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Alternatives for the chemical control of voluntary plants of showy crotalaria in different application modalities[1]

Alternativas para o controle químico de plantas voluntárias de crotalária em diferentes modalidades de aplicação

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Abstract - With the insertion of showy crotalaria as an antagonistic plant in areas with nematodes infestation history, the occurrence of volunteer plants from this species became common, making it necessary to adopt measures for their management. Thus, this work had the goal to evaluate the effectiveness of herbicides used on different species that where grown in rotation with showy crotalaria (*C. spectabilis*), aiming at its use in controlling volunteer plants from this species. Two experiments (herbicides applied in pre and post-emergence) were conducted on the field using the randomized block design, in (8x2)+1 factor scheme, with four replications. The variable evaluated in the experiments was the control percentage in different periods after treatment application; a plant stand was performed in the experiment with herbicides applied in pre-emergence. Atrazine and diuron, applied in pre-emergence, were the best treatments to control showy crotalaria volunteer plants; they did not suffer any influence from the applied dose. In addition to these, flumioxazin and fomesafen (60 and 375 g ha^{-1}, respectively) were also good alternatives to control showy crotalaria in this application modality. For pre-emergent herbicides, with the exception of diuron (1500 g ha^{-1}), all the other treatments were effective in controlling showy crotalaria in applications performed on plants with 2 to 4 leaves. As for the second application stage, 6 to 8 leaves, in addition to diuron (both doses), fomesafen applied in a lower dose (187.5 g ha^{-1}), was not effective in controlling showy crotalaria, either.
Keywords: cover crops; *Crotalaria spectabilis*; herbicide management

Resumo - Com a inserção da crotalária como planta antagonista em áreas com histórico de infestação de fitonematoides, a ocorrência de plantas voluntárias desta espécie passou a ser comum, tornando-se necessária a adoção de medidas para o seu manejo. Assim, o presente trabalho teve por objetivo avaliar alternativas herbicidas aplicadas em diferentes modalidades (pré e pós-emergência) que possam ser utilizadas no controle de crotalária (*Crotalaria spectabilis*). Dois

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experimentos (herbicidas aplicados em pré e pós-emergência) foram conduzidos em campo adotando-se delineamento blocos ao acaso, em arranjo fatorial (8x2)+1, com quatro repetições. A variável avaliada nos experimentos foi porcentagem de controle em diferentes períodos após a aplicação dos tratamentos, sendo realizado estande de plantas no experimento com herbicidas aplicados em pré-emergência. Atrazine e diuron, aplicados em pré-emergência, consistiram nos melhores tratamentos visando ao controle de plantas voluntárias de crotalária, não sofrendo influência da dose aplicada. Além destes, flumioxazin e fomesafen (60 e 375 g ha^{-1}, respectivamente) também consistiram em boas alternativas para o controle de crotalária nesta modalidade de aplicação. Para os herbicidas pós-emergentes, excluindo o diuron (1500 g ha^{-1}), todos os demais tratamentos apresentaram eficácia no controle de crotalária em aplicações realizadas em plantas com 2 a 4 folhas. Para o segundo estádio de aplicação, 6 a 8 folhas, além do diuron (ambas as doses), o fomesafen aplicado na menor dose (187,5 g ha^{-1}), também não apresentou eficácia no controle de crotalária.
Palavras-chaves: culturas de cobertura; *Crotalaria spectabilis*; manejo de herbicidas

Introduction

The adoption of conservationist systems of soil management such as the no-tillage system constitutes an alternative to contribute to the economic and environmental sustainability of the agro-ecosystems, mainly on extremely frail soils, since these systems enable the maintenance and improvement of the physical, chemical and biological properties of the soil (Silva et al., 2000). In this context, the use of green manure in the crop rotation over no-tillage areas is essential, since it brings various benefits such as mobilization of nutrients and subsequent reduction of expenses with mineral fertilizers, protection of soil against erosion, increase in crop yield, as well as the control of nematodes and weeds, through the release of allelopathic compounds from plants (Severino and Christoffoleti, 2001; Kappes et al., 2011).

