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Dry season and soil texture affect the chemical control of *Senna obtusifolia* in sugarcane[1]

Época seca e textura do solo afetam o controle químico de ***Senna obtusifolia*** *em cana-de-açúcar*

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Abstract - Because of its intrinsic characteristics, sicklepod (*Senna obtusifolia*) has gained importance in sugarcane, especially where there is a predominance of straw after mechanical harvest. The objective of this study was to evaluate the efficacy of preemergence herbicides used in sugarcane to control sicklepod in different soil textures and application timings. Two experiments were carried out for each application season (dry and wet), and one experiment for each soil textural class (clay and sandy clay loam), totaling four experiments. The treatments consisted in 17 herbicides in the wet season and 11 herbicides in the dry season (all herbicides were applied at 50 and 100% of the recommended dose) and a check without application for each season and soil, and the design was completely randomized. Soil texture and application timing have altered the herbicide efficacy. For the wet season, initially, all herbicides, except trifluralin and s-metolachlor, resulted in satisfactory control of sicklepod. Tebuthiuron was the herbicide that provided the longest period of residual control. For the dry season, amicarbazone, flumioxazin, hexazinone, imazapic, [diuron + hexazinone] F1 and isoxaflutole were efficient in both soils, but only in initial evaluations; [diuron + hexazinone] F1 and amicarbazone were the herbicides that provided the longest period of residual control.
Keywords: residual control; preemergence; sicklepod; herbicides

Resumo - Devido às suas características intrínsecas, o fedegoso (*Senna obtusifolia*) tem ganhado importância em canaviais, principalmente onde há predomínio de palhada após a colheita mecânica. O objetivo deste trabalho foi avaliar a eficácia de herbicidas pré-emergentes utilizados na cultura da cana-de-açúcar no controle de fedegoso em solos de diferentes texturas e épocas de aplicação. Foram realizados dois experimentos para cada época de aplicação (seca e úmida), sendo um para cada classe textural de solo (muito-argiloso e franco-argilo-arenoso), totalizando quatro experimentos. Os tratamentos foram constituídos por 17 herbicidas na época úmida e 11 herbicidas na época seca (todos os herbicidas foram aplicados em 50 e 100% da dose recomendada), além da testemunha sem aplicação para cada época e solo, sendo o delineamento inteiramente ao acaso. O

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tipo de solo e a época de aplicação alteraram a eficiência dos herbicidas. Para a época úmida, inicialmente, todos os herbicidas, exceto trifluralin e s-metolachlor, resultaram em controle satisfatório de fedegoso. Tebuthiuron foi o herbicida que proporcionou maior período residual de controle. Para a época seca, amicarbazone, flumioxazin, hexazinone, imazapic, [diuron + hexazinone] F1 e isoxaflutole foram eficazes em ambos os solos, mas somente em avaliações iniciais; [diuron + hexazinone] F1 e amicarbazone foram os herbicidas que proporcionaram maior período residual de controle.
Palavras-chaves: controle residual; pré-emergência; fedegoso; herbicidas

Introduction

One of the main weed species in the sugarcane has been *Senna obtusifolia*, popularly known as sicklepod (also Chinese senna and American sicklepod). This species often infests crops in tropical and subtropical regions of the world, occurring mainly in pastures areas converted into sugarcane plantations. *S. obtusifolia* is an annual plant, reproduced by seeds that arise especially in spring and summer, even in periods of very low water availability in soil. It features an ultra-aggressive root system, giving it a high competitive capacity (Kissmann and Groth, 1999).

Because seeds of *S. obtusifolia* present a relatively large size, they accumulate reserves, which favors the emergence of such weed in mechanical harvesting systems where sugarcane is not burned and, therefore, a great amount of crop residues is left on soil surface. Teem et al. (1980) have observed that seeds of *S. obtusifolia* have the capacity to emerge at depths of up to 12.7 cm. This may explain why, even with large amounts of straw on the soil, *S. obtusifolia* plants are still able to emerge, frequently occurring in non-burned sugarcane areas. Studies developed by Gravena et al. (2004) demonstrate that crop residues from mechanically harvested sugarcane (15 t ha^{-1}) have not affected the emergence of *S. obtusifolia*; however, the combination of straw with the application of herbicide can be an effective alternative for the management of this species.

Thus, the use of preemergence herbicides with long residual effect is an important tool since it allows weed control during the critical period of competition (Monquero et al., 2008). It has also been shown to be a more selective mode of application to this crop, as compared to post-emergence applications. These applications are targeted to provide control of the early weed flows without affecting the crop early growth. With lower initial number of plants, the objective is to reduce the number of applications in postemergence, with better control of remaining plants (Oliveira Jr. et al., 2012).

