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Persistence and Leaching of Herbicides in Oxisol and Their Efficiency in Suppressing Weed Emergence Flow

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SRB and CAMA designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author MBBS managed the literature searches, analyses of the study performed the analysis. Author FDC managed the experimental process and author MBBS identified the species of plant. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this study was to evaluate the residual effect of herbicides on the flow of emerging plants over time, at different depths of soil in an area of cane sugar over a oxisol.
Study Design: In the field, the design was a randomized block with six treatments and four replications. In the greenhouse, the completely randomized design while maintaining the same treatment in the field, In both steps, we used the following herbicides, sulfentrazone, amicarbazone, tebuthiurom, diuron + hexazone, imazapic and control treatment.
Place and Duration of Study: The field experiment was carried out at Sugarcane Center in Ribeirão Preto, São Paulo State, Brazil (21°12'00.4"S, 47°52'21.7"W) during the rainy season (setember to march).

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Methodology: To assess the leaching were used PVC pipe of 10 cm in diameter, longitudinally sectioned, were buried to a depth of 20 cm attempting to maintain the original structure of soil. After fixing the pipes in the ground, were sown seeds of ivy-leaf morning glory (*Ipomoea hederifolia*) between cane rows, in order to verify the effectiveness of herbicides in controlling this plant daninha. After 90 days, the tubes were removed, separated into halves and placed in greenhouse, where seeds of the test plants rope-glory (*Ipomoea hederefolia*) lengthwise along the profile of each half of the tubes. At 30 days after sowing, the number of plants was recorded at depths 0-5, 5-10, 10-15 and 15-20 cm.

Results: The herbicides sulfentrazone and amicarbazone obtained greater control of *Ipomoea hederifolia* emergency flow over other treatments. For 0-5 cm deep layer of the herbicides studied showed leaching. The herbicide sulfentrazone showed higher leaching compared to other herbicides in the 0-5 and 5-10 cm deep. Tebuthiuron controlled germination of *Ipomoea hederifolia* at depths greater than 10cm,

Conclusion: The suppressive effect on emergency flow of weeds was observed only superficially.

Keywords: Chemical management; Ipomoea hederifolia; weeds; sugar cane; leaching.

1. INTRODUCTION

Sugarcane is a major crop cultivated in tropical and sub-tropical countries. It is cultivated in about 200 countries and Brazil is the world's largest cane producer and contributes to 25% of world's total production [1].

Major changes occurred in the sugarcane industry after the establishment of the Environmental Protocol in 2007, in which straw burning should be eliminated by 2017 [2]. This new process, known as green sugarcane harvesting, leaves 5-20 Mg ha-1 of straw on the soil surface, promoting significant changes in its physical, chemical, and biological properties [3,4]. This physical barrier over the soil surface stopped most weeds from germinating and growing up through the trash blanket. This greatly reduced the amount of grass and broadleaf weeds that grew in the crop after harvest, and reduced the reliance on herbicides for weed control.

As this farming system stabilised, the types of weeds that infested cane fields changed. Stronger, more vigorous weeds that could penetrate through the trash layer became dominant. Weeds such as vines, nut grass, couch grass and guinea grass have often become greater problems after the introduction of GCTB [5]. Medeiros and Christoffoleti [6] found that *Urochloa decumbens*, *Urochloa plantaginea*, *Digitaria horizontalis* and *Panicum maximum* had reduced infestation in treatments where there was the presence of sugarcane straw, contrary to the plots without straw. These authors also reported that while *Euphorbia heterophylla* and *Ipomoea hederifolia* species have emerged in the plots without straw in the fields with straw was higher emergency rate of these species. It is possible that sugarcane straw remaining on the soil surface may create a favorable environment for the seed germination and the development of these weeds due to a reduced daily temperature range, increased soil moisture retention, and improved physical and chemical soil attributes.

Vines germinate readily through a straw blanket, grow prolifically and are particularly important because, if left uncontrolled, they can impede harvesters. Where vines are prolific, they entangle several rows of cane and harvesters have difficulty separating the rows. Harvester operators may have to stop the machine and manually separate the cane, or the machine can damage the cane crop by pulling it out of the ground. If the harvester manages to separate the cane and feed it into the machine, the vines wrap around the moving parts of the harvester and may require manual removal [5]. Ivyleaf morningglory can reduce sugarcane yield 20 to 25% due to physical hindrance and by reducing harvest efficiency [7].

Weed control programs in sugarcane are based on the use of PRE herbicides for control of emerging annual grasses and broadleaf weeds, and POST herbicides for control of weeds, including some perennial weeds emerging later in the season [8]. It is difficult to apply pre-emergent herbicides to a trash blanket and so knockdown herbicides can be used for control of vines applied broadcast-directed below the crop canopy after the final inter row cultivation to control weeds, especially morningglories, until the crop is harvested [9].

