

## Mobility of flumioxazin herbicide in a Dystrophic Red Yellow Latosol at Brazilian Southern Amazon

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### Abstract

Herbicides are chemicals which can contaminate soil and water, if inadvertently used. In the soil, the herbicide may undergo adsorption and leaching or degradation by physical, chemical and biological processes in addition to being absorbed by the weeds and / or cultivation. The aim of this study was to determine the mobility of flumioxazin in Dystrophic Red Yellow Latosol, in the southern Amazon, using sorghum plant as test under different rainfall indexes. We used PVC pipes, which were filled with soil. The experimental design was completely randomized in a 2x2x5 factorial scheme, consisting of herbicide treatments [with or without flumioxazin (50 g i.a. ha<sup>-1</sup>)], rain (40 or 80 mm) and soil depths (2.5, 5, 10, 15 and 30 cm). After each rainfall simulation, the tubes were removed and sorghum seeds were placed in the depths 2.5, 5, 10, 15 and 30 cm from the top of the columns. It was observed a higher activity of flumioxazin in the initial 2.5 cm. In all depths where herbicide effect was observed, it was also observed the interruption of sorghum growth, being more intense in the simulations of 80 mm of rainfall. The herbicide presented high adsorptive capacity in Dystrophic Red Yellow Latosol, with mobility up to the first 2.5 cm along the profile.

**Keywords:** leaching, herbicide, contamination, sorghum bioassay.

**Abbreviations:** PVC pipe\_polyvinyl chloride pipe.

### Introduction

In order to decrease weed population and to improve the efficiency of production, herbicides have been used in agricultural production. However, the indiscriminate use of this product has contributed to the increase of contamination of soil, water and ultimately on animal and human life as well (Nicholls, 1988; López-Piñeiro, 2013).

Once herbicides penetrate into the soil, they can interact by adsorption, leaching, degradation or absorption by means of physical, chemical and biological processes with cultivated plants and weeds. Thus, knowledge about these factors is valuable in order to predict herbicide interactions in the environment and subsequent crops (Troiano et al., 2001; Carbonari et al., 2010).

Currently, agricultural systems are dependent on the use of agrochemicals, that can provide leaching of molecules and water contamination. Thus, it should be analyzed by professionals and agencies of control (Rozemeijer & Broers, 2007; Alister et al., 2008).

Herbicide leaching becomes a problem when water enters the system through rainfall or irrigation. When water contacts soil and plants, it dissolves and transport part of these chemical substances, through soil pores, until finally

reaches soil saturated zone. This negatively affects the quality of subsurface reservation water (Mitchell et al., 2005; Papiernik et al., 2012).

However, leaching is a critical factor for herbicides application, since the process is necessary for superficial incorporation of most part of these products applied directly in the soil. Leaching process allows the products achieving seeds or plants in their early development. Usually, leaching is greater in sandy soil than clayey and silty soils (Fast et al., 2010).

The behavior of herbicides depends on climatic factors and soil properties. There are mainly three processes that can occur with herbicides in the soil, namely retention, processing and transportation (Silva et al. 2007; Mueller et al., 2014).

Flumioxazin presents low solubility in water (1.79 mg L<sup>-1</sup> at 25 °C) and low vapor pressure (Rodrigues & Almeida, 2011), suggesting it has low potential for volatilization. Its activity depends on environmental factors, such as light and temperature, but the process is decreased when exposed to dry soil (Ferrel et al., 2005; PPDB, 2017).

As this herbicide is used in pre-emergence, it is essential to know its activity in the soil, knowledge of sorption processes, as well as leaching of herbicides, allows the recommendation of different herbicide rates according to soil type and, consequently, more efficient weed control (Deuber et al., 2009; Alister et al., 2008; Umiljendić et al., 2013; Yamashita et al., 2018).

Incorrect and indiscriminate use of herbicides in crops is known to have caused several environmental problems, such as contamination of soil and surface and groundwater (Tanabe et al., 2001; Prado et al., 2013; Pereira et al., 2017). This is due to the poor information on the dynamics of herbicides applied in different biomes, with soils with specific characteristics that result in a single recommendation for different cultivation conditions, generating short and long term problems that are often difficult to reverse. Adsorption and bleaching studies demonstrate that organic matter content in different soil types influences flumioxazine adsorption, suggesting that this herbicide rate may be recommended according to soil adsorption capacity (Carbonari et al., 2010; Yamashita et al., 2018). In addition, there has been little published information on flumioxazin behavior in tropical soils and even more so when it comes to the use of this herbicide under cultivation conditions in the Amazon biome. Thus, there is a lack of information for these specific conditions, both soil and climate and rainfall. From the knowledge of the behavior of this herbicide in this condition, it will be possible to make safe recommendations from both the technical and environmental point of view, this work was done.

