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ORIGINAL ARTICLE

Physicochemical properties of soil and rates of saflufenacil in emergence and growth of soybean

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Abstract

The study of herbicide dynamics in the soil and their interaction with the components of the environment makes it possible to ensure the selectivity of crops and the agronomical efficiency. The aim of this research was to evaluate the influence of soil physicochemical properties on the emergence and growth of soybean, with pre-emergence application of various saflufenacil rates. An experiment was carried out in a greenhouse with a completely randomized design, testing different soil types containing "Erechim", "Santa Maria" and "Eldorado do Sul", at different saflufenacil rates: 0, 12.5, 25, 50, 100, 200, 400 g a.i. · ha^{-1}. The application was performed 1 day after soybean sowing, and analyzed variables were: the phytotoxicity emergence of seedlings, dry mass and height of the soybean. The saflufenacil effective dose of 50% response in soybean (ED_{50}) and the characteristics of the soils showed that the soil contained clay and sand which were the components most related to the saflufenacil availability to the plants. A lower ED_{50} by phytotoxicity to the soybean was found in soil with lower and greater content of clay and sand, respectively. The physicochemical properties of soil influenced the saflufenacil activity, having greater potential of injury to soybean in the soil from Eldorado do Sul, due to its clay and sand content.

Keywords: adsorption, clay, *Glycine max*, phytotoxicity

Introduction

Due to good adaptation, survival and occurrence of herbicide resistance, there has been increased infestation of hairy fleabane (*Conyza* spp.) the areas of soybean production in Brazil. The use of herbicides with different mechanisms of action, such as inhibitors of protoporphyrinogen oxidase (PROTOX), have stood out as alternatives for the management of hairy fleabane biotypes resistant to glyphosate (Montgomery *et al.* 2017), the most commonly applied herbicide in the cultivated areas of soybean with Roundup Ready® technology.

Saflufenacil belongs to the PROTOX mode of action, controlling broad leaves, and can be applied in the pre-sow or preharvest burndown (Grossmann *et al.* 2010). Nowadays, its use is to control horseweed glyphosate resistance before the soybean sow, but injuries can occur in some circumstances (Gannon *et al.* 2014). Thus, understanding herbicidal behavior as a function of soil physiochemical properties can help to prevent these crop injuries and determine the correct rate to control weeds (Gannon *et al.* 2014).

The herbicidal availability in the soil is related to adsorption between the herbicide molecule and the local bind in the soil surface (Khorram *et al.* 2017). Anionic herbicides, such as saflufenacil which has acid ionization constant p*K*a 4.4, shows low adsorption to the soil components when the pH is optimal to soybean growth (pH 6.0) due to the negative chargers remaining dissolved and available in soil solution (Szmigielski *et al.* 2018). However, a binding with positive chargers present in the clay minerals surface can occur, decreasing the availability for radicular adsorption (El-Nahhal and Hamdona 2016). Still, the organic matter content of the soil affects herbicide adsorption, reducing the leaching potential and the plant absorption (Rojas *et al.* 2014). Furthermore, it is an important factor to saflufenacil adsorption (logarithm of octanol-water partition coefficient [log K_{ow}] of 2.6) (Gannon *et al.* 2014).

Due the great variability of the physical-chemical properties of Brazilian soils, different behaviors of herbicides in relation to the sorption of these to the particles of soil and its persistence in the environment (Alekseeva *et al.* 2014) can be predicted. Therefore, it is impossible to consider a unique recommendation of herbicidal use with residual effect. Thus, a better understanding of interactions among the soil, plant and herbicide is fundamental for efficient weed control and reducing the negative impact on the environment and injuries to the crop (Gannon *et al.* 2014). Therefore, the aim of this study was to evaluate the influence of the texture and organic matter rate of the soil on the emergence and growth of soybean, as a function of the application of saflufenacil rates in pre-emergence.