Among the plants used for green manure purposes, the ones coming from the Fabaceae family are widely cultivated, since they present high nitrogen supply for succession crop (Erasmo et al., 2004). Species from the *Crotalaria* genus are tropical leguminous plants, whose use as green manure is widely suggested due to its fast growth, great biomass production, nutrients cycling, easy decomposition and effective nitrogen biological fixation (Dourado et al., 2001; Kappes et al., 2012). In Brazil, some crotalaria species have been sowed in nematode-infested areas, with an emphasis on *Crotalaria spectabilis*, which is considered effective in managing root lesion and root-knot nematodes (Wang et al., 2002; Morris and Walker, 2002).

Since showy crotalaria presents slow initial development and medium size, compared with other species from the same genus, its sowing has been recommended for populations with elevated plant per hectare (Carvalho et al., 2003). From the nematode management perspective, this greater density contributes to increase the possibility that the plant-parasitic allocate itself next to the root system of the showy crotalaria, since there are more plants per area. On the other hand, the distribution of a greater quantity of seeds contributes to increase the bank seed in the soil; this may result into higher emergence frequency of showy crotalaria volunteer plants in succession crops. In addition, showy crotalaria seeds present dormancy (Albuquerque et al., 2000), which contributed to greater longevity of these propagating materials in the soil seed bank.

In addition, other factors that make it common to have showy crotalaria volunteer plants in succession crops are: spontaneous dehiscence, loss of threshed seeds from the pods before harvesting or at the time of this operation, and unevenness of pod ripeness presented by this species. In areas where showy crotalaria is not harvested, sometimes these plants are also

not eliminated before the production of pods, which also contributes to the increase in the soil seed bank.

The permanence of showy crotalaria volunteer plants in the cultivations may bring damages to the initial development of the crops, causing initial interference on its. Thus, it becomes important to search for information referring to the use of herbicides to control showy crotalaria volunteer plants; it is still scarce, since there are no registered products for this use in different crops in Brazil.

Part of the available works about controlling showy crotalaria is related to the elimination of adult plants (flowered), since management at this stage is also an obstacle in agricultural areas where this species is cultivated. Among options reported as effective in controlling adult showy crotalaria plants, it is possible to highlight associations of glyphosate with the herbicides 2,4-D-amine, flumioxazin or metsulfuron-methyl (Oliveira Neto et al., 2011; Inoue et al., 2012). In the United States, where this species is considered a weed, there is information about controlling plants at initial development stages, including data about the use of herbicides in pre-emergence; the active ingredients diuron, atrazine, fomesafen, lactofen and paraquat were effective (Maddox et al., 2001).

In this context, the aim of this work was to evaluate the effectiveness of herbicides used on different species that are grown in rotation with showy crotalaria (*C. spectabilis*), for the control of volunteer plants from this species.

Material and Methods

Two experiments were conducted on field at the Centro de Treinamento em Irrigação (CTI) of the Universidade Estadual de Maringá (UEM), located in the city of Maringá (Paraná state), whose geographic coordinates are 23º23'59.23''S and 51º57'00.79''O, and altitude of 501 m. The Experiment 1 consisted in the evaluation of herbicides applied in the pre-emergence of showy crotalaria, whereas in Experiment 2 applications were performed in post-emergence. The experiments were conducted from 01/03/2014 to 03/14/2014.

The soil in the experimental area presented pH in H_2O = 6.0; 16 g dm^{-3} C; 52 g kg^{-1} of sand; 218 g kg^{-1} of silt and 730 g kg^{-1} of clay. Before the experiment, the area was in fallow, presenting high weed infestation. For this reason, a burndown program was used through two herbicide applications; the first performed seven days before sowing (12/27/2013) with the application of glyphosate (1458 g a.i. ha^{-1}), and the second was performed on 01/03/2014, with the application of paraquat (600 g ha^{-1}) with the addition of Agral® 0.5% $v.v^{-1}$.

According to the Köppen classification, the climate for the location is Cfa, humid subtropical, with rainfalls in the summer and fall and hot summer; rainfalls observed during the conduction of the experiment are in Figure 1.