Residual control depends on the herbicide persistence in soil, which greatly varies according to the molecule chemical structure, the type of soil and climatic conditions such as soil moisture, which in turn affect adsorption, leaching, and microbial and chemical decomposition (Silva et al., 1999; Marchiori Jr. et al., 2005). Therefore, many herbicides are more effective when applied during the rainy season because the water available in soil and the intensive development of weeds favor the herbicides absorption. However, in the Southeast and Central-West regions of Brazil, part of the sugarcane harvest begins in April/May, lasting until November/December. In such cases, farmers have problems to concentrate herbicide applications only in the rainy season, which leads them to apply also in periods of low water availability in soil, so that it persists in the soil until the beginning of the rainy season (Azania et al., 2009).

Herbicides used in the dry season should have high water solubility, low adsorption in soil colloids and mainly microbial degradation (Guimarães, 1987). Therefore, even in a low soil moisture condition, part of the herbicide will be present in the soil solution and available for absorption by seedlings. Among the herbicides registered for sugarcane, some herbicides such as amicarbazone, imazapic, hexazinone, isoxaflutole, sulfentrazone and tebuthiuron are recommended for the dry season (Agrofit, 2015).

Isoxaflutole, for example, is an herbicide which activity depends on the conversion to the diquetonitrile metabolite, which occurs only when water is available in soil (Oliveira Jr et al., 2006). Thus, the applications of this herbicide has been successfully done during the driest period of the year. After the beginning of the rainy season, the conversion occurs simultaneously with the emergence of weeds, which prolongs its residual activity in the field. This is particularly interesting for the areas of sugarcane harvest with focus on periods of low water availability in the soil (Marchiori Jr. et al., 2005).

Because of the importance of sicklepod chemical control in sugarcane and the various factors that influence herbicides efficiency, the aim of this study was to evaluate the residual control of the main herbicides used in sugarcane to control sicklepod (*Senna obtusifolia*) in preemergence in the dry and wet seasons and under different soil textures.

Material and Methods

The experiments were conducted from January to May 2013, in a greenhouse at Centro de Treinamento em Irrigação (CTI-UEM), which belongs to the central campus of Universidade Estadual de Maringá (UEM), located in the Brazilian city of Maringá, Paraná.

Four experiments were simultaneously conducted. The experiments encompassed simulations of dry and wet seasons. The simulations were based on periods in days in which the experiments had restricted irrigation, so that there was a situation similar to what is commonly called in sugarcane producing regions as dry and wet seasons.

For the wet season, two experiments were carried out, one for each soil textural class. For each season, two experiments were also performed for each soil type, totaling four experiments. In each experiment, two doses corresponding to 50 and 100% of the recommended doses for each product, were used, in order to visualize the major differences among the residual control of each herbicide (Tables 1 and 2). The experimental design was completely randomized, with three replications.

The experimental units consisted of 3 dm^3 pots, which were filled with two soil materials. The first one, sandy clay loam textural class, pH(H_2O) of 5.5; 3.1 $cmol_c$ of $H^+ + Al^{+3}$ dm^{-3} of soil, 16 g dm^{-3} of C; 417 g kg^{-1} of coarse sand; 662 g kg^{-1} of fine sand; 68 g kg^{-1} of silt and 270 g kg^{-1} of clay. The second one, clay textural class, pH(H_2O) of 5.5; 3.8 $cmol_c$ of $H^+ + Al^{+3}$ dm^{-3} of soil; 24.1 g dm^{-3} of C; 34 g kg^{-1} of coarse sand; 105 g kg^{-1} of fine sand; 210 g kg^{-1} of silt and 685 g kg^{-1} of clay. Both soil samples were collected from areas with no history of herbicide application and air dried before being packaged in pots.

Thirty sicklepod seeds were sown (*Senna obtusifolia*) per pot, and thereafter only the wet season experiments were irrigated. After that, herbicides applications were carried out. The pots of the wet season experiments were daily irrigated, keeping the soil in pots with moisture nearly at field capacity, and the accumulated rainfall in both experiments was approximately 525 mm. The dry season experiments were kept without irrigation up to 60 days after application (DAA) of the treatments, with the aim of simulating the dry season. After this period without irrigation, the pots of these experiments were also submitted to daily irrigation, as described for the wet season experiments. For all experiments, the plants started to emerge only after the beginning of irrigation and consequently the control was evaluated only after this period.

Table 1. Herbicides treatments and doses used in the wet season experiments. Maringá-PR/2013.