Thus, for the related conditions, this work aimed to evaluate the mobility of flumioxazine under different conditions of simulated water regime in a Dystrophic Red Yellow Latosol.

## Results

### Data analysis

Data analysis showed significance for dry matter and plant height with triple interaction among factors (herbicide, rainfall, depth). About phytotoxicity, there was significance for herbicide and depth, and interactions between herbicide versus depth and rainfall versus depth (Table 2).

### Herbicide and rainfall simulations

After rainfall simulations of 40 and 80 mm, the flumioxazin herbicide was found up to 0.10 and 0.30 m respectively. It caused a dry matter decrease in sorghum crop. Therefore, the flumioxazin has capability to leach through the studied layers of soil and provided phytotoxicity up to 0,30 m that negatively impacted sorghum's dry matter (Table 3).

These results suggest that leaching of flumioxazin depends on the amount of water in the soil. Similar results showed leaching of flumioxazin up to 5 cm in a ultisol and up to 10 cm in an Dystrophic Red Yellow Latosol, with simulated rainfall of 45 and 90 mm (Oliveira et al., 1999). However, Deuber et al. (2009), found flumioxazin leaching only at depths 2.75 and 2.20 cm, for 50 mm rainfall simulation, in a Eutrophic Red Latosol and in a Dystrophic Red Yellow Latosol, respectively. These differences possibly occurred due to the composition of clays and to the presence of organic matter in the different soil types. When simulating a 40 mm rainfall amount on a Dystrophic Red Yellow Latosol at

more superficial layer (2.5 cm), it was found lower dry matter amount per plant, regardless of herbicide treatments (Table 4). Regarding the rainfall of 80 mm, for soil with and without herbicide presence, it was possible to note that biomass production was similar through all the sowing depths (Table 5). When the rainfall simulation was of 40 mm, it was found that the herbicide caused phytotoxic effects in sorghum plants up to 10 cm of soil depth. From this depth, the biomass values reached were at least 21% higher than lower depths, allowing inferences about the reduced mobility of flumioxazin in the soil under these conditions. When simulating a 50 mm rainfall, Deuber et al. (2009) observed reduced herbicide mobility and phytotoxicity on cucumber at just 1.50 cm deep. The low leaching of the herbicide, regardless of soil moisture, due to its low solubility in water has been reported, indicating that the recommendation of applying the herbicide should be directed according to the adsorptive capacity of each soil (Mueller et al., 2014; Lima et al., 1999).

