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RESEARCH ARTICLE

TRANSPOSITION OF HERBICIDES ON STRAW SUGAR CANE WITH DIFFERENT RAINFALL INTENSITIES

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ABSTRACT

The sugar cane is one of the most important crops in Brazil, both in the economic as social and environmental. The sugar cane is of fundamental importance as a raw material for the production of sugar and alcohol, which enables the replacement of fossil fuels with renewable. Mechanized harvesting sugar cane without burning straw gave rise to a new production system called green cane. The straw originated this system, combined with the intensity of rainfall determined new concepts on transposition of herbicides to the ground. The work had as objective to evaluate the passage of tebuthiuron, imazapic, hexazinone and diuron herbicides applied to different amounts of straw sugar cane and rainfall. The experiment was conducted in the greenhouse. The experimental design was distributed in a factorial 4x3 (0, 10, 20 and 30 t ha-1 of straw cane sugar and 0, 10 and 20 mm of precipitation) with 6 repetitions. Visual assessment of the indicator plant, sorghum, was based on the scale of the Brazilian Society of Science of Weed at 28 days after herbicide application. The control efficacy of the hexazinone tebuthiuron, diuron and imazapic herbicides were reduced with increasing the amount of straw sugar cane deposited on the soil surface, and increased with greater precipitation. The herbicide hexazinone showed more efficient control while diuron, less control efficiency.

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INTRODUCTION

Brazil is the largest producer of sugarcane. The importance of this sector in the Brazilian society is due to the exports of sugar and alcohol, two of the most important commodities for agribusiness, besides the great potential to generate direct and indirect jobs. It is estimated that sugar production will be 655.2 million tones in the 2015/16 crop (Conab, 2016). The excellent perspective of domestic and international trade for sugar and alcohol, the rise in international oil prices, the growth in demand for flex-fuel vehicles, and the effect of the Kyoto Protocol has stimulated the growth of this sector. The trend for the coming years is that each plant for processing of sugarcane to produce, in addition to sugar, alcohol and energy, carbon credits and a large number of industrial raw materials (Sachs, 2002).Recently, the manual harvest with the previous burning of the sugarcane was the predominant system in Brazil.

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However, this practice is associated with environmental problems such as the degradation of ecosystems and the emission of gases to the atmosphere. Therefore, Law 11,241 of 19/09/2002 came to impose the gradual elimination of the use of fire in detract within 20 years to mechanized areas and 30 years for non-mechanized. As a result of this fact finds the increase of mechanized harvesting practices of culture, since the manual cutting of sugarcane raw becomes unfeasible in the current production scenario. The mechanized harvesting system grinds and throws on the ground leaves, sheaths and hands, forming a plant residue cover called straw or straw. The amount of harvested straw reeds ranges from 10 to 30 t ha-1 depending on the variety used (Trivelin *et al.*, 1996). Among the advantages of maintaining this cover on the soil surface can highlight the reduction of carbon emissions, increased soil organic matter and erosion protection, however, the interference coverage require adjustments in crop management (Mendoza *et al.*, 2000; Bezerra and Cantalice, 2006; Paula *et al*, 2010). The chemical, physical and biological changes in the soil caused by the layer of straw interfere directly on the weed community and the action of herbicides.

According belt and Durigan (2004), species such as (*Brachiariadecumbens*), (*Digitariahorizontalisi*), (*Sidaspinosa*) have a density reduced by straw quantities greater than or equal to 10 t ha^{-1}, however, (*Ipomoea grandifolia*) species, and (*Ipomoea hederifolia*) tend to maintain themselves as competing plant while (*Ipomoea quamoclit)* should increase its population density. The main method of control of weeds present in the sugar cane industry is the chemical, through the application of herbicides in post-emergence of the species. The effectiveness of these products may be altered by the presence of straw, as it intercepts the herbicide on its way to the ground. Adsorption the cover exposes the herbicides to solar radiation and high temperatures, which provides its volatilization and photodegradation. The transport through the cover is associated with the physic and chemical characteristics of each product, as well as the rain occurrence period after application (Simoni *et al.*, 2006; Monquero *et al.*, 2009; Carbonari *et al*., 2010).