Treatments	Dose (g a.i ha^{-1})			
	50%		100%	
	S.C.L. Text.	C. Text.	S.C.L. Text.	C. Text.
1-Amicarbazone	525.00	700.00	1050.00	1400.00
2-Ametryn	1.50	2.00	3.00	4.00
3-Clomazone	0.45	0.50	0.90	1.00
4-Diuron	0.80	1.00	1.60	2.00
5-[Diuron+hexazinone] F1[1]	[0.42+0.12]	[0.59+0.17]	[0.84+0.24]	[1.17+0.33]
6-[Diuron+hexazinone] F2[2]	[0.55+0.07]	[0.97+0.12]	[1.11+0.13]	[1.94+0.23]
7-[Diuron+hexazinone+ sulfometuron]	[0.51+0.14 +0.01]	[0.69+0.2 +0.02]	[1.03+0.29 +0.02]	[1.39+0.39 +0.04]
8-Flumioxazin	87.50	87.50	175.00	175.00
9-Hexazinone	0.09	0.25	0.19	0.50
10-Imazapic	52.50	122.50	105.00	245.00
11-Diclosulam	63.00	84.00	126.00	168.00
12-Isoxaflutole	56.26	56.26	112.5	112.5
13-Metribuzin	0.84	0.96	1.68	1.92
14-S-metolachlor	0.72	0.96	1.44	1.92
15-Sulfentrazone	0.30	0.30	0.60	0.60
16-Tebuthiuron	0.50	0.60	1.00	1.20
17-Trifluralin	0.27	0.53	0.53	1.07
18-Testemunha sem herbicida	-	-	-	-

[1]F1=Formulation 1=Velpar®; [2]F2=Formulation 2=Advance®; S.C.L.: Sandy clay loam; C.: Clay. Products between brackets mean formulated mixture.

Table 2. Herbicides treatments and doses used in the dry season experiments. Maringá-PR/2013.

Treatments	Dose (g a.i ha^{-1})			
	50%		100%	
	S.C.L. Text.	Text. M.A	S.C.L. Text.	Text. M.A
1-Amicarbazone	525.00	700.00	1050.00	1400.00
2-Clomazone	0.45	0.50	0.90	1.00
3-[Diuron+hexazinone] F1[1]	[0.42+0.12]	[0.59+0.17]	[0.84+0.24]	[1.17+0.33]
4-[Diuron+hexazinone+ sulfometuron]	[0.51+0.14 +0.01]	[0.69+0.2 +0.02]	[1.03+0.29 +0.02]	[1.39+0.39 +0.04]
5-Flumioxazin	87.50	87.50	175.00	175.00
6-Hexazinone	0.09	0.25	0.19	0.50
7-Imazapic	52.50	122.50	105.00	245.00
8-Diclosulam	63.00	84.00	126.00	168.00
9-Isoxaflutole	131.25	131.25	262.5	262.5
10-Sulfentrazone	0.30	0.30	0.60	0.60
11-Tebuthiuron	0.50	0.60	1.00	1.20
12-Testemunha	-	-	-	-

[1]F1=Formulation 1=Velpar®; S.C.L.: Sandy clay loam; C.: Clay. Products between brackets mean formulated mixture.

In all applications, a CO_2-backpack sprayer under 2.0 kgf cm^{-2} constant pressure was used, equipped with three spray nozzles (XR-110.02), spaced 50 cm from each other. These application conditions provided the equivalent of 200 L ha^{-1}. Climatic conditions at the application of the wet season experiments were: 28.0 °C; RH = 68.0%; wind of 1.2 km h^{-1}. For the dry season they were: 27.0 °C; RH = 66.0%; wind of 1.1 km h^{-1}.

Two reseedings were performed during each experiment (Figure 1). The first one was held 30 days after beginning of irrigation (30 DAI or 30 DAA for the wet season experiments and 90 DAA for the dry season experiments). The second reseeding was done 45 days after the first reseeding (45 DAR1 or 75 DAA for the wet season experiments and 135 DAA for the dry season experiments). Reseeding was performed revolving the smallest possible amount of soil in the experimental units, in order to allow an adequate cover of the seeds.

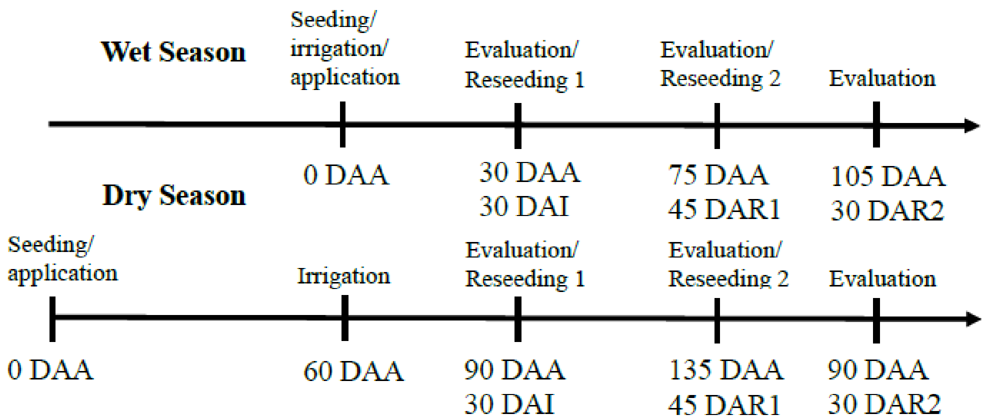

Figure 1. Succession of applications, evaluations, irrigation, seeding and reseeding during the dry season and wet season experiments. DAA = days after application; DAI = days after irrigation; DAR1 days after reseeding 1; DAR2 = days after reseeding 2. Maringá, PR/2013.