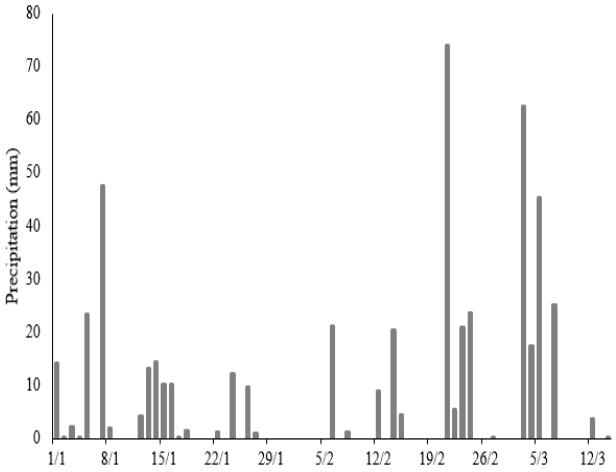

Figure 1. Rainfall (mm) data during the experiments conduction period. Maringá (PR), 2014. Source: Instituto Nacional de Meteorologia (INMET).

Herbicides applied in pre-emergence

Sowing was performed on 01/03/2014, with the help of a manual seeder, distributing 25 showy crotalaria seeds per point, creating 25 points per plot. Plots were 2.5 m wide and 4 m long, totalizing an area of 10 m^2. In the

evaluations, 0.25 m were excluded from each plot edge, which totalized a usable area equivalent to 7 m^2.

The experimental design used was the randomized completely blocks, in a factorial arrangement of (8x2)+1, totalizing seventeen treatments and four replications. The first factor corresponded to the different herbicides applied in pre-emergence of showy crotalaria. The second factor consisted in application of two doses of each herbicide, corresponding to 100 and 50% of the registered dose for each crop whose commercial products present recommendation (Rodrigues and Almeida, 2011). Moreover, an additional treatment composed by a check with no herbicide application was included (Table 1). While selecting herbicides and doses to compose the present experiment, the results obtained in the work developed by Braz et al. (2015) were considered.

Table 1. Relation of the herbicide treatments applied in pre-emergence aiming the control of showy crotalaria. Maringá (PR), 2014.

Treatments	Dose (g ha^{-1})	
	D100*	D50
Flumioxazin	60	30
Fomesafen	375	187.5
Sulfentrazone	600	300
Isoxaflutole	60	30
Atrazine	2500	1250
Diuron	2000	1000
Metribuzin	480	240
Prometryne	1000	500
Check without herbicide	-	

* D100 - Higher dose recorded for use in crops for which the herbicide is recorded (Rodrigues and Almeida, 2011); D50 - 50% of the recommended dose.

Herbicide application in pre-emergence was performed immediately after showy crotalaria sowing. During application, the soil had low humidity, air temperature was 27°C, the relative air humidity was 65%, the sky had clouds and the wind speed was 0.8 km h^{-1}. For all applications, a CO_2-based constant pressure backpack sprayer was used, equipped with a bar containing four XR-110.02 fan type nozzles, spaced 50 cm apart, under pressure of 2 kgf cm^{-2}. These application conditions provided the equivalent to 200 L ha^{-1} spray volume.

For the control evaluations, the infestation of showy crotalaria plants existing in the check plots without herbicide was used as a reference. Evaluations of control were performed at 7, 14 and 28 DAE (days after emergence), using a 0-100% visual scale, where 0% means absence on injury symptoms caused by the herbicides and 100% means total plant death (SBCPD, 1995). In addition to this, on the same dates, the evaluation of the stand was performed, counting the number of showy crotalaria plants in a sample square of 0.5 x 0.5 m (0.25 m^2), taken randomly on three different points inside each experimental unit, presenting the average data equivalent to one point.

Herbicides applied in post-emergence

In order to verify the effect on different application stages, showy crotalaria was sown at two different dates, each one in an area corresponding to half of the plot; the first one was on 01/03/2014 and the second one, ten days after (01/13/2014). In both sowings, the operation was performed by hand, distributing the equivalent of 10 kg ha^{-1}. Later, the incorporation was made with the help of a hoe, covering seeds with a layer of approximately 2 cm of soil. Plots were 2.5 m wide and 4 m long, totalizing an area of 10 m^2. In the evaluations,

0.25 m were excluded from each plot edge, which totalized a usable area equivalent to 7 m^2.