Studies by Cavenagui *et al*. (2007) with Amicarbazone herbicide applied in areas with amounts equal to 5 t ha^{-1} thatched roof, the transposition of the product was found to be void at the time of application. For there to be carryover most amicarbazone to the ground, the intensity of 20 mm of rainfall was essential, however, increasing the amount of straw 15 and 20 t ha^{-1} caused a reduction in leaching, although the action simulated rain. Simoni *et al*. (2006) found that the application of the herbicide sulfentrazone in the presence of 20 t ha^{-1} straws significantly reduces their effectiveness; however simulation of 20 mm of precipitation was sufficient for the herbicide to be transported to the soil. The same study showed that the transposition of imazapic was not affected straw coverage, the herbicide showed good performance independent of rainfall intensity. According Oliveira and Freitas (2009), straw amounts of sugarcane between 8 and 12 t ha^{-1} provided the interception of ready-mix trifloxysulfuron sodium + ametryn. For herbicides are recommended with greater efficiency it is necessary to investigate the dynamics of these new products in this sugarcane production system. Thus, the study aims to assess the implementation of tebuthiuron herbicides, imazapic, hexazinone and diuron applied to different amounts of straw sugarcane and rainfall after herbicide application.

The tebuthiuron herbicides, imazapic, hexazinone and diuron were chosen because of their different physical and chemical characteristics and the high commercial demand for these products in Brazilian sugarcane fields. The technical information of the herbicides was summarized in (Table 1).The experimental design was completely randomized with six replications. The treatments were arranged in a factorial 4 x 4 x 3 four amounts of sugarcane straw left on the soil surface (0, 10, 20 and 30 t ha-1) and three rainfall intensities (0, 10 and 20 mm). Each experimental unit consisted of a polyethylene pot having 15 cm diameter and 20 cm in depth. The straw of sugarcane was obtained from plant sugar and alcohol Bandeirantes (USIBAN), Bandeirantes, Parana State. The amount of straw added to each pot was determined by the treatment. The amount of water to be applied to the test plants during the experiment was measured to reach 80% of field capacity used in the vessels. Were used as indicator plant to assess the implementation of herbicides by straw of sugarcane, the kind of sorghum (*Sorghum bicolor*) due to its susceptibility to herbicides. For each experimental unit was seeded 10 sorghum seeds.

The tails of the products tested were prepared in the amount of one liter and placed in bottles type "pet". Herbicides were applied in single doses as the recommendations established by the manufacturer (Table 1). Before application, set the flow rate of the spray assembly, and the speed of last applicator (1 ms^{-1}) to ensure equivalent solution consumption 200 L ha^{-1}. Herbicides were applied one day after sowing Sorghum pre-emergence with costal pressurized spray for CO_2 under constant pressure of 40 pounds pol^{-2}, application bar provided four nozzles with spray tips of the fan type Teejet XR110.02® and spaced from between 0.50 m and 0.5 m target height. Weather conditions during spraying were room temperature 22,1°C, 71% relative humidity and wind speed below 1 m s^{-1}. After 24 hours of application, it proceeded to rain simulation with 10 L of intensities m-2 and 20 l m^{-2}. For this, we used beakers and bottles type "pet" with volume of 500 mL. In the neck of the bottle it was combined with a sprinkler nozzle for adjusting the flow rate of the irrigated area vessels. After 24 hours, it removed all trash deposited in the vessels.