Materials and Methods

The study was conducted in 2018, in a greenhouse, in a randomized complete design with four replications, and experimental units of 1 l plastic pots. The treatments were in a factorial scheme, where factor A was the type of soil, named "Erechim", "Santa Maria" and "Eldorado do Sul" according to their origin. Each soil had different properties (Table 1). Factor B tested different rates of the saflufenacil, which were: 0, 12.5, 25, 50, 100, 200, 400 g a.i. · ha^{-1}, expressing 0, 0.25×, 0.5×, 1×, 2×, 4× and 8× the recommended rate for the burndown application of broadleaf weeds prior to the soybean sow (50 g a.i. · ha^{-1}).

The soil samples were sifted (mesh size: 7/16") and conditioned to the pots. Fertilizing was done according to soil chemical analysis, and the pH was corrected with liming to the soybean standard (pH 6.0) (3.7, 5.4 and 9.1 g lime kg · $soil^{-1}$ to Eldorado do Sul, Erechim and Santa Maria, respectively). Four soybean seeds of Brasmax Icone cultivar by experimental unit were sown, with a germination percentage of 80%, at 3 cm depth. The seeds were treated with pyraclostrobin, fipronil and thiophanate-methyl (5, 50 and 45 g 100 kg · $seeds^{-1}$, respectively), and an inoculant based on *Bradyrhizobium elkanii* (200 ml 100 kg · $seeds^{-1}$). The saflufenacil rates were applied 1 day after sowing, in damp soil, using a CO_2 pressurized backpack sprayer, calibrated to deliver a spray volume of 150 l · ha^{-1}, using flat fan nozzles model TeeJet® XR 110.015. Water was supplied daily.

The analyzed variables were: phytotoxicity, emergence of seedlings, dry mass and height of soybean plants. The soybean phytotoxicity was evaluated at 3, 7, 10, 14 and 32 days after emergence (DAE), using a scale of 0 (no injury) to 100% (plant death). The emergence date was considered when 50% of the plants had cotyledons completely above the soil level forming a 45° angle or more with their respective hypocotyls.

At 32 DAE the height and dry mass of soybean plants were measured from the soil surface to the last node observed in the main stem. For dry mass, the plants were collected and dried at 65 ± 5°C for 72 h, and then weighed. The percentage of emerged plants, height and dry mass values of soybean plants were converted to percentage values in relation to the control without application of herbicide, for the respective soil types.

The data were submitted to the analysis of variance ($p > 0.05$) using the R statistical software and the ExpDes package (Ferreira *et al.* 2011). Then, after analysis of regression using the logistic sigmoid model was calculated according to the following equation:

Table 1. Physicochemical properties of tested soils

Soil	pH (H_2O)	Texture [%]			Organic matter [%]	P	K	Ca	Mg
		sand	clay	silt		[mg · dm^{-3}]		[$cmol_c$ · dm^{-3}]	
Erechim	4.6	8	60	32	5.5	17.3	74.0	7.2	2.0
Santa Maria	4.0	40	26	34	1.9	7.5	29.0	5.3	2.0
Eldorado do Sul	4.6	56	18	26	2.0	11.0	32.0	3.7	1.2

$$Y = \frac{a}{1+\left(x/x_0\right)^b},$$

where: Y – the analyzed variable; x – the saflufenacil rate; a – the difference between the maximum and minimum points of curve; x_0 – the saflufenacil rate that provides 50% of response in soybean (ED_{50}) and b – the relative slope around ED_{50}.

For the comparison of ED_{50} values of each soil type, it was necessary to calculate the confidence interval (≥0.95). The overlap of confidence interval among the ED_{50} of different soils tested indicates an absence of significant difference. The relative data for the ED_{50} values of the phytotoxicity variable were related to the components of clay, sand, and organic matter soil through the following linear equation:

$$Y = a + bx,$$

where: Y – soil characteristics; x – ED_{50} values; a – intercept and b – linear coefficient.

Results and Discussion

The analysis of variance showed interaction between the studied factors for the analyzed variables (data not shown). This result indicates that the soil type influenced the herbicide activity in the initial growth of soybean. The equations had satisfactory adjustment, allowing for the estimation of the ED_{50} value for each soil type. At 3 DAE, it was found that the soil from Eldorado do Sul had the greatest phytotoxicity among the soils (Fig. 1A). This difference can be attributed to the lowest and greatest matter of clay and sand, respectively, observed in this soil in comparison to the others. Nevertheless, at 7, 10 and 14 DAE, a similar response was seen in this soil and that from Santa Maria, with less damage to the crop with the herbicide when applied in Erechim soil, whose sand content is low and clay and organic matter are high (Fig. 1A, C, D).