Leftover and unburned straw from sugarcane cutting may compromise the ability of residual herbicide to reach the soil [10]. The presence of the straw may compromise herbicide efficacy and environmental behavior, especially for those with higher residual activities since rainwater has to transfer them to the soil [11]. For example, a straw layer of 7 tons per hectare can hold up to 200 L of the sprayed herbicide [12], reducing its leaching and groundwater contamination.

Most herbicides molecules registered in Brazil are residual action molecules applied as pre-emergent. Many have long residual power, especially those suitable for the crop planted at the end of the rainy season [13].

When straw remains on the soil, herbicides are potentially lost by photodegradation, volatilization, and even adsorption to plant residues. The degree of decomposition or plant residue age may affect its ability to adsorb the herbicide [14]. For the areas where the green cane is grown, leaching has two important features: it is critical for surface embedding of most of the herbicides, crossing throught trash-blanketing and reaching seeds or plants in germination, but, when excessive, can adduce them to deeper soil layers, limiting its action and may even promote contamination of the water table [15].

Leachability is a product of a herbicide's solubility and how strongly it adsorbs onto soil particles. Soil-applied herbicides, which have very low solubility, must be incorporated or receive rainfall to achieve good distribution. Soluble products, move with the soil water which can leave the field through runoff or leaching through the soil profile [5].

Leaching is critical for surface incorporation of most herbicides, reaching seeds or plants germinating, but when excessive, can carry them into deeper layers of the soil, limiting its action, and may even promote groundwater contamination [16].

The aim of this study was to evaluate the residual effect of herbicides sulfentrazone, amicarbazone, tebuthiuron, diuron + hexazinone and imazapic applied on oxisol cultivated with green-cane on the flow of emerging vines and their leaching at different depths.

2. MATERIALS AND METHODS

Two experiments were developed for this work, the first experiment was conducted under field conditions during the months from September to December 2012, on a Red Oxisol [17], previously characterized by chemical and physical analysis (Table 1), which was grown cv. IACSP95-2042 of sugarcane.

The experimental area, located in the municipality of Ribeirão Preto, São Paulo, Brazil, is 545 m height above sea level and the climate is characteristic for dry winter and cold and humid and hot summer, according to Koppen classification [18], considered as Cwa.

The experimental design used for the field experiment was randomized blocks with six treatments and four replications. The treatments consisted of a control treatment and the residual herbicides suitable for the cultivation of sugarcane, sulfentrazone; amicarbazone; tebuthiuron; hexazinone + diuron and imazapic, applied in pre-emergence (PRE) of ivy-leaf morning glory (*Ipomoea hederifolia* L.) seedlings on the sugarcane straw at recommended doses by the manufacturers listed in Table 2.

The experimental plots consisting of four lines of sugarcane spaced 1.50m each other and 8m long. Prior to application of herbicides, half of the plot (6x4 m) was seeded with *Ipomoea hederefolia*, in the remaining area were threaded two PVC pipe sections cut longitudinally with 20 cm length and 10 cm in diameter. The application of herbicides was conducted with pressurized costal equipment with regulated CO2 to provide spray volume of 200 L/ha. During the application were recorded the following weather conditions (Table 3).

Ninety days after application (DA) was visually estimated the number of emerged plants, using scale from 0 to 100% control of weeds.

For the second experiment, 90 days after herbicide application, the two pipe sections threaded in previous experimental plots were taken using appropriate tools to preserve soil structure.

The pipe sections were taken to the greenhouse, put in benches, adopting a completely randomized design with 6 treatments and 8 repetitions and then these were sown with glory ivy-leaf morning (*Ipomoea hederifolia* L). Seeding was performed on an imaginary line drawn along the center of the pipe section, with the seeds separated by 1 cm apart. During the experiment, irrigation was kept enough for germination and development of seedlings.

Table 1. Physical and chemical Attributes in a Red Oxissol, in Ribeirao Preto, SP, Brazil

Layer	Bulck density	Particle density	Clay	Silt	Sand	OM	P	pH	K	Ca	Mg	H+Al	Basis	CEC	V
m	kg/dm^3	kg/dm^3	%	%	%	g/dm^3	g/dm^3	$CaCl^2$	....						%
0.00 - 0.20	1,35	2,8	60	18	22	32	62	5.0	4.0	40	22	51	66	110	56
0.20 - 0.40	1,4	2,8	61	19	21	30	29	4.5	3.0	22	9	72	35	101	37

Table 2. Doses for herbicides applied in preemergence (PRE) of *Ipomoea hederifolia* L. seedlings on the sugarcane straw