Table 1. Technical information of the herbicides used in the experiment

Formulated product	Active ingredient (A.I.)	Solubility in water	Concentration of (A.I.)	dose applied
Combine®	Tebuthiuron	2.570 mg L^{-1}	500 g L^{-1}	2,4 L ha^{-1}
Plateau®	Imazapique	2.200 mg L^{-1}	700 g Kg^{-1}	200,0 g ha^{-1}
Hexanil®	Hexazinona	32.000 mg L^{-1}	750 g Kg^{-1}	400,0 g ha^{-1}
Diuron NTX®	Diuron	42 mg L^{-1}	500 g L^{-1}	5,0 L ha^{-1}

MATERIALS AND METHODS

The work was conducted in a greenhouse environment, the experimental area of the Department of Agronomy, Centre of Agricultural Sciences, State University of Londrina, Londrina, PR, in the period between July and August 2014. The soil used in the experiment was classified as Oxisoil clayey, representative soil of sugarcane fields of northern Paraná. The soil was collected from a depth of 0.00 to 0.20 m, and then was passed through 5-mm mesh sieve for use in the assembly of the experiment.

During the experiment, the soil water content was maintained at 80%, conditions suitable for germination and plant growth during the experiment period of development. We conducted the evaluation of the efficiency of the products tested over the emerged plants count, and visual evaluation of sorghum plants at 28 days after the application based on the scale proposed by the Brazilian Society of Science of Weed (SBCP) (Table 2).The obtained qualitative data were submitted to analysis of variance and significant effects, Tukey test at 5% significance level. The data of different amounts of straw were analyzed by linear regression.

Table 2. Conceptual scale weeds control experiment to evaluate the use of herbicides proposed by the Brazilian Society of Science of Weed Plants (SBCP)

Concept	Control Description
A	Excellent
B	Good or acceptable
C	Moderate and insufficient
D	Deficient or expressionless
E	Null or missing

Source: (SBCP, 1995).

Table 3. Average Percentage of control of indicator plants with herbicide application on four quantities of straw sugarcane deposited on the ground 28 days after application

Straw coverage (t ha^{-1})	Control(%)	Concept
0	93.6 a*	B
10	76.9 b	C
20	59.2 c	D
30	41.1 d	D
C.V. (%)	10,96	

* Means followed by the same letter in the column do not differ significantly by Tukey test at 5% probability.

Table 4. Average Percentage control of indicator plants with the simulation of three levels of rainfall after herbicide application on the straw of sugarcane deposited on the ground 28 days after application

Rain (mm)	Control(%)	Concept
0	46.9 c*	D
10	74.3 b	C
20	81.9 a	C
C.V. (%)	13,27	

* Means followed by the same letter in the column do not differ significantly by Tukey test at 5% probability.

Table 5. Percentage of the average indicator plant control with application of four herbicides at 28 days after application

Herbicides	Control(%)	Concept
Hexazinona	79.6 a*	C
Diuron	56.5 c	D
Tebuthiuron	66.8 b	C
Imazapique	67.9 b	C
C.V. (%)	13,27	

* Means followed by the same letter in the column do not differ significantly by Tukey test at 5% probability.

RESULTS AND DISCUSSION

There was a significant interaction between the covers of sugarcane straw and rainfall in control of the indicator plant showing the influence of these variables on the transposition of herbicides. Herbicide application directly on the ground provided a medium control considered good or acceptable to the conceptual scale proposed by SBCP (19952). According to Costa (2001), residual herbicides should be introduced directly into the ground to present greater distribution and persistence, thus exerting their activity on weeds effectively. In this study, the interposition of the straw layer significantly decreased the control efficiency of products, placing 10 t ha^{-1} of straw provided moderate or insufficient control while 20:30 t ha^{-1} crop was poor or unimpressive (Table 3).

According VELINI and Negrisoli (2000), a layer of straw 1 t ha^{-1} enabled only 35.5% of the sprayed syrup herbicides imazapic, imazapyr and trifloxysulfuron-sodium + ametryn reach the ground, and a layer of 10 and 15 t ha^{-1} let pass only 0.6% and 0.5% of the product to the ground, respectively. The surface of the straw intercepted the transposition of herbicides into the soil leaving them vulnerable to degradation caused by volatilization and / or photolysis to be leached into the soil (Locke and Bryson, 1997).The experiment soil is clayey the characteristic features and organic matter. According to Inoue *et al*. (2008), the sorption of diuron is positively correlated with the levels of organic matter, that is, the higher the lower the organic matter content is the leaching of the herbicide into the soil. Treatments where the herbicides were applied directly on the ground, 0 ton ha^{-1} of straw, showed no significant difference between them 28 days after application. The B concept shows that this condition the control indicator plant was good or acceptable (Table 3). The increase in sugarcane straw coverage levels had a negative influence on the herbicides of control percentage tested showing the interception of syrup during the transposition of the product to the ground.