Control evaluations (visual rating, percentage of control) at 30 days after irrigation (DAI), at 45 days after reseeding 1 (DAR1) and at 30 days after reseeding 2 (DAR2) using a scale where 0% represents no effect of herbicides on plants and 100% represents death of all plants, according to Brazilian Society of Weed Science, SBCPD (1995).

Data were submitted to analysis of variance by F-test when a significant effect was found; the means were compared by Scott-Knott grouping test at 10% probability.

Results and Discussion

Wet season – Sandy clay loam soil

All herbicides, except s-metolachlor and trifluralin, provided excellent control of *S. obtusifolia* at 30 DAI, even when only 50% of the recommended dose were applied (Table 3). In second and third levels of control, isoxaflutole and diclosulam stood out, respectively. S-metolachlor and trifluralin herbicides provided less than 80% control, and little or no observable effect of such herbicides on sicklepod plants.

These results are expected since trifluralin usually has greater efficacy in monocotyledonous plants than in eudicotyledonous plants such as sicklepod (Raimondi et al., 2010). As for s-metolachlor, it can have its effectiveness on *S. obtusifolia* increased when applied in combination with other herbicides such as flumioxazin (Daniel et al., 2010).

In the assessment performed at 45 DAR1, amicarbazone, diuron, [diuron + hexazinone + sulfometuron], [diuron + hexazinone] F1, imazapic, metribuzin and tebuthiuron still provided high control levels (> 90%). Herbicides such as [diuron + hexazinone] F2, hexazinone and sulfentrazone were ranked in a second group of efficacy, and provided control percentages ranging from 75.0 to 83.3%. The other treatments did not show satisfactory control of *S. obtusifolia* in this assessment.

At 30 DAR2, it was observed that, in most treatments, residual control of the herbicides was very low. Amicarbazone and imazapic still provide some level of suppression of *S. obtusifolia* (56.6 and 38.3% respectively). On the other hand, the only treatment in which residual activity provided sicklepod control above 90% was tebuthiuron. Negrisoli et al. (2011) have found that the residual activity of tebuthiuron was enough to keep 100% monocotyledonous weed control at 42 DAA, regardless of soil moisture condition.

Table 3. Residual control of herbicides on *Senna obtusifolia* in sandy clay loam soil and wet season (Experiment 1). Maringá-PR/2013.

Treatment	% of control (50% of the dose)			% of control (100% of the dose)		
	30 DAI	45 DAR1	30 DAR2	30 DAI	45 DAR1	30 DAR2
1-Amicarbazone	99.6 a	95.0 a	56.6 b	100.0 a	100.0 a	30.6 c
2-Ametryn	100.0 a	50.0 d	0.0 d	100.0 a	60.0 d	0.0 e
3-Clomazone	100.0 a	46.6 d	0.0 d	100.0 a	73.3 c	0.0 e
4-Diuron	100.0 a	91.3 a	0.0 d	100.0 a	100.0 a	0.0 e
5-[Diuron+hexazinone] F1[1/]	99.6 a	90.0 a	0.0 d	100.0 a	100.0 a	0.0 e
6-[Diuron+hexazinone] F2[2/]	99.3 a	75.0 b	0.0 d	100.0 a	83.0 b	0.0 e
7-[D+H+S][3/]	99.6 a	99.6 a	0.0 d	100.0 a	96.0 a	0.0 e
8-Flumioxazin	98.6 a	63.3 c	0.0 d	100.0 a	91.3 b	0.0 e
9-Hexazinone	100.0 a	83.3 b	0.0 d	100.0 a	99.6 a	0.0 e
10-Imazapic	97.0 a	90.6 a	38.3 c	97.6 a	90.0 b	45.0 b
11-Diclosulam	85.0 c	21.6 f	0.0 d	93.3 a	25.0 e	0.0 e
12-Isoxaflutole	91.3 b	13.3 f	0.0 d	99.6 a	33.3 e	0.0 e
13-Metribuzin	100.0 a	96.6 a	0.0 d	100.0 a	99.6 a	0.0 e
14-S-metolachlor	13.3 d	10.0 f	0.0 d	16.6 c	11.6 e	0.0 e
15-Sulfentrazone	100.0 a	78.3 b	0.0 d	100.0 a	85.0 b	38.3 c
16-Tebuthiuron	100.0 a	100.0 a	97.6 a	100.0 a	99.6 a	97.6 a
17-Trifluralin	0.0 e	0.0 g	0.0 d	35.0 b	0.0 f	0.0 e
18-Testemunha	0.0 e	0.0 g	0.0 d	0.0 d	0.0 f	0.0 e
F	309.5	32.2	92.0	98.3	45.4	136.4
CV (%)	4.1	18.7	46.4	6.3	14.2	32.2

[1/]F1=formulation 1=Velpar®; [2/]F2=formulation 2=Advance®; [3/][D+H+S]=[diuron+hexazinone+sulfometuron]; Sandy clay loam; C.: Clay. DAI: days after the irrigation; DAR1: days after the reseeding 1; DAR2: days after reseeding 2. *Means followed by the same letter in the column do not differ by the Scott-Knott test at 10% of probability.