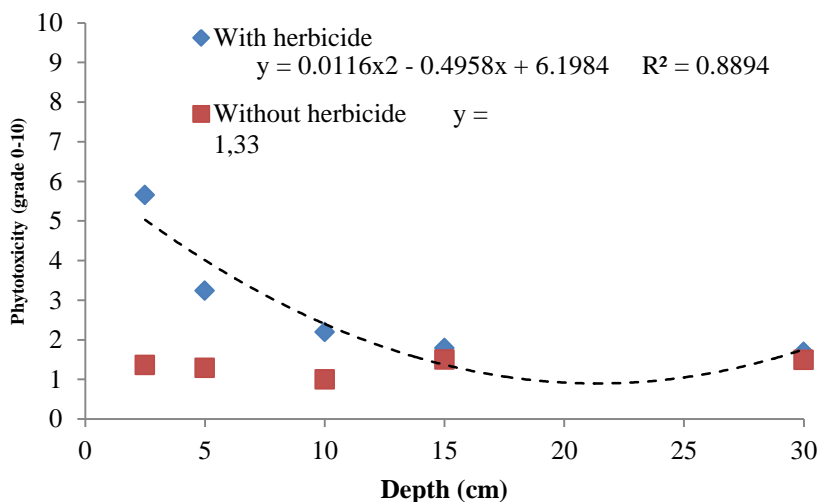
### Herbicide and soil depth

Even in presence of the herbicide, regardless of soil depth, there was no difference in biomass production for a simulation of 80 mm of rainfall. In this condition, the rainfall simulation provided dilution of the flumioxazin through the soil column. Similar results were observed by Oliveira et al. (1999), indicating that lower adsorption of the herbicide due to soil adsorptive sites occupied with water, can contribute positively to go down of the product. Height of sorghum plants were significantly affected by the residual effect of the herbicide. For simulation of 40 mm of rainfall, there was a reduction in height of sorghum plants only in the smaller depth, that is, at 2.5 cm depth, sorghum plants were very effectively affected by the action of the herbicide (Table 6). For simulation of 80 mm of rainfall, flumioxazin mobility was increased, and up to 10 cm of soil depth, the height of plants was lower than those in uncontaminated soil. The low mobility of the herbicide, limited to 2.5 and 10.0 cm of soil depth for rainfall of 40 and 80 mm, respectively, indicates that flumioxazin has low solubility in water, does not dissociate, presenting low mobility along the soil profile (WSSA, 2002; Carbonari et al., 2010). Analyzing herbicide and depth interaction, in soil contaminated with flumioxazin for simulation of 40 mm of rainfall, the height of plants was affected only up to 2.5 cm of soil depth, providing a 43.0% reduction when compared to a 80 mm rainfall simulation. This indicates that lower rainfall can reduce herbicide mobility throughout the soil profile, harming the plants which are sown at lower soil depths (Table 7). In the absence of herbicide, simulation of 80 mm of rainfall was more suitable for initial growth of sorghum plants than half of this volume. At all soil depths, height of plants was negatively affected by the lower volume of supplied water. This result is due to the fact that these plants are more susceptible to hydric stress under these conditions. Without herbicide application, there was no difference in height of sorghum plants through the soil depths studied for both rainfall simulated amounts (Table 8). However, with flumioxazin application, simulation of 40 mm of rainfall provided more stratification and mobility throughout of substrate profile than simulation of 80 mm of rainfall. Rainfall of 40 mm provided smaller plants height at the lowest depth, this difference was significant regarding 5 and 10 cm depth. The highest plants were obtained in depths greater than 15 cm.

**Table 1.** Chemical, Physical, and Mineral Analysis of the Dystrophic Red Yellow Latosol used as substrate.

pH (H <sub>2</sub> O)	P - mg dm <sup>-3</sup>	K	Ca+Mg	Ca	Mg	Al	H	H+Al	O.M.* g dm <sup>-3</sup>
			----- cmolc dm <sup>-3</sup> -----						
5.30	2.0	70.0	2.13	1.25	0.88	0.19	3.39	3.58	26.00
V (Base Saturation)			T**(pH 7)	Fe <sub>2</sub> O <sub>3</sub>	Sand (g kg <sup>-1</sup> )			Silt	Clay
%			cmolc dm <sup>-3</sup>	g Kg <sup>-1</sup>	Total	Coarse	Fine	----- g kg <sup>-1</sup> -----	
5.90			39.20	10.0	692	344	348	97	211

\*O.M.: organic matter; \*\* T: cation exchange capacity.

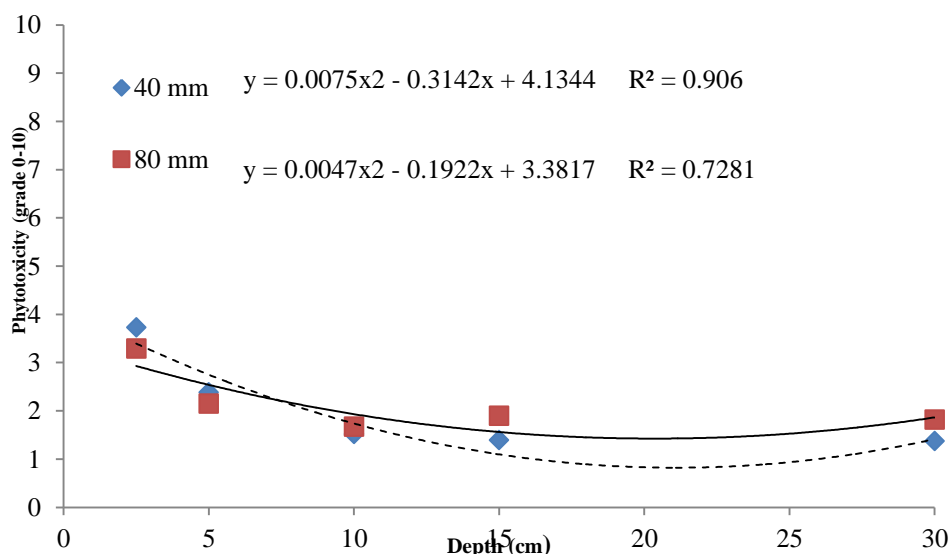


**Fig 1.** Phytotoxicity grade of sorghum by depth for flumioxazin herbicide presence.

**Table 2.** Statistical analysis for dry matter, plant height and phytotoxicity of sorghum cultivated in a Dystrophic Red Yellow Latosol