Herbicide application on the straw and lack of rainfall after application provided expressionless control (46.9%) (Table 4). The efficiency of the applied herbicide was increased to rain. Rainfall rates of 10 and 20 mm showed controls considered moderate or insufficient (below 85%) of the plant control. The rainfall led to the drag of the herbicide through the straw of sugarcane to the ground, but it was not enough to provide an acceptable control. The herbicides showed different behavior to the treatments, the amount of straw sugarcane deposited on the ground and rainfall rate. The hexazinone herbicide had the highest average control followed by tebuthiuron, imazapic and diuron (Table 5). The performance of herbicides is the result of straw transposition capacity of sugarcane deposited on the ground, that is, the control efficiency of the weed is totally dependent on the mobility and solubility of its active ingredient of the herbicide.

For Rodrigues (1993), the solubility in water is the main feature that gives greater or lesser capacity of the herbicide to reach the soil under no-tillage system. The hexazinone is a high water solubility herbicide (32.0. mg L^{-1} at 25 °C) which provides a further implementation of the herbicide by crop residues of sugarcane, by contrast, diuron herbicide has low solubility (42 mg L^{-1} to 25 °C) which makes your drag the straw (Table 1). The tebuthiuronimazapic and herbicidal control obtained very similar results, solubilization capacity in water of 2.570 mg L^{-1} at 20 ° C and 2,200 mg L^{-1} at 25 °C, respectively. The application of hexazinone herbicides diuron, tebuthiuron and imazapic propitiated control over 80% when there is no deposition of straw, but with the addition of sugar cane straw level there was gradual reduction control of herbicides (Figures 1A, 1B, 1C and 1D, respectively). The hexazinone herbicide showed the best performance control when it was applied to the straw with the increased rainfall. Monquero *et al*. (2007) studied the effect of different amounts of straw sugarcane (0, 5, 10, 15 and 20 t ha^{-1}) on the efficacy of certain herbicides, including diuron + hexazinone (1,170 + 330 g ai ha^{-1}) and diuron + hexazinone

Table 6. Average of percentage of indicator plant control with the application of four herbicides on four straw amounts of sugarcane at 28 days after application