With the use of 100% of the recommended dose of herbicide, most herbicides provided excellent control levels of *S. obtusifolia* at 30 DAI (Table 4). As for the treatments with s-metolachlor and trifluralin, the sicklepod control was very low, as observed using 50% of the recommended dose of these products (16.6 and 35.0%, respectively).

At 45 DAR1, the best control levels were observed in treatments with amicarbazone, diuron, [diuron + hexazinone] F2, hexazinone, metribuzin, [diuron + hexazinone + sulfometuron] and tebuthiuron. In a second control level were [diuron + hexazinone] F1, flumioxazin, imazapic and sulfentrazone, which still controlled the sicklepod plants in a satisfactory way. Clomazone and ametryn caused visual symptoms of phytotoxicity in plants, but not enough to perform satisfactory residual control. The other herbicides diclosulam, isoxaflutole, s-metolachlor and trifluralin had very little control in this evaluation. Also according to Vivian et al. (2007), in evaluations of persistence and leaching of ametryn in sugarcane areas, the persistence of this herbicide was of 180 days after application on the soil surface. Oliveira Jr. et al. (2006) found that, as the time and number of irrigation events between herbicide application and sowing of a bioindicator species are increased, there is a reduction in the potential control exercised by isoxaflutole in dystrophic red latosol conditions.

At the last evaluation performed at 30 DAR2, the only treatment that still maintained effective control of *S. obtusifolia* was tebuthiuron. Nevertheless, some herbicides such as sulfentrazone still showed residual activity in the soil, but not enough to exercise adequate control of sicklepod plants. In accordance with the data obtained in this study, sulfentrazone residual activity results show that the herbicide persistence at a dose of 0.6 kg ha^{-1} lasts 601 DAA, whereas when applied at the dose of 1.2 kg ha^{-1} it can exceed 704 DAA (Blanco et al., 2010).

Wet season – clay soil

In the first assessment performed at 30 DAI, it was observed that most of the herbicides provided control of *S. obtusifolia* above 80% (Table 4). However, residual control of herbicides flumioxazin, imazapic and diclosulam, plus trifluralin and s-metolachlor, was considered unsatisfactory in controlling this species.

At 45 DAR1, the herbicides that were grouped among the ones of better control of *S. obtusifolia* were diuron, metribuzin, [diuron + hexazinone + sulfometuron], tebuthiuron, [diuron + hexazinone] F1 and [diuron + hexazinone] F2. Clomazone and hexazinone have also satisfactorily controlled sicklepod plants (> 80%); however, they were grouped together below the top herbicide treatments of this evaluation. Ametryn, isoxaflutole, s-metolachlor and trifluralin were not effective in controlling this species.

Table 4. Residual control of herbicides on *Senna obtusifolia* in clay soil and wet season (Experiment 2). Maringá-PR/2013.

Treatment	% of control (50% of the dose)			% of control (100% of the dose)		
	30 DAI	45 DAR1	30 DAR2	30 DAI	30 DAI	45 DAR1
1-Amicarbazone	93.3 b	15.0 g	0.0 c	99.6 a	18.3 e	3.3 d
2-Ametryn	100.0 a	0.0 h	0.0 c	100.0 a	0.0 f	0.0 d
3-Clomazone	100.0 a	84.0 b	0.0 c	100.0 a	94.0 a	15.0 c
4-Diurom	100.0 a	99.0 a	0.0 c	100.0 a	99.6 a	0.0 d
5-[Diuron+hexazinone] F1[1/]	100.0 a	97.0 a	0.0 c	100.0 a	99.6 a	0.0 d
6-[Diuron+hexazinone] F2[2/]	100.0 a	98.3 a	0.0 c	100.0 a	100.0 a	0.0 d
7-[D+H+S][3/]	100.0 a	99.6 a	0.0 c	100.0 a	99.6 a	0.0 d
8-Flumioxazin	68.6 c	28.3 f	0.0 c	100.0 a	53.3 c	0.0 d
9-Hexazinone	100.0 a	84.3 b	0.0 c	100.0 a	92.6 a	0.0 d
10-Imazapic	65.0 c	60.0 d	0.0 c	75.0 c	66.0 b	0.0 d
11-Diclosulam	66.6 c	45.0 e	0.0 c	81.6 b	56.6 c	0.0 d
12-Isoxaflutole	89.3 b	0.0 h	0.0 c	100.0 a	0.0 f	0.0 d
13-Metribuzin	99.6 a	93.3 a	0.0 c	99.3 a	99.6 a	0.0 d
14-S-metolachlor	10.0 d	0.0 h	0.0 c	25.0 d	13.3 e	0.0 d
15-Sulfentrazone	100.0 a	75.0 c	23.3 b	99.6 a	91.3 a	51.6 b
16-Tebuthiuron	100.0 a	98.0 a	98.6 a	100.0 a	99.3 a	99.0 a
17-Trifluralina	1.6 e	0.0 h	0.0 c	6.6 d	0.0 f	0.0 d
18-Testemunha	0.0 e	0.0 h	0.0 c	0.0 f	0.0 f	0.0 d
F	135.0	132.1	3110.8	277.5	131.8	184.1
CV (%)	6.71	12.5	11.1	4.1	10.8	35.8