The experimental design used was the randomized completely blocks, in a factorial arrangement of (8x2)+1, totalizing seventeen treatments and four replications. The first factor corresponded to the different herbicides applied in post-emergence of showy crotalaria. The levels of the second factor were constituted by the doses of each herbicide, corresponding to 100 and 75% of the registered dose for each crop whose commercial products present recommendation (Rodrigues and Almeida, 2011). Moreover, an additional treatment was included as a check, without applying any herbicide (Table 2). Similarly, to the experiment conducted with herbicides applied in pre-emergence, while selecting herbicides and doses to compose the experiment, the results obtained in the work developed by Braz et al. (2015) were considered.

Table 2. Relation of the herbicide treatments applied in post-emergence aiming the control of showy crotalaria. Maringá (PR), 2014.

Treatments	Dose (g ha^{-1})	
	D100*	D75
Flumioxazin[1]	25	18.75
Fomesafen[2]	250	187.5
Lactofen	150	112.5
Saflufenacil[1]	35	26.25
Atrazine[1]	2500	1875
Diuron	2000	1500
Amonio-glufosinate[3]	500	375
Glyphosate	1944	1458
Check without herbicide	-	

* D100 - Higher dose recorded for use in crops for which the herbicide is recorded (Rodrigues and Almeida, 2011); D75 - 75% of the recommended dose. [1] Mineral oil (Assist®) 0.5% $v.v^{-1}$; [2] Anionic surfactant (Iharaguen®) 0.2% $v.v^{-1}$; [3] Vegetable oil (Aureo®) 0.2% $v.v^{-1}$.

The application was performed in post-emergence of showy crotalaria plants on 01/25/2014. During application, the soil was humid, air temperature was 25°C, the relative air humidity was 68%, the sky had clouds and the wind speed was 0.6 km h^{-1}. Showy crotalaria plants from the stage denominated I presented 2 to 4 leaves, whereas the ones from the second stage (Stage II) had 6 to 8 leaves. The equipment used for the applications, as well as its adjustments (pressure, number of nozzles, nozzle type) were the same used for Experiment 1, providing a spray volume of 200 L ha^{-1}.

For the control evaluations, the infestation of showy crotalaria plants existing in the check plots without herbicide was used as a reference. Evaluations of control percentage, for both application stages (Stage I and II), were performed at 7, 14 and 48 DAA (days after application), using the same scale described for the Experiment 1 (SBCPD, 1995). In control evaluations, grades were assigned only to plants that received the application of treatments, whereas the ones emerged after this operation were not considered.

Data from both experiments was submitted to analysis of variance. When there was significance between the factors of between the levels of each factor, the Scott-Knott test was applied, at 5% probability ($p \leq 0.05$). The comparison between treatments and control sample without herbicide was performed by Dunnett`s test ($p \leq 0.05$).

Results and Discussion

Herbicides applied in pre-emergence

In the first control evaluation, performed at 7 DAE, it was possible to verify the high effectiveness of atrazine and diuron when

applied at "full" doses (D100). For treatments applied at half dose (D50), satisfactory control levels were observed only in plots that received diuron, in spite of the fact that this treatment did not differ from atrazine applied at 1250 g ha^{-1} (Table 3). In addition to the above-mentioned treatments, flumioxazin, when applied at full dose, also performed satisfactory control levels (>80%) over showy crotalaria, not differing in terms of performance from the herbicides fomesafen and sulfentrazone.

Table 3. Control (%) of showy crotalaria in function of different herbicides applied in pre-emergence. Maringá (PR), 2014.