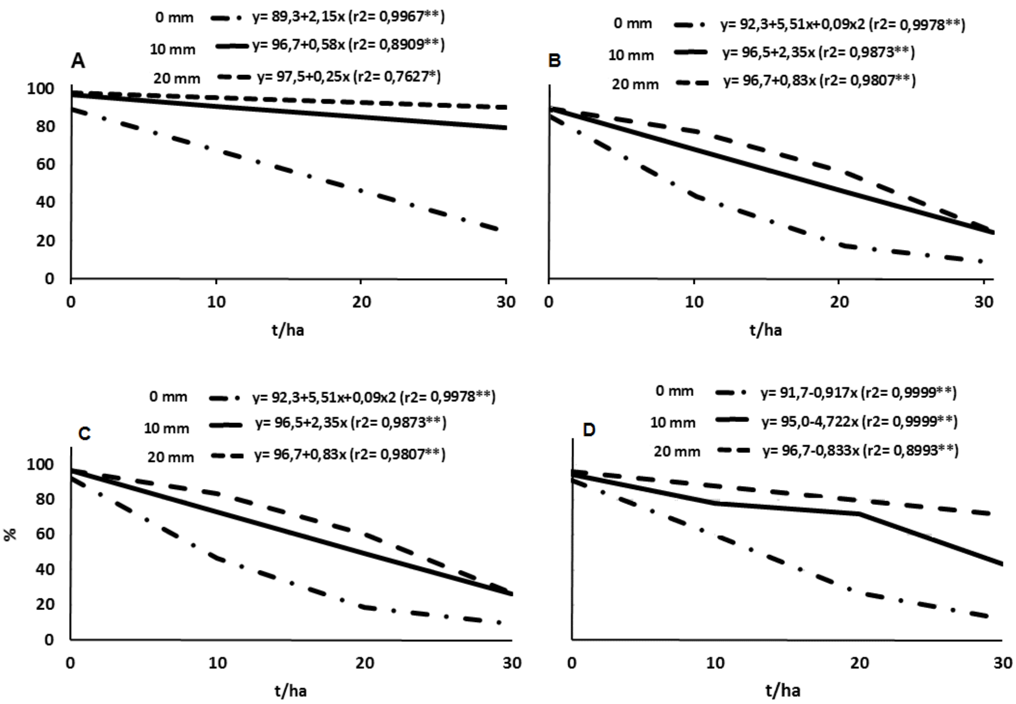
Herbicides	Straw Quantity (t ha-1)							
	0		10		20		30	
	Control(%)	concept	Control (%)	concept	Control (%)	concept	Control (%)	concept
Hexazinona	93.3 a A	B	85.6 a B	B	76.1 a C	C	63.3 a D	C
Diuron	93.3 a A	B	71.1 b B	C	41.1 cC	D	20.6 cD	E
Tebuthiuron	93.9 a A	B	75.6 b B	C	58.3 b C	D	39.4 bD	D
Imazapic	93.9 a A	B	75.6 b B	C	61.1 b C	C	41.1 bD	D
C.V. (%)	13.27							

* Means followed by the same capital letter in line or lower case letter in the column do not differ by Tukey test at 5% probability.

Table 7. Percentage of the average indicator plant control with the application of four herbicides and three levels of precipitation at 28 days after application

Herbicides	Precipitation Index (L m-2)					
	0		10		20	
	Control(%)	Concept	Control(%)	Concept	Control(%)	Concept
Hexazinona	57,1 a B	D	87,9 a A	B	93,8 a A	B
Diuron	41,7 b B	D	61,3 c A	C	66,7 c A	C
Tebuthiuron	44,2 b C	D	73,3 b B	C	82,9 b A	C
Imazapic	45,0 b C	D	74,6 b B	C	84,2 b A	C
C.V. (%)	13,27					

* Means followed by the same capital letter in line or lower case letter in the column do not differ by Tukey test at 5% probability.



* Significant at 5% probability. ** Significant at 1% probability.

Figure 1. Effectiveness of the hexazinone herbicide (A), diuron (B), tebuthiuron (C) imazapic (D) under different straw coverage amounts (0, 10, 20 and 30 t ha-1) and simulated rainfall (0, 10 and 20 mm) at 28 days after application

Table 8. Average Percentage of control of herbicides submitted to interaction of four amounts of straw sugarcane and three levels of precipitation at 28 days after application

Herbicide	0 t ha-1			10 t ha-1			20 t ha-1			30 t ha-1		
	0 mm	10 mm	20 mm	0 mm	10 mm	20 mm	0 mm	10 mm	20 mm	0 mm	10 mm	20 mm
Hexazinona	88,3aAB	95,0aA	96,7aA	70,0aC	91,7aAB	95,0aA	45,0aD	88,3aAB	95,0aA	25,0aE	76,7aBC	88,3aAB
Diuron	91,7aAB	93,3aAB	95,0aA	48,3 bC	76,7 bB	83,3aAB	16,7bDE	51,7 cC	55,0 bC	10,0 bE	23,3cDE	28,3 cD
Tebuthiuron	90,0aA	95,0aA	96,7aA	53,3 bCD	81,7abAB	91,7aA	21,7 bE	68,3 bBC	85,0aAB	11,7abE	48,3 bD	58,3bCD
Imazapique	91,7aA	95,0aA	95,0aA	60,0abCD	78,3abAB	83,3aA	16,7 bE	81,7abAB	85,0aAB	11,7abE	43,3 bD	68,3bBC
C.V. (%)	13.27											

* Means followed by the same capital letter in line or lower case letter in the column do not differ by Tukey test at 5% probability.