The analysis of the ED_{50} value at 3 DAE confirmed the differences between the soil of Eldorado do Sul and the others, which were similar, when there was overlap of reliable interval (Fig. 1A, Table 2). At 7, 10 and 14 DAE, we found that the ED_{50} values of Erechim soil, which have the greatest percentage of clay particles and organic matter, and the lowest sand content, were different than the soils of Eldorado do Sul and Santa Maria (Fig. 1B, C, D, Table 2). Furthermore, we pointed out that with more DAE there was an increase in ED_{50} values in the three soil types, indicating a decrease of phytotoxicity of herbicide in the soil due to the probable recovery of some plants.

At 32 DAE there was stratification of the ED_{50} between the soils (Fig. 1E), whose values were 19.34, 34.38 and 48.36 for Eldorado do Sul, Santa Maria and Erechim soils, respectively (Table 2). This suggests that the lower content of clay (32 to 18%, in Erechim and Eldorado do Sul, respectively) and/or the greater sand content (8 to 56%, in Erechim and Eldorado do Sul, respectively), there is greater damage to the soybean at the same herbicide rate. Similarly, the granulometric composition of soil influenced the injury levels of clomazone to irrigated rice cultivars (Sanchotene *et al.* 2010). Irrigated rice cultivars tolerated higher clomazone rates when applied in soil with higher clay and organic matter content (43 and 3.2%, respectively) compared to soils with low levels of clay and organic matter (16 and 1.6%, respectively) (Sanchotene *et al.* 2010).

Generally, the soybean plants cultivated in Erechim soil, having high content of clay (60%) and organic matter (5.5%) and low content of sand (8%) in its composition, presented lower initial injury and faster injury recovery (Fig. 1, Table 2). Consequently, it is possible to assume that in this soil type there is a lower risk of phytotoxicity to soybean through saflufenacil application, and there is lower negative interference potential in the establishment of this crop compared to other types of soil. In general, the ED_{50} values observed showed a direct relation to the levels of organic matter and clay, and inverse relation to the sand (Fig. 2). The main reason that saflufenacil can be sorved by organic matter and clay particles, resulting in the herbicide being less available in the soil solution (Gannon *et al.* 2014). Meanwhile, with sand particles the herbicide will be more available. So, when the herbicide is available in the solution, it is more likely that injuries will happen. With 60% clay content and 8% sand the greatest ED_{50} values were found which indicate lower phytotoxicity to soybean, while with 18% clay and 56% sand, the lowest ED_{50} values were found. This result demonstrates the effect of soil texture on the phytotoxicity of saflufenacil to soybean. It is then necessary to be aware of this characteristic when using the herbicide.

The relationship between ED_{50} values of saflufenacil herbicide and the soil characteristics showed that the most related components to saflufenacil adsorption on soil were the clay and sand contents, whose linear coefficient values of the equation were 1.30 and –1.44, respectively, while for the organic matter the value was 0.11 (Fig. 2, Table 3). It was possible to determine that although the content of organic matter in the soils of Santa Maria and Eldorado do Sul is similar, the last one showed greater injuries to the soybeans than the first, confirming the relationship of clay and sand to the herbicide availability.

Other studies performed with herbicide PROTOX inhibitors showed the importance of organic matter in soil in the sorption of these herbicides, as well as its availability in the soil solution. The content of organic