Treatments	Control (%)											
	7 DAE				14 DAE				28 DAE			
	D100[1]		D50		D100		D50		D100		D50	
Flumioxazin	85.8	Ab*	59.0	Bb*	88.8	Ab*	64.5	Bb*	79.5	Ab*	53.8	Bb*
Fomesafen	74.5	Ab*	49.5	Bb*	79.5	Ab*	40.8	Bc*	72.5	Ab*	25.0	Bc*
Sulfentrazone	75.8	Ab*	30.0	Bc*	79.5	Ab*	25.0	Bd*	55.0	Ac*	10.0	Bd
Isoxaflutole	31.3	Ad*	17.5	Ac	48.3	Ac*	25.0	Bd*	42.5	Ad*	6.3	Bd
Atrazine	95.5	Aa*	72.0	Ba*	99.3	Aa*	96.3	Aa*	100.0	Aa*	98.3	Aa*
Diuron	98.5	Aa*	85.8	Aa*	100.0	Aa*	97.3	Aa*	100.0	Aa*	98.5	Aa*
Metribuzin	17.5	Ad	12.8	Ac	30.0	Ad*	13.8	Ad	18.8	Ae	8.0	Ad
Prometryne	46.3	Ac*	16.0	Bc	61.3	Ac*	21.3	Bd	38.8	Ad*	11.3	Bd
Check without herbicide	0.0				0.0				0.0			
CV %	20.24				18.55				19.24			

[1] D100 - Higher dose recorded for use in crops for which the herbicide is recorded (Rodrigues and Almeida, 2011); D50 - 50% of the recommended dose. * Differ from the check by the Dunnett's test ($p \leq 0.05$); Means followed by different uppercase letters in the lines and lowercase letters in the column differ by the Scott-Knott test ($p \leq 0.05$).

In relation to the effect of using different doses of these herbicides applied in pre-emergence over the initial control (7 DAE) of showy crotalaria volunteer plants, it was verified that, only for diuron, metribuzin and isoxaflutole, the increase in the applied active ingredient dose did not result into an increase in control levels. As for the other treatments, the use of the "full" dose resulted in a 30% average increase in control, with an emphasis on sulfentrazone which, when applied at 600 g ha^{-1} provided 45% more control in relation to its half dose.

At 14 DAE, it is possible to observe that for both evaluated doses, atrazine and diuron were the herbicides with the best pre-emergent control levels over showy crotalaria, obtaining a general average among these treatments that was over than 98%. PROTOX inhibitors herbicides (flumioxazin, fomesafen and sulfentrazone), when applied at D100, managed to impose good control levels over showy crotalaria, with a great reduction in the effectiveness of these treatments when applied at half dose (D50), especially for fomesafen and sulfentrazone, which had an average effectiveness reduction of almost 58%.

Control levels verified in treatments with prometryne and isoxaflutole, in spite of not being comprised in the level that ensures the acceptable effectiveness of herbicides, in practical terms is an important help to manage weeds in crops where they can be used. The intoxication caused by these herbicides over showy crotalaria plants may leave them more sensitive to the application of herbicides in post-emergence or even to the cultural control imposed by the shadowing of the cultivated species (Braz et al., 2014).

In the final control evaluation, performed at 28 DAE, emerged showy crotalaria seedlings were not observed in the plots that received the application of higher doses of atrazine and diuron; control levels were equal to 100% (Table 3). It is also possible to highlight in this evaluation the performance of

flumioxazin and fomesafen, both applied at the full dose (60 and 375 g ha^{-1}, respectively), since in spite of not having presented high effectiveness, they provided control levels close to the standard that is considered satisfactory (80%). In the results of the experiments conducted by Braz at al. (2015), the potential of the herbicides metribuzin, sulfentrazone and prometryne in controlling showy crotalaria with applications performed in pre-emergence was demonstrated. It is worth highlighting that the fact of not having observed similar results in this work is related to the soil texture class, since this work was conducted on a soil with a very clayey texture and the referred work, on a soil with a loam texture.

Another important variable to be analyzed in studies conducted with pre-emergent herbicides is the plant stand, since these herbicides directly influence the emergence of the species that are sensitive to them (Silva et al., 2012). At 7 DAE, in spite of the fact that flumioxazin presented lower control levels than atrazine and diuron, in relation to the number of emerged plants, these treatments, applied at the full dose (100%), are similar (Table 4). This demonstrates that even if intoxication symptoms are higher in showy crotalaria plants that developed in soils with the presence of atrazine and diuron, in relation to the reduction in the interference potential by the decrease in the number of emerged plants, these treatments are similar to flumioxazin.