(1,330 + 160 g ai ha^{-1}) applied pre-emergence of (*Euphorbia heterophylla)*, with 14 mm of rain simulation 24 hours after the application, and concluded that the presence of 10 t ha^{-1} and 15 t ha^{-1} of straw provided control considered good or acceptable (average 90%) and 20 t ha-1 was deficient or expressionless for the first (control 45.0%) and second formulation (control 37.5%).The results Monquero *et al*. (2007) are similar to the present work, the application of hexazinone in area with presence of 10 t ha-1 of straw and rainfall of 10 mm provides control over 85.0% (Tables 8 and 9). The four herbicides applied in the field with no straw above showed 93.0% control and added as straw in the area reduced to control the efficiency of the four herbicides (Tables 6 and 7).Cavenaghi *et al*. (2002) evaluated the dynamics of diuron in straw cane sugar, and also observed a significant reduction in herbicide transposition with straw in excess of 2.0 t ha^{-1} and zero implementation with straw in excess of 15 t ha^{-1}. This result is similar to those obtained in this experiment, the presence of 20 t ha-1 of straw in the treatments without rain simulation showed negligible control. The occurrence of precipitation after the application of hexazinone herbicide, diuron, and tebuthiuronimazapic is essential for them to work and bring success in controlling weed of sugarcane (Table 8).

The results obtained with the herbicide tebuthiuron corroborate those obtained by Tofoli *et al*. (2009), amounts greater than 5 t ha^{-1} sugarcane straws provide intercept almost total product, and transpositions less than 10.0% of the applied amount of herbicide and determined by high-performance liquid chromatography (HPLC). The same authors found that the first 20 mm of rain are critical to the loading process of tebuthiuron the ground.Monquero *et al*. (2009) studied the effect of different amounts of sugarcane straw in the effectiveness of imazapic for controlling Ipomoea grandifolia. Imazapic The herbicide was applied over a layer of 10 t ha^{-1} sugarcane straw and simulation 14 mm rainfall provided an opportunity unsatisfactory control. The low level of control was probably due the reduced dose of the used product, 84 g ha^{-1}, while in this study we used 200 g ha^{-1}, which gave good or acceptable control (85.6%). Interference of sugarcane straw layer deposited on the soil surface on the action of herbicides imazapic and imazapic + pendimethalin were studied by Hernandez *et al*. (2001), they concluded that precipitation of 30 mm is sufficient for imazapic herbicide transpose a mulch of 12 t ha^{-1} and percolate the first 15 cm of soil depth ensuring efficient action of weed control.

According to Silva *et al*. (2011), the presence of sugarcane straw in the field assures increased control of the weed species for the areas treated with imazapic. This disagreement with the results of this study may be due to the amount of simulated rainfall of 30 mm on straw 5 and 10 t ha^{-1} Increased herbicide leaching, fouled collegues straw is left on the seeded pots after spraying, then this Could have hindered the emergence of seedlings. According Negrisoli *et al*. (2007), the straw can interfere in various ways in the establishment of weeds, among which are the creation of a physical barrier to be by Implemented the plant growth, increasing the amount of microorganisms Which can decompose the seeds of These plants as well as to provide possible allelopathic effects of inhibition of seed germination.

Conclusion

For the experimental conditions, it can be concluded that:

- Control efficacy of hexazinone herbicide tebuthiuron, imazapic and diuron decreased with increasing amount of straw of sugarcane deposited on the soil surface;
- The control efficacy of herbicides hexazinone, tebuthiuron, imazapic and diuron applied to the straw of sugarcane increased with precipitation increase;
- The hexazinone herbicide showed better control efficiency;
- The herbicide diuron showed less control efficiency.

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