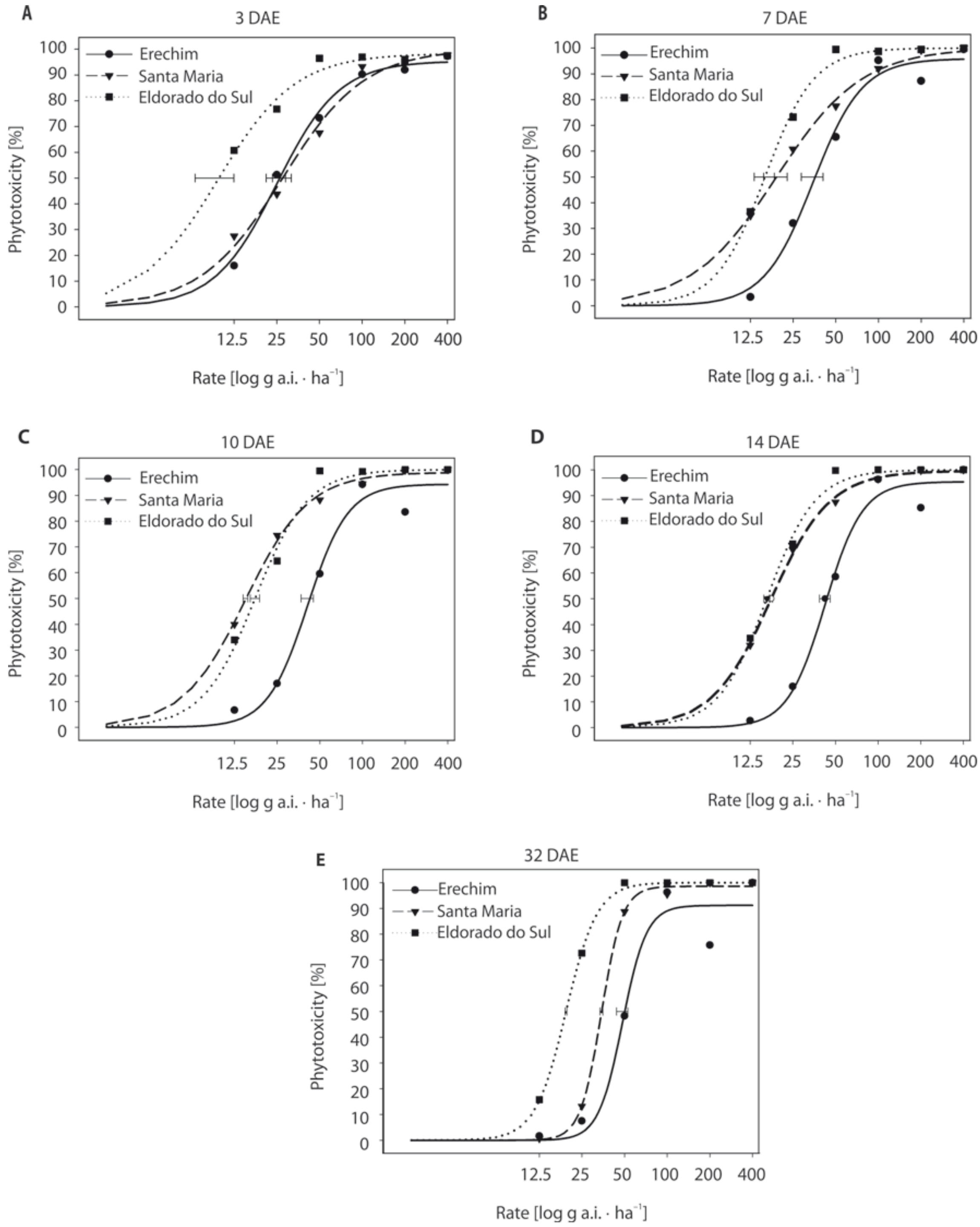

Fig. 1. Phytotoxicity (%) at 3 (A), 7 (B), 10 (C), 14 (D) and 32 (E) days after emergence (DAE) of soybean after application of several saflufenacil rates in different soil types

matter is related to flumioxazin (Ferrell *et al.* 2005), sulfentrazone (Passos *et al.* 2013) and fomesafen (Silva *et al.* 2013) adsorption. Clay content is also relevant in the last two herbicides. The phytotoxicity of sulfentrazone in *Beta vulgaris* L. was reduced in soils with high contents of organic carbon and clay, demanding sometimes greater rates for weed control (Szmigielski *et al.* 2009).