Table 4. Stand (number of plants in 0.25 m^2) of showy crotalaria in function of different herbicides applied in pre-emergence. Maringá (PR), 2014.

Treatments	Plant stand											
	7 DAE				14 DAE				28 DAE			
	D100[1]		D50		D100		D50		D100		D50	
Flumioxazin	3.8	Ac*	7.0	Ab*	3.5	Ab*	4.8	Ab*	3.3	Bb*	7.0	Ab*
Fomesafen	7.0	Bb*	11.3	Aa*	6.3	Ab*	7.5	Ab*	3.8	Bb*	8.3	Ab*
Sulfentrazone	7.0	Bb*	14.0	Aa	4.3	Bb*	11.3	Aa*	7.5	Ba*	14.5	Aa
Isoxaflutole	11.8	Aa	15.0	Aa	11.5	Aa*	12.8	Aa	8.3	Aa*	11.3	Aa*
Atrazine	2.5	Bc*	8.5	Ab*	0.5	Ac*	2.3	Ac*	0.0	Ac*	0.8	Ac*
Diuron	0.8	Bc*	5.3	Ab*	0.0	Ac*	1.0	Ac*	0.0	Ac*	0.8	Ac*
Metribuzin	14.5	Aa	14.3	Aa	11.5	Aa*	14.0	Aa	10.8	Aa*	12.8	Aa
Prometryne	8.5	Bb*	14.3	Aa	6.0	Bb*	12.3	Aa*	7.3	Ba*	11.5	Aa*
Check without herbicide	17.5				17.5				17.3			
CV %	31.87				33.91				31.36			

[1] D100 - Higher dose recorded for use in crops for which the herbicide is recorded (Rodrigues and Almeida, 2011); D50 - 50% of the recommended dose. * Differ from the check by the Dunnett's test ($p \leq 0.05$); Means followed by different uppercase letters in the lines and lowercase letters in the column differ by the Scott-Knott test ($p \leq 0.05$).

Excluding metribuzin and isoxaflutole (applied at both doses), and prometryne and sulfentrazone (only when applied at D50), all the other treatments caused reduction in the emergence of showy crotalaria in the first plant stand evaluation.

At 14 DAE, the results of the control evaluations were directly related to the number of emerged plants, where the best treatments aiming at the chemical management of showy crotalaria, that is atrazine and diuron, provided a reduction in the stand equal to at least 85%. This reduction in the number of emerged showy crotalaria plants provided by the herbicides applied in pre-emergence demonstrates that these products may be used not only on areas where the species interferes with the crop, but also in places meant for livestock farming, since the seeds produced by crotalarias are toxic for animals (Wills and McWhorter, 1981).

In the final stand evaluation, performed at 28 DAE, it was verified that all herbicides, when used at their highest doses, caused reduction in the emergence of showy crotalaria

seedlings in relation to the check without herbicide. When applied at half dose, metribuzin and sulfentrazone presented a number of plants similar to the check.

In order to prevent the emergence of showy crotalaria volunteer plants by using herbicides in the pre-emergence of different crops, the best options that aims at controlling these species are atrazine and diuron, regardless of the applied dose. In addition to these treatments, flumioxazin and fomesafen (60 and 375 g ha^{-1}, respectively) presented effectiveness aiming at the control of this leguminous vegetable as well.

Herbicides applied in post-emergence

At 7 DAA, for showy crotalaria plants that received the application of herbicides in a more precocious development stage (2 to 4 leaves) (Stage I), it was possible to observe that, with the exception of diuron, all the others treatments presented high effectiveness in controlling this species, and there was no influence from the used dose (Table 5). Even not reaching satisfactory levels, there was a 25% increase in control of showy crotalaria when the full dose of diuron was used.

Table 5. Control (%) of showy crotalaria (Stage I - 2 to 4 leaves) in function of different herbicides applied in post-emergence. Maringá (PR), 2014.