[1/]F1=formulation 1=Velpar®; [2/]F2=formulation 2=Advance®; [3/][D+H+S]=[diuron+hexazinone+sulfometuron]; Sandy clay loam; C.: Clay. DAI: days after the irrigation; DAR1: days after the reseeding 1; DAR2: days after reseeding 2. *Means followed by the same letter in the column do not differ by the Scott-Knott test at 10% of probability.

The only treatment whose residual activity provided excellent control of sicklepod up to 30 DAR2 was tebuthiuron. On the other hand, the other treatments were found to be ineffective, since from these only sulfentrazone still had some residual activity in the soil (23.3%)

With the use of 100% of the recommended dose of herbicides, high levels of sicklepod control were found at the first assessment (30 DAI). Additionally, unlimited control with s-metolachlor and trifluralin was also detected. Herbicides diclosulam and imazapic provided less control than the best treatments, and provided control percentages of 81.6 and 75.0%, respectively.

Herbicides that still had satisfactory control at 45 DAR1 were clomazone, diuron, [diuron + hexazinone] F1, [diuron + hexazinone] F2, [diuron + hexazinone + sulfometuron], hexazinone, metribuzin, sulfentrazone and tebuthiuron. The least effective treatments were diclosulam, isoxaflutole, s-metolachlor, trifluralin, amicarbazone and diuron. Flumioxazin and diclosulam had intermediate residual control, but insufficient to effectively control sicklepod plant emergence (53.3 and 56.6%, respectively).

In the last evaluation performed at 30 DAR2 in both soils, the only treatment that still maintained effective control of *S. obtusifolia* plant emergence was tebuthiuron. Nevertheless, some herbicides such as sulfentrazone still showed residual activity in the soil, but not enough to exercise an adequate control of sicklepod plants. The long residual period presented by tebuthiuron is due, among other factors, to its half-life, ranging from 10 to 12 months, which directly contributes to its persistence in soil (Souza et al., 2001).

Consistent with the results observed in this study. Christoffoleti et al. (2010) have evaluated the susceptibility of *Senna occidentalis* to the application of flumioxazin in different soils and concluded that for most clay soils higher doses of the product are required. Furthermore, the application of 185 g a.i. ha^{-1} of flumioxazin in preemergence provided satisfactory control (> 80%) of *S. occidentalis* up to 60 days after application in clayey soil.

Considering these two experiments conducted in the wet season, some considerations can be done. Some herbicides like amicarbazone, flumioxazin and imazapic were less effective in heavy clay soil than in loam texture soil. Moreover, herbicides as clomazone and [diuron+ hexazinone] F2, for example, have higher efficacy when applied to high clay soil.

Such observation may be related to the fact that in soils with high contents of clay and organic matter a large extent of herbicide sorption may occur, requiring higher doses, whereas in sandy soils with low content of organic matter low doses can provide good initial control; however, the residual period of these products can be compromised (Tavares et al., 1996). Thus, the adsorption and the residual period depend on the physicochemical characteristics of each product, such as K_{oc} and $t_{1/2}$. In the case of diuron, for example, the molecules of this herbicide are sorbed by organic matter and also by clay and, for this reason, a suitable dose is highly dependent on the soil characteristics (Vasilakoglou et al., 2001).

Dry season – Sandy clay loam texture

In the first evaluation performed at 30 DAI, when there was the option to use 50% of the dose of herbicides, amicarbazone, flumioxazin, imazapic, hexazinone, and isoxaflutole provided high levels of residual control (Table 5). In the second level of effectiveness, [diuron + hexazinone] F1 and sulfentrazone provided 77 and 63.3% of control, respectively; however, these percentages did not result in an adequate control. Other treatments caused only some symptoms of phytotoxicity in sicklepod plants and the control was unsatisfactory.

No herbicide was effective in controlling sicklepod at 45 DAR1, and even the best treatment, with hexazinone, provided only 71.6%, followed by amicarbazone (48.3%) and sulfentrazone (40.0%). At the very last evaluation, performed at 30 DAR2, signs of injuries in sicklepod plants were not found in all evaluated treatments.

For 100% of the recommended dose of herbicides, the first evaluation performed at 30 DAI, treatments with amicarbazone [diuron + hexazinone] F1, flumioxazin, imazapic, hexazinone, and isoxaflutole provided high levels of control. The other treatments have not been effective in controlling *S. obtusifolia*. Sulfentrazone followed by [diuron + hexazinone + sulfometuron] and tebuthiuron presented a medium control. The other treatments provided low control and were ranked at the same level of the control without herbicide.