Soybean emergence was negatively influenced by greater saflufenacil rates in the different types of soil studied. In the soil from Eldorado do Sul, the emergence percentages of seedlings were lower and did not have emergence from the rate of 50 g a.i.· ha^{-1} onwards, while that for the soils of Santa Maria and Erechim, the absence of emergence was from 200 and 400 g a.i. · ha^{-1} of saflufenacil, respectively (Fig. 3A).

Table 2. Equations and parameters of logistic sigmoidal types of phytotoxicity, seedling emergence, height and dry mass of soybean according to different soil types and saflufenacil rates

Soil	Equation	R^2	ED_{50}	IC
		Phytotoxicity		
		3 DAE		
Erechim	$Y = 95.41 / [1 + (x / 24.95)^{1.97}]$	0.95	24.95	21.02–28.88
Santa Maria	$Y = 100.0 / [1 + (x / 27.46)^{1.50}]$	0.97	27.46	23.2–31.64
Eldorado do Sul	$Y = 98.33 / [1 + (x / 09.53)^{1.58}]$	0.94	9.53	6.63–12.44
		7 DAE		
Erechim	$Y = 95.92 / [1 + (x / 34.63)^{2.50}]$	0.93	34.63	28.60–40.65
Santa Maria	$Y = 100.0 / [1 + (x / 19.12)^{1.44}]$	0.95	19.12	15.50–22.75
Eldorado do Sul	$Y = 100.0 / [1 + (x / 15.86)^{2.51}]$	0.92	15.86	13.29–18.43
		10 DAE		
Erechim	$Y = 94.34 / [1 + (x / 40.99)^{3.04}]$	0.98	40.99	36.85–45.12
Santa Maria	$Y = 98.93 / [1 + (x / 14.95)^{1.95}]$	0.99	14.95	14.36–15.55
Eldorado do Sul	$Y = 100.0 / [1 + (x / 17.47)^{2.34}]$	0.99	17.47	16.15–18.79
		14 DAE		
Erechim	$Y = 95.37 / [1 + (x / 42.22)^{3.27}]$	0.99	42.22	38.57–45.87
Santa Maria	$Y = 99.57 / [1 + (x / 17.57)^{2.08}]$	0.99	17.57	17.11–18.02
Eldorado do Sul	$Y = 100.0 / [1 + (x / 16.42)^{2.54}]$	0.99	16.42	15.63–17.21
		32 DAE		
Erechim	$Y = 91.19 / [1 + (x / 48.36)^{5.12}]$	0.97	48.36	43.99–52.73
Santa Maria	$Y = 98.61 / [1 + (x / 34.38)^{5.83}]$	0.99	34.38	33.58–35.18
Eldorado do Sul	$Y = 100.0 / [1 + (x / 19.34)^{3.92}]$	0.99	19.34	19.06–19.61
		Emergence		
Erechim	$Y = 113.94 / [1 + (x / 40.92)^{2.11}]$	0.86	40.92	23.93–57.91
Santa Maria	$Y = 100.99 / [1 + (x / 45.49)^{1.55}]$	0.94	45.49	31.65–59.33
Eldorado do Sul	$Y = 099.61 / [1 + (x / 09.86)^{2.71}]$	0.93	9.86	4.55–15.17
		Height		
Erechim	$Y = 097.46 / [1 + (x / 51.27)^{8.83}]$	0.95	51.27	41.20–61.34
Santa Maria	$Y = 101.94 / [1 + (x / 31.16)^{2.20}]$	0.97	31.16	26.85–35.47
Eldorado do Sul	$Y = 096.49 / [1 + (x / 25.90)^{5.42}]$	0.89	25.90	20.92–30.88
		Dry mass		
Erechim	$Y = 117.61 / [1 + (x / 32.18)^{2.91}]$	0.90	32.18	22.71–41.65
Santa Maria	$Y = 111.83 / [1 + (x / 29.40)^{3.38}]$	0.95	29.40	24.11–34.69
Eldorado do Sul	$Y = 097.83 / [1 + (x / 17.51)^{1.63}]$	0.88	17.51	9.61–25.41