Treatments	Dose (g/ha)
Sulfentrazone	1600
Amicarbazone	2000
Tebuthiuron	2400
Diuon+hexazinone	1004+396
Imazapic	175
Control treatment	-----

Table 3. Climatic conditions during application of herbicides, Ribeirão Preto, SP, Brazil

	Application start	Application end
Hour	08:15h	09:35h
Relative humidity	38%	29.1%
Nebulosity	0%	10%
Wind speed	2.5 km/h	7 km/h
Air temperature	30.2℃	34℃

After 30 days of sowing was evaluated the germination of *I. hederifolia* plants in in the depths of 0 to 5; 5 to 10; 10 to 15 and 15 to 20 cm of the pipe sections deep. Herbicide leaching was considered the inverse of germination, i.e. the absence of germination was considered effect of herbicide leached.

The data obtained in percentage were tested for their normality and subject to angular transformation:

$$\arcsin \sqrt{\frac{x + 0.5}{100}}\ . \qquad (1)$$

Then the data were submitted to analysis of variance by F test and means were compared by Tukey's test at p <0.05 probability.

3. RESULTS AND DISCUSSION

The data in Table 4 indicate that in field tests all herbicides provided control of *Ipomoea hederifolia* when compared to control treatment. Sulfentrazone herbicide obtained greater control efficiency of emergence *I. heredifolia* flow relative to other treatments. The treatments with amicarbazone, imazapic and tebuthiuron presented intermediate behavior, differing significantly from the best and the worst treatment; it was the mixture of diuron and hexazinone, which ensured only 42% of the morning-glory control.

Sulfentrazone 2',4' dichloro-5-(4-difluoromethyl-4,5-dihydro 3 methyl-5-oxo-1H1,2,4-triazol-1-yl) methanesulfonanilide is listed as an herbicide for use in sugarcane production during the dry season and is an inhibitor of protoporphyrinogen oxidase (PROTOX) specifically recommended for the pre-emergence control of species in agricultural areas used for sugarcane, coffee, citrus, eucalyptus, and soy crops as well as non-agricultural areas in Brazil [19]. Sulfentrazone is highly water-soluble (solubility = 490 mg/L), nonvolatile (vapor pressure = 1.0×10^{-9} mm Hg at 25℃), anionic (pK = 6.56), and hydrophilic (Kow = 1.48) [19]. These parameters convey the stability of the molecule and its affinity for water, which underlie the potential losses of the herbicide to the environment [10].

Studies conducted in soybean have indicated excellent entireleaf morning glory (*Ipomoea hederacea* var. *integriuscula* Gray) [20] and pitted morning glory (*Ipomoea lacunosa* L.) [21] control with sulfentrazone. Other studies have assessed the efficacy of sulfentrazone in controlling *Ipomoea* species in sugarcane crop production [22,23]. The susceptibility of species in this genus to sulfentrazone has been attributed to a low metabolism rate of the herbicide by the plants along with inefficient antioxidant systems [24], because sulfentrazone promotes singlet oxygen production, antioxidant systems can reduce the damage caused to plants by the herbicide.

Table 4. Efficiency of herbicides applied in preemergence to control *Ipomoea hederifolia*. Ribeirão Preto, SP, Brazil

	Dose (g/ha)	Efficiency (%)
Control treatment	--------------	0.0 d
sulfentrazone	1600	98.8 a
amicarbazone	1400	77.5 b
tebuthiuron	2400	68.8 b
diuron+hexazinone	1404+369	42.5 c
imazapic	175	68.7 b
F-Test	57.31**	
CV%	15.24	
LSD	20.79	
P-value	p<0.001	

*[1]Means followed by the same letters do not differ significantly by Tukey's test (p<0.05); ** Significant at 0.01 probability by the F-test; [ns] No significant*

Among the various herbicides options recorded for culture of sugarcane, are the inhibiting acetolactate synthase (ALS) herbicides, as imazapic, imazapyr, trifloxysulfuron-sodium + ametryn, halosulfuron and flazasulfuron, and inhibiting photosynthesis herbicides, ametryn, metribuzin, diuron and tebuthiuron alone or in admixture with hexazinone. Most of these herbicides has action in pre and early post-emergence, being recommended in control of grasses, broadleaf and perennial weeds difficult to control. Moreover, they can provide effective control periods of the top land 100 days [25]. Monquero et al. [26] observed that 15 to 20 ton/ha of straw cause negative effect on the effectiveness of trifloxysulfuron-sodium + ametryn, imazapic, imazapyr and diuron + hexazinone.

In the bioassay to test the leaching of herbicides conducted in the greenhouse, there was interaction between the molecule of herbicide used and the depth ranges (Table 5).