Table 5. Residual control of herbicides on *Senna obtusifolia* in sandy clay loam soil and dry season (Experiment 3). Maringá-PR/2013.

Treatment	% of control (50% of the dose)			% of control (100% of the dose)		
	30 DAI	45 DAR1	30 DAR2	30 DAI	45 DAR1	30 DAR2
1-Amicarbazone	92.6 a	48.3 b	0.0	100.0 a	98.6 a	0.0
2-Clomazone	5.0 c	0.0 e	0.0	16.6 e	1.6 f	0.0
3-[Diuron+hexazinone] F1[1/]	77.0 b	11.6 e	0.0	99.0 a	78.3 b	0.0
4-[D+H+S][2/]	13.3 c	0.0 e	0.0	50.0 c	53.3 c	0.0
5-Flumioxazin	100.0 a	5.0 e	0.0	100.0 a	18.3 e	0.0
6-Hexazinone	100.0 a	71.6 a	0.0	100.0 a	79.0 b	0.0
7-Imazapic	100.0 a	33.3 c	0.0	100.0 a	65.0 c	0.0
8-Diclosulam	1.6 c	11.6 e	0.0	10.0 e	30.0 d	0.0
9-Isoxaflutole	100.0 a	21.6 d	0.0	100.0 a	30.0 d	0.0
10-Sulfentrazone	63.3 b	40.0 b	0.0	63.3 b	73.3 b	0.0
11-Tebuthiuron	10.3 c	8.3 e	0.0	35.0 d	18.3 e	0.0
12-Testemunha	0.0 c	0.0 e	0.0	0.0 e	0.0 f	0.0
F	89.2	35.3	-	40.1	33.1	-
CV (%)	17.6	30.3	-	17.1	22.0	-

[1/]F1=formulation 1=Velpar®; [2/][D+H+S]=[diuron+hexazinone+sulfometuron]; Sandy clay loam; C.: Clay. DAI: days after the irrigation; DAR1: days after the reseeding 1; DAR2: days after reseeding 2. * Means followed by the same letter in the column do not differ by the Scott-Knott test at 10% of probability.

At 45 DAR1, only amicarbazone was effective in controlling sicklepod (98.6%). Although treatments have not achieved satisfactory levels of control, the descending order in terms of effectiveness was hexazinone, [diuron + hexazinone] F1, sulfentrazone, imazapic and [diuron + hexazinone + sulfometuron], which provided suppression of 65-78% in *S. obtusifolia* plants. The other treatments caused few symptoms of injury in plants.

At the last evaluation performed after the second reseeding (30 DAR2), even by the use of 100% of the recommended dose of herbicides, no symptoms of injury was visually present in sicklepod plants.

Dry season – clay texture

The use of 50% of the recommended dose of herbicides amicarbazone, [diuron + hexazinone] F1, flumioxazin, imazapic, hexazinone, and isoxaflutole and tebuthiuron was sufficient to provide a satisfactory control of *S. obtusifolia* at the first assessment performed at 30 DAI (Table 6).

After 45 DAR1, there was no herbicide providing satisfactory levels of control. The best results were observed with amicarbazone, [diuron + hexazinone] F1, flumioxazin, hexazinone and tebuthiuron at 45 DAR1 and [diuron + hexazinone] F1, sulfentrazone and tebuthiuron at 30 DAR2. When the herbicides were applied at the recommended dose (100% of the recommended dose), only amicarbazone, [diuron + hexazinone] F1, flumioxazin, imazapic, hexazinone, and isoxaflutole provided satisfactory control of *S. obtusifolia* at 30 DAI.

At 45 DAR1, besides amicarbazone, [diuron + hexazinone] F1 also provided control of *S. obtusifolia* above 80%, which are the best treatments in this assessment. The residual control of these herbicides after simulation of a long drought is probably associated to the fact that both amicarbazone as hexazinone have high solubility in water, which allows these herbicides to remain in the soil solution even under low soil moisture (Bouchard et al., 1985; Vencill, 2002).

Table 6. Residual control of herbicides on *Senna obtusifolia* in clay soil and dry season (Experiment 4). Maringá-PR/2013.