R^2 – coefficient of determination; ED_{50} – dose of herbicide that causes 50% of phytotoxicity (g a.i. · ha^{-1}); IC – reliable interval at 95% of average; DEA – days after emergence

Table 3. Linear type equations, coefficient of determination (R^2) and values of statistic F of the model based on ED_{50} values for soybean sowed in soils with different characteristics and applications of saflufenacil rates

Characteristic of soil	Equation	R^2	F
Clay	$Y = 1.37 + 1.30x$	0.67	26.12*
Sand	$Y = 71.43 - 1.44x$	0.68	27.39*
Organic matter	$Y = 0.22 + 0.11x$	0.60	20.04*

*it indicates statistical significance of the model ($p \leq 0.01$); R^2 – coefficient of determination; F – value of F-statistics

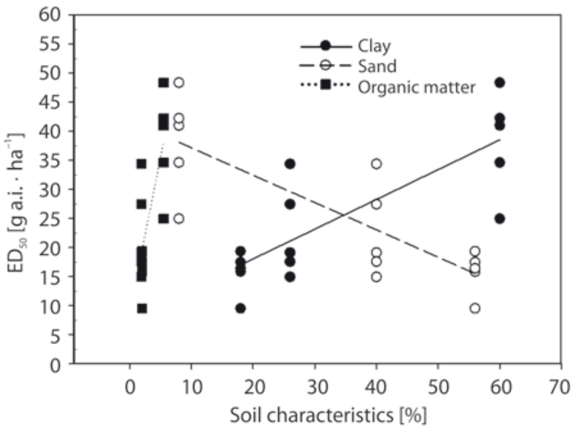

Fig. 2. Relation between ED_{50} values for saflufenacil, calculated from the phytotoxicity to the soybean, and soil characteristics: clay (●), sand (○) and organic matter (■) of different soil types

When analyzing the reduction of soybean plant height percentage, a similar response to emergence was observed (Fig. 3B). So, ED_{50} in Erechim soil was 51.27 g a.i. · ha^{-1} and differed from that observed in the other soils (Fig. 3B, Table 2). For the shoot dry mass there was reduction according to the increase of saflufenacil rates, except for the dose of 12.5 g a.i. · ha^{-1} in soils from Erechim and Santa Maria, where there were greater values of dry mass in relation to the control (Fig. 3C). This behavior can be explained by hormesis, term that characterizes the phenomenon associated with toxic compounds that present responses of stimulation to the vegetal development and growth under low rates and the inhibition of at high rates (Pawłowska *et al.* 2019).

