drafting the article; SILVA, A.A.: conception and design, analysis and interpretation of data, drafting the article. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

Acknowledgments: This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES)- Finance Code 001 and Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG).

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Received: 23 April 2021 | **Accepted:** 19 January 2022 | **Published:** 9 September 2022