Treatment	% of control (50% of the dose)			% of control (100% of the dose)		
	30 DAI	45 DAR1	30 DAR2	30 DAI	45 DAR1	30 DAR2
1-Amicarbazone	99.3 a	63.3 a	0.0 b	99.6 a	91.6 a	0.0 c
2-Clomazone	45.6 c	6.6 d	0.0 b	66.6 c	18.3 d	0.0 c
3-[Diuron+hexazinone] F1[1/]	98.3 a	56.6 a	33.3 a	99.3 a	85.0 a	66.0 a
4-[D+H+S][2/]	8.3 d	3.3 d	0.0 b	18.3 e	13.3 d	0.0 c
5-Flumioxazin	86.6 a	66.6 a	0.0 b	100.0 a	20.0 d	0.0 c
6-Hexazinone	99.0 a	60.0 a	0.0 b	100.0 a	70.0 b	0.0 c
7-Imazapic	99.3 a	36.6 b	0.0 b	100.0 a	43.3 c	0.0 c
8-Diclosulam	8.3 d	11.6 d	0.0 b	60.0 d	20.0 d	0.0 c
9-Isoxaflutole	100.0 a	25.0 c	0.0 b	98.6 a	21.6 d	0.0 c
10-Sulfentrazone	15.0 d	8.3 d	4.3 b	77.0 b	16.6 d	18.3 b
11-Tebuthiuron	80.0 b	56.6 a	20.0 a	75.0 b	79.3 b	68.3 a
12-Testemunha	0.0 d	0.0 d	0.0 b	0.0 f	0.0 e	0.0 c
F	47.7	15.0	189.2	181.4	30.6	34.7
CV (%)	17.7	38.2	24.4	6.9	25.1	53.3

[1/]F1=formulation 1=Velpar®; [2/][D+H+S]=[diuron+hexazinone+sulfometuron]; Sandy clay loam; C.: Clay. DAI: days after the irrigation; DAR1: days after the reseeding 1; DAR2: days after reseeding 2. * Means followed by the same letter in the column do not differ by the Scott-Knott test at 10% of probability.

In second and third levels of residual control are the treatments with tebuthiuron and imazapic, respectively. Despite the treatment with tebuthiuron provided a high percentage of control, it was not sufficient to be considered as appropriate. The other treatments only caused mild symptoms in sicklepod plants.

The effective residual activity of imazapic after simulation of drought was also reported by Monquero et al. (2008), where this herbicide was able to cause injuries in a bioindicator plant around 80% in the evaluation performed 111 days after application, even after simulation of 90 days of low water availability in the soil. This behavior may be associated with the herbicide degradation on the soil, which is predominantly microbial and has its activity improved by humid and warm conditions (Renner et al., 1998).

At the last evaluation (30 DAR2), it was found that only [diuron + hexazinone] F1, sulfentrazone and tebuthiuron still had some residual effect in the soil. In this evaluation, the best treatments were [diuron + hexazinone] F1 and tebuthiuron, followed by sulfentrazone. Nevertheless, this residual effect did not provide effective control of *S. obtusifolia*.

Some aspects can be observed, considering these two experiments conducted in the dry season. In a heavy clay soil, herbicides such as sulfentrazone and [diuron + hexazinone + sulfometuron] are less effective than in loam texture soil. However, herbicides such as flumioxazin, tebuthiuron and clomazone, for example, had better residual control in heavy clay soil.

Another factor to consider is that many herbicides, regardless of the type of soil in which the experiment was conducted, provided limited efficacy after simulation of a water restriction period. Among these herbicides are clomazone, [diuron + hexazinone + sulfometuron], diclosulam, sulfentrazone and tebuthiuron. This information is extremely important, since in most sugarcane areas the crop harvest is not performed in the rainy season, when there is an adequate water availability in the soil.

In short, each herbicide behaves differently, depending on the dose applied, the soil texture and on water availability in soil. Increasing herbicide dose will not always result in a proportional gain in the residual activity (Raimondi et al., 2010; Inoue et al., 2011). In the experiments in wet season, a relatively high level of weed control in the first evaluations is expected, since when there is enough moisture in soil to allow herbicides to be present in the soil solution and to be are absorbed by plants and, therefore, exert its effect before degradation.

The lowest control percentages observed after a simulation of dry period may be associated with losses due to the photodegradation, and to other factors such as severe volatilization by high temperature in the soil surface, chemical degradation, and sorption and desorption, which should be considered to explain the reduction in the residual herbicides in the soil (Silva et al., 2007). Another important factor to take into consideration is the hysteresis rate, which is the compound ability to remain sorbed in the soil. Herbicides such as ametryn have their greatest hysteresis index when there is increased soil pH. This means that by increasing the pH, the amount of herbicide which tends to return to the soil solution decreases, since the higher the hysteresis rate, the lower the herbicide desorption capacity, and consequently a smaller amount of herbicide will be available again in the absorption of plants (Andrade et al., 2010).

Conclusions

The dry season and soil textural class change the efficiency of herbicides applied in preemergence in control of sicklepod. For the wet season, all herbicides except trifluralin and s-metolachlor provided satisfactory control up to 30 days after irrigation (DAI) or 30 days after application (DAA). However, tebuthiuron was the only herbicide that provided effective control of sicklepod up to 30 days after the second reseeding (DAR2) or 105 DAA. During the dry season, the control of most herbicides was compromised and only amicarbazone, flumioxazin, hexazinone, imazapic, [diuron + hexazinone] F1 and isoxaflutole were effective in both soils at 30 DAI or 90 DAA, but only amicarbazone and [diuron + hexazinone] F1 exerted control over 80% within 45 days after the first reseeding (DAR1) or 135 DAA.

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