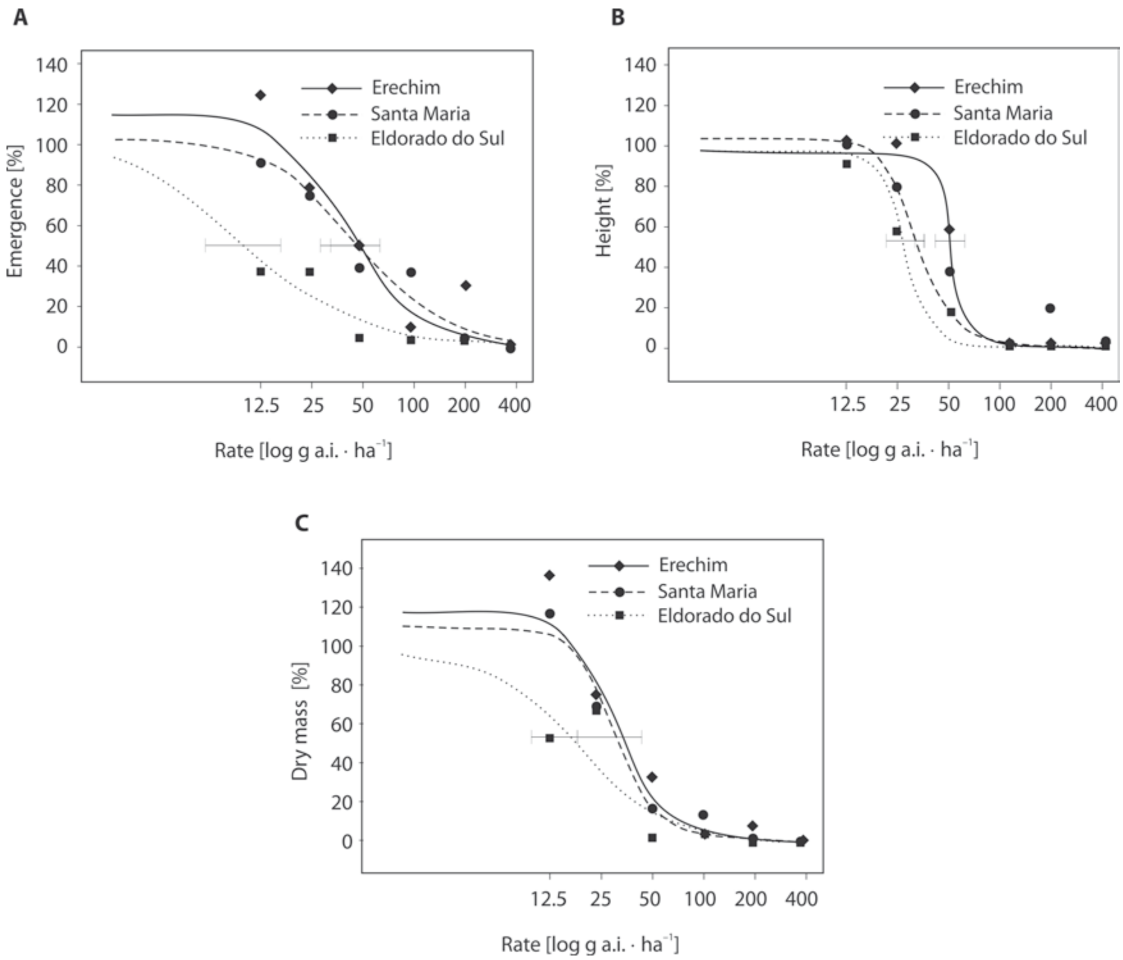

Fig. 3. Reduction of emergence (A), height (B) and shoot dry mass (C) of soybean after application of different saflufenacil rates in different soil types

Corroborating with this behavior, the ED_{50} values for the soils of Eldorado do Sul, Santa Maria and Erechim were 9.86; 45.49 and 40.92 g a.i. · ha^{-1}, respectively. The difference was observed between the soil of Eldorado do Sul and the others (Fig. 3A, Table 2).

The ED_{50} values calculated from dry mass were 17.51, 29.40 and 32.18 g a.i. · ha^{-1} for the soil of Eldorado do Sul, Santa Maria and Erechim, respectively (Table 2). These values followed the same tendency observed for the other tested variables. The ED_{50} of fomesafen for shoot dry mass of sorghum was of 32.12 ml · ha^{-1} for Cambisol (76% sand, 17% clay and 1.1% MO) and 525.13 ml · ha^{-1} for Organosol (37% sand, 36% clay and 20.2% MO), where the ratio of herbicide sorption was greater in this last soil which has a high content of organic matter and a high clay percentage (Silva *et al.* 2013). This corroborates the results of the present work.

The application of herbicides can cause different kinds of stress in plants. Even those that are tolerant, waste energy for their recovery. When there is permanent stress, the growth rate of the plant is affected, and is reduced in comparison to plants that were not exposed to xenobiotic. As a result, there are relevant changes in the crop growth stages (Carvalho *et al.* 2009). This process of delay in growth of plants can explain the lower height and dry mass of soybean plants when exposed to saflufenacil rates since it is easily available in the soil of Eldorado do Sul. However, it is important to highlight that the plants can recover after exposure to these herbicides, and more studies should be carried out, mainly under field conditions, for adequate evaluation of soybean growth and development.

Conclusions

The physicochemical properties of soil, mainly, contents of clay, sand and organic matter, influence saflufenacil herbicide activity when applied in pre-emergence in soybean. We conclude in this study that saflufenacil has more potential of soybean injury in soil that comes from Eldorado do Sul, due the lowest ED_{50} values, which can be attributed to the lowest and greatest content of clay and sand in this soil, respectively.

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