Regarding the persistence of herbicides in the soil, the herbicide Sulfrentazone introduced greater control of *I. hederifolia* germination (90%) in the range from 0 to 5 cm deep. For the same depth the Imazapic herbicides, Amicarbazone and Tebuthiuron had intermediate efficiency. The mixture hexazinone + diuron showed the worst control efficiency at 0 to 5 cm deep with 55% control of *I. hederifolia* germination, 90 days after application.

This is a reality for Brazilian soils that have a pH range that include the pK of sulfentrazone (6.56), theoretically in two soils in the same climatic region with soil texture and organic matter equal but with the soil pH ranging from 5.5 to 7.2, the percentage of ionization would vary from 8.01 and 81.32% respectively, and may thus influence significantly the sorption of herbicides to soil colloids and in consequence, there are different persistence just for this variation in soil pH [27].

The increase in temperature and precipitation in early spring was only sufficient to that the herbicide was dissipated partly because after the dry season was necessary a rainy season, so that there were further dissipation of the herbicide and progressive reduction of their concentration in the soil, Blanco et al. [27] have determined in their studies the end of persistence of sulfentrazone in sugarcane crop in the highest dose (1.2 kg/ha) at 704 DAT.

When leaching and herbicides efficiency in subsurface soil layers are observed Sulfrentazone was more efficient in the layer of 5 to 10 cm deep. This herbicide controlled 50% of *I. hederifolia* seeded while the other herbicides tested controlled germination of 25% of weeds, at most.

Several studies have shown that the dynamics of sulfentrazone depends largely on the physical and chemical characteristics of the soil, especially the organic matter content, pH and mineralogy [28,29]. According to Procópio et al. [30], in tropical conditions where soils are highly weathered, there are predominantly oxides and hydroxides of iron and aluminum and silicate clays 1:1 of low reactivity (kaolinite); thus, organic matter is the primary contributor to these soils CEC. Sulfentrazone lower mobility seems to be related to the higher content of organic matter and clay [31].

In the layer of 10 to 15 cm soil depth only tebuthiuron herbicide showed some efficiency in the control of *I. hederifolia* (20%), while the others showed no control, suggesting that this herbicide has suffered greater leaching than the others. So tebuthiuron herbicide although not the most efficient in the surface layers of soil after 90 days of your application, controls the emergence of *I. hederifolia* at greater depths.

The literature indicates a tebuthiuron half-life of 12 to 15 months, as reported in the Weed Science Society Herbicide Handbook [32], but Cerdeira et al. [33] found a maximum of 20 days. Matallo et al. [34] also found a rapid dissipation of tebuthiuron in Brazilian soils. This finding is not surprising given the greater microbial activity in semitropical and tropical soil, which would enhance degradation of herbicides [35].

Mathematical modeling of tebuthiuron has shown leaching potential in sandy soils down to 10 m, but in field study there was no detectable residue in the soil below the 40 cm depths at any time [33]. Apparently, the herbicide moved to the 20–

Table 5. Efficiency of herbicides after 90 days of application in different soil depths to control to control *Ipomoea hederifolia*. Ribeirão Preto, SP, Brazil

Herbicides		Soil depths (cm)			
	Dose (g/ha)	0-05	05-10	10-15	15-20
Control treatment	--------------	00% cA	00% dA	00% bA	00% aA
Sulfentrazone	1600	90% aA	50% aB	00% bC	00% aC
Amicarbazone	1400	65% abA	05% cdB	00% bB	00% aB
Tebuthiuron	2400	65% abA	25% bB	20% aB	00% aC
Diuron+hexazinone	1404+369	55% bA	15% bcB	00% bC	00% aC
Imazapic	175	75% abA	05% cdB	00% bB	00% aB
F-test plot		38.8124**			
p-plot		<0.0001			
F-test subplot		240.7575**			
p-subplot		<0.0001			
F-test Interaction		16.1428**			
p-interaction		<0.0001			
CV plot (%)		29.68			
CV subplot (%)		20.55			

40 cm depth faster and deeper when applied on soil without sugarcane coverage possibly due to the fact that the cropped plot would have greater evapotranspiration, and hence retard the downward movement of water and chemicals.

4. CONCLUSION

The sulfrendazone herbicide when applied pre-emergence under field conditions proved to be the most persistent herbicides, showing greater control efficiency Ipomoea emergency flow hederifolia after 90 days of application. When considering the leaching, the suppressive effect of herbicides on the emergency flow of weeds was observed only superficially. Only the herbicide tebuthiuron controlled *Ipomoea hederifolia* germination at depths greater than 10 cm, showing more leaching compared to other herbicides.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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