Variation source	Dry matter	Plant height	Phytotoxicity
	----- mean square -----		
Herbicide (H)	0.0000**	73.829**	50.212**
Rainfall (C)	0.0000**	68.582**	0.149ns
Depth (P)	0.0000**	14.687**	10.886**
H*C	0.0002**	15.390**	0.239ns
H*P	0.0000**	12.461**	11.171**
C*P	0.0001**	10.313**	0.0682*
H*C*P	0.0037*	4.922*	0.331ns
Residue	0.000014	0.950	0.216
C.V. (%)	9.95	5.28	21.92

Significance mean: \* p < 0.05; \*\* p < 0.01; ns = Not significant



**Fig 2.** Phytotoxicity grade of sorghum by depth for rainfall simulation (40 and 80 mm).

**Table 3.** Unfolding of plant dry matter values of sorghum plants for the interaction between the factors "rain simulation", "depth" and "herbicide presence". The values shown in the table refer to the plant dry matter of sorghum plants (in grams).

Rainfall (mm)	Depth (cm)	Herbicide	
		With	Without
40	2.5	18.1 b	33.3 a
	5.0	26.9 b	47.5 a
	10.0	30.4 b	43.3 a
	15.0	35.0 a	38.7 a
	30.0	40.0 a	40.4 a
80	2.5	32.1 b	45.0 a
	5.0	27.2 b	50.0 a
	10.0	30.3 b	46.6 a
	15.0	34.1 b	43.3 a
	30.0	34.2 b	50.0 a
C.V. (%)	9.95		

Mean followed by the same letter on the line, do not differ by Tukey test at 5% probability.

**Table 4.** Unfolding of plant dry matter values of sorghum plants for the interaction between the factors "herbicide presence", "depth" and "rain simulation". The values shown in the table refer to the plant dry matter of sorghum plants (in grams).

Herbicide	Depth (cm)	Rainfall (mm)	
		40	80
With	2.5	18.1 b	32.1 a
	5.0	26.9 a	27.2 a
	10.0	30.3 a	30.4 a
	15.0	38.7 a	34.1 a
	30.0	40.4 a	34.2 a
Without	2.5	33.3 b	45.0 a
	5.0	47.5 a	50.0 a
	10.0	43.3 a	46.6 a
	15.0	35.0 b	43.3 a
	30.0	40.0 b	50.0 a
C.V. (%)	9.95		

Mean followed by the same letter on the line, do not differ by Tukey test at 5% probability.

**Table 5.** Unfolding of plant dry matter values of sorghum plants for the interaction between the factors "herbicide presence", "rain simulation" and "depth". The values shown in the table refer to the plant dry matter of sorghum plants (in grams).

Herbicide	Rainfall (mm)	Depth (cm)				
		2.5	5.0	10.0	15.0	30.0
With	40	18.1 c	26.9 b	30.4 b	38.7 a	40.4 a
	80	32.1 a	27.2 a	30.3 a	34.1 a	34.2 a
Without	40	33.3 c	47.5 a	43.3 ab	35.0 c	40.0 bc
	80	45.0 a	50.0 a	46.6 a	43.3 a	50.0 a
C.V. (%)	9.95					

Mean followed by the same letter on the line do not differ by Tukey test at 5% probability.

**Table 6.** Unfolding height values of sorghum plants for the interaction between factors "rain simulation", "depth" and "herbicide presence". The values shown in the table refer to the height of sorghum plants (in cm).

Rainfall (mm)	Depth (cm)	Herbicide	
		With	Without
40	2.5	12.33 b	17.63 a
	5.0	16.07 a	17.17 a
	10.0	17.55 a	18.67 a
	15.0	19.64 a	18.24 a
	30.0	19.49 a	18.60 a
80	2.5	17.72 b	21.20 a
	5.0	16.64 b	21.20 a
	10.0	17.98 b	20.23 a
	15.0	19.21 a	20.25 a
	30.0	18.41 a	21.06 a
C.V. (%)	5.28		

Mean followed by the same letter on the line, do not differ by Tukey test at 5% probability.