Treatments	Control (%)							
	7 DAA				14 DAA			
	D100[4]		D75		D100		D75	
Flumioxazin[1]	98.3	Aa*	91.0	Ab*	94.5	Aa*	87.3	Ab*
Fomesafen[2]	95.3	Aa*	89.3	Ab*	87.3	Ab*	76.5	Bc*
Lactofen	98.0	Aa*	96.8	Aa*	95.8	Aa*	96.5	Aa*
Saflufenacil[1]	97.8	Aa*	97.5	Aa*	95.8	Aa*	92.0	Aa*
Atrazine[1]	98.8	Aa*	100.0	Aa*	100.0	Aa*	100.0	Aa*
Diuron	71.3	Ab*	47.5	Bc*	78.8	Ac*	19.5	Bd*
Amonio-glufosinate[3]	100.0	Aa*	100.0	Aa*	100.0	Aa*	100.0	Aa*
Glyphosate	100.0	Aa*	99.8	Aa*	100.0	Aa*	100.0	Aa*
Check without herbicide	0.0				0.0			
CV (%)	6.71				6.17			

Treatments	Control (%)							
	28 DAA				48 DAA			
	D100		D75		D100		D75	
Flumioxazin[1]	98.3	Aa*	98.0	Aa*	97.5	Aa*	94.3	Aa*
Fomesafen[2]	96.5	Aa*	94.0	Aa*	95.0	Aa*	92.5	Aa*
Lactofen	98.3	Aa*	99.0	Aa*	98.3	Aa*	98.3	Aa*
Saflufenacil[1]	99.0	Aa*	98.8	Aa*	98.3	Aa*	98.5	Aa*
Atrazine[1]	100.0	Aa*	100.0	Aa*	100.0	Aa*	100.0	Aa*
Diuron	92.5	Aa*	67.5	Bb*	93.0	Aa*	46.3	Bb*
Amonio-glufosinate[3]	100.0	Aa*	100.0	Aa*	100.0	Aa*	100.0	Aa*
Glyphosate	100.0	Aa*	100.0	Aa*	100.0	Aa*	100.0	Aa*
Check without herbicide	0.0				0.0			
CV (%)	5.31				7.73			

[1] Mineral oil (Assist®) 0.5% $v.v^{-1}$; [2] Anionic surfactant (Iharaguen®) 0.2% $v.v^{-1}$; [3] Vegetal oil (Aureo®) 0.2% $v.v^{-1}$. [4] D100 - Higher dose recorded for use in crops for which the herbicide is recorded (Rodrigues and Almeida, 2011); D75 - 75% of the recommended dose. * Differ from the check by the Dunnett's test ($p \leq 0.05$); Means followed by different uppercase letters in the lines and lowercase letters in the column differ by the Scott-Knott test ($p \leq 0.05$).

In the second control evaluation (14 DAA), atrazine, glyphosate and ammonium-glufosinate stand out; they were the only ones causing the death of all showy crotalaria plants in all plots. In addition to these, PROTOX inhibitors herbicides (flumioxazin, fomesafen,

lactofen and saflufenacil) presented good control levels when used in early applications over showy crotalaria plants. In this evaluation, the only treatments where the use of higher doses appeared to be viable in order to obtain higher control levels were fomesafen and diuron.

At 28 DAA, diuron applied at the highest dose (D100) also started to present effectiveness in controlling showy crotalaria (applications performed at Stage I), demonstrating that, differently from the other evaluated treatments, in order to reach maximum control, the referred herbicide needs a longer period of action (Table 5). In spite of having an increase in the control levels for the use of diuron at D75, it was not able to impose its effectiveness in the management of this leguminous plant. A possible explanation for having lower control levels with the use of diuron in post-emergence is related to the fact that adjuvant was not added to the application mixture of this herbicide.

In the last control evaluation of showy crotalaria for plants receiving application in EI, among the sixteen evaluated herbicide options, fifteen out of them presented effectiveness in the chemical management of this species (Table 5). Atrazine, glyphosate and ammonium-glufosinate, in spite of not differing from the other treatments, presented as a benefit the death of all plants, which indicates in practical terms that they were not capable of reaching the reproductive stage, and this contributed to the non-increase in the showy crotalaria seed bank in the soil.

As for diuron, the need to guarantee that the application is performed in a correct way, placing the herbicide in the biological target in an effective way, become evident, since a 25% reduction in the applied dose was able to jeopardize all the effectiveness presented by the active ingredient when used in the higher dose. Among the various factors that may interfere so that an herbicide reaches its maximum effectiveness, one of the essential is the guaranteeing that the product is deposited correctly (Gazziero et al., 2006).