**Table 7.** Unfolding the height values of sorghum plants for the interaction between the factors "herbicide presence", "depth" and "rain simulation". The values shown in the table refer to the height of sorghum plants (in cm).

Herbicide	Depth (cm)	Rainfall (mm)	
		40	80
With	2.5	12.33 b	17.72 a
	5.0	16.07 a	16.64 a
	10.0	17.55 a	17.98 a
	15.0	19.64 a	19.21 a
	30.0	19.49 a	18.41 a
Without	2.5	17.63 b	21.20 a
	5.0	17.17 b	21.20 a
	10.0	18.67 b	20.23 a
	15.0	18.24 b	20.25 a
	30.0	18.60 b	21.06 a
C.V. (%)	5.28		

Mean followed by the same letter on the line, do not differ by Tukey test at 5% probability.

**Table 8.** Unfolding the height values of sorghum plants for the interaction between the factors "rain simulation", "depth" and "herbicide presence". The values shown in the table refer to the height of sorghum plants (in cm).

Herbicide	Rainfall (mm)	Depth (cm)				
		2.5	5.0	10.0	15.0	30.0
With	40	12.33 c	16.07 b	17.55 b	19.64 a	19.49 a
	80	17.72 ab	16.64 b	17.98 ab	19.21 a	18.41 ab
Without	40	17.63 a	17.17 a	18.67 a	18.24 a	18.60 a
	80	21.20 a	21.20 a	20.23 a	20.25 a	21.06 a
C.V. (%)	5.28					

Means followed by the same letter on the line, do not differ by Tukey test at 5% probability.

was increased, smaller phytotoxicity grade were noted. These results indicate flumioxazin mobility is limited to depths near to 10 cm for rainfall lower than 80 mm.

In general terms, it can be concluded that the low flumioxazin mobility along the Dystrophic Red Yellow Latosol profile does not provide residual effects on the substrate, which could to harm the subsequent crops. Similar results were observed by Alister et al. (2008) and Deuber et al. (2009).

## Discussion

Despite the movement of herbicide molecules and their interaction in adsorption and desorption processes are not total know in Brazilian weather conditions and soils, processes such as sorption and desorption can influence the movement of the herbicide into the soil.

This study demonstrated that in both of the simulated amounts of rainfall (40 and 80 mm), the dry matter of the plants was considerably reduced with the presence of flumioxazin. However, in 40 mm rainfall simulation, the dry matter decreased only in minors depth. That shows that leaching of the flumioxazin herbicide depends of the water amount.

The herbicide presence in the soil affected the plant development, including its heights. The reduction of the biomass production and plant height can be due to the reduction in the amount of photo-assimilated that were transported to the roots, affecting their normal development. The herbicide movement in soil layers and the consequent contamination provided a significant decrease of these variables.

It was noted that the amount of water from rain or irrigation favors the movement of flumioxazin herbicide through the layers of Dystrophic Red Yellow Latosol. Thus, the depth that flumioxazin herbicide can achieve depends of the amount of

water in the soil, where more water means a greater depth, like observed in Oliveira et al. (1999) and Deuber et al. (2009).

The composition of clays and organic matter present in the Dystrophic Red Yellow Latosol may have been the most important factor that caused the flumioxazin sorption. That could prevent the flumioxazin to reach a greater depth for 40 mm rainfall simulation. It is known that, in general, there is an inverse relationship between the sorption and herbicide leaching potential (Vivian et al., 2007).

Moreover, the herbicidal sorption capacity of the soil is important because it is directly related to the availability of these particles to their herbicidal action, to microbial attack and biodegradation, being inversely proportional to the possibility of leaching and contamination at great depths (Andréa and Luchini, 2002).

In terms of adsorption capacity, it was high for the flumioxazin herbicide, providing a low movement of the herbicide through the soil layer. The effect of reducing the availability of flumioxazin may be related to phenomena of interaction between the sorptive soil complex cations and the rich centers electrons herbicide molecule and cation binders (eg, calcium and or magnesium) of exchange complex and clays (Lima et al., 1999) and / or soil organic matter and pH (Grey et al., 1997).

Notice that high ionic exchange capacity may also cause a positive correlation with the sorption capacity of other herbicides, like the sulfentrazone herbicide (Vivian et al., 2007). These results were also found by other authors in different soil types (Sprankle et al., 1975).

However the process of distribution and herbicide degradation in soil is dynamic and unique to each soil-herbicide. It depends of the relation among chemical and physical properties of the herbicide, interaction with the soil and its half-life ( $t_{1/2}$ ), climate conditions, vegetation, soil

properties and management area (Hager and Nordby, 2004; Vivian et al., 2007).

## Materials and methods

### Local e material used

Between August and October of 2018, a laboratory experiment was carried in Alta Floresta-MT, in the Southern Amazon, Brazil, geographical coordinates 9°53'50''S and 56°5'41''W and 320 m of altitude. The studied variable was flumioxazin's effect on initial development of sorghum (*Sorghum vulgare*) for different rainfall simulated levels.

A PVC pipe, with paraffin in internal walls, was filled with substrate. Soil, classified as Order: Latosol, suborder: Red Yellow Latosol, Group: Dystrophic Red Yellow Latosol, subgroup: Dystrophic Red Yellow Latosol (Embrapa, 2013) was the substrate, taken from the 0 to 0.20 m upper layer. The soil utilized had never been cultivated. Once soil samples were collected, they were dried indoors for 48 hours and subsequently sieved (2 mm). Substrate samples were submitted to chemical and physical analyses (Table 1). The analyses were conducted at Plante Certo Laboratory (Várzea Grande – MT, Brazil).

Preparation of experimental units and application of treatments Primarily, PVC pipes (0.50 m of length and 0.10 m of diameter) received a full central longitudinal cut. Following, the PVC pipes were re-assembled with duct tape as original shape. They were closed in one extreme by a permeable membrane. Later on, they were buried in vertical position into a sand box (membrane side facing down), supported by a wood structure. PVC pipes were then filled with substrate and water was added until the soil reached its field capacity. PVC pipes were kept for 24 hours in vertical position in order to allow drainage.

After this period, flumioxazin was applied in the PVC pipes (50 g i.a. ha<sup>-1</sup>). For the application process, a sprayer of CO<sub>2</sub> (pressure of 3.00 bar, nozzle model SF 110.02) was used, calibrated to spray volume of 250 L ha<sup>-1</sup>. At the time of application, air temperature was of 30 °C, relative humidity 63.00%, cloudiness 25.00% and negligible wind.

### Plant materials

After a period of 24 hours, daily rainfall amount of 10 mm was simulated within the PVC pipes, until a total amount of 40 and 80 mm was reached. Then, immediately, PVC pipes were put into horizontal position and the duct tape was removed, resulting in two pieces of PVC pipes with substrate. For each piece, five sorghum seeds (*Sorghum vulgare* L., commercial variety BRS 655) were sown, with distances 0.025; 0.05; 0.10; 0.15 and 0.30 m from the upper to lower sides.

### Variables analyzed

Sorghum plants developed through 15 days, after which plant height, dry biomass weight and phytotoxicity were determined. Plant height was considered as the distance from the base until the last leaf apex, and it was measured by using a ruler. Dry biomass weight determination was done after plants were cut from the base and dried for 96 hours in a forced air oven (70 °C). Weight of dried samples was determined using a digital balance. For the phytotoxicity determination, grades from 1 (no phytotoxicity) up to 9

(death of the plant) were used, following method from Alam (1974).

### Statistical design

A factorial experiment design, with 3 factors and 4 repetitions, was adopted. The factors were represented by herbicide (with and without application), rainfall (total of 40 and 80 mm) and depth (0.025; 0.05; 0.10; 0.15 and 0.30 m). Measure data was analyzed using ANOVA and Tukey's mean test (5.00 and 1.00%). Regression analysis was performed in order to assess quantitative factors. We used the statistical program SISVAR (Ferreira, 2011).

### Conclusions

According to the evaluations, and from the results obtained, it can be concluded that the herbicide flumioxazin has low mobility in a Dystrophic Red Yellow Latosol at Brazilian Southern Amazon. It can also be verified that this herbicide has high adsorptive capacity along the profile in Red Dystrophic Red Latosol. In addition, it does not cause residual effects on the substrate, ie its mobility is limited to the first 2.5 cm along the profile of this soil.

Thus, it is possible to infer that, despite having great soil contamination capacity, this herbicide, if used correctly, only moves in the superficial part of the Amazonian soil, which allows its conscious use and can be part of weeds management programs in this Biome.

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