In Table 6, there are the results of the four control evaluations after the application of the herbicides in the post-emergence of showy crotalaria over plants in a more advanced development stage (6 to 8 leaves) (Stage II). Similarly to the results of the initial control evaluation for plants that received the herbicide application at Stage I, when treatments were used at D100, only diuron was not effective in controlling showy crotalaria.

When observing control results at 7 DAA for the herbicides applied at D75, there was a slight decrease in control levels when comparing Stage II plants to Stage I ones. Analyzing the minimum desirable effectiveness level for herbicides, which corresponds to a 80% control (currently, this value is adopted by the Ministry of Agriculture, Livestock and Food Supply in order to register herbicides in Brazil), it was possible to observe in this first control evaluation that lactofen, atrazine, glyphosate and ammonium-glufosinate were the treatments that reached these levels at stage II; and for plants receiving application on Stage I, flumioxazin, fomesafen and saflufenacil were also effective in the initial control of showy crotalaria.

At 14 DAA, the treatments that were capable of performing the best control levels in the post-emergence of showy crotalaria plants were atrazine, glyphosate and ammonium-glufosinate. When applied at full dose (D100), PROTOX inhibitors herbicides did not differ in terms of performance in controlling leguminous vegetables; however, for the use at a lower dose of each herbicide (D75), it was possible to verify that fomesafen was weaker that the other ones, presented control of approximately 15% less than flumioxazin, lactofen and saflufenacil.

The effectiveness demonstrated by glyphosate, ammonium glufosinate and PROTOX inhibitors herbicides constitutes important information for agricultural production systems, since it indicates that there are alternatives for the chemical control of showy crotalaria in the main crop with which the species will be rotated. In addition, the

results demonstrated that there are herbicides to be positioned for the management in conventional and transgenic varieties, be them RR® or LL®.

Table 6. Control (%) of showy crotalaria (Stage I - 6 to 8 leaves) in function of different herbicides applied in post-emergence. Maringá (PR), 2014.

Treatments	Control (%)			
	7 DAA		14 DAA	
	D100[4]	D75	D100	D75
Flumioxazin[1]	85.3 Aa*	78.8 Ab*	82.3 Ab*	77.8 Ab*
Fomesafen[2]	91.0 Aa*	78.5 Ab*	71.8 Ab*	61.5 Ac*
Lactofen	91.3 Aa*	89.5 Aa*	81.3 Ab*	81.5 Ab*
Saflufenacil[1]	90.0 Aa*	77.8 Ab*	83.8 Ab*	75.8 Ab*
Atrazine[1]	96.0 Aa*	96.0 Aa*	100.0 Aa*	100.0 Aa*
Diuron	37.5 Ab*	22.5 Bc*	40.5 Ac*	16.5 Bd*
Amonio-glufosinate[3]	95.5 Aa*	93.3 Aa*	98.8 Aa*	100.0 Aa*
Glyphosate[1]	95.0 Aa*	97.3 Aa*	100.0 Aa*	99.0 Aa*
Check without herbicide	0.0		0.0	
CV (%)	11.35		10.05	

Treatments	Control (%)			
	28 DAA		48 DAA	
	D100	D75	D100	D75
Flumioxazin[1]	94.0 Aa*	91.3 Aa*	88.5 Ab*	87.3 Aa*
Fomesafen[2]	92.0 Aa*	79.3 Bb*	86.0 Ab*	74.5 Ab*
Lactofen	90.8 Aa*	96.3 Aa*	84.8 Ab*	93.3 Aa*
Saflufenacil[1]	96.5 Aa*	93.3 Aa*	94.3 Aa*	90.8 Aa*
Atrazine[1]	100.0 Aa*	100.0 Aa*	100.0 Aa*	100.0 Aa*
Diuron	55.0 Ab*	53.8 Ac*	36.3 Ac*	31.3 Ac*
Amonio-glufosinate[3]	99.5 Aa*	100.0 Aa*	99.5 Aa*	100.0 Aa*
Glyphosate[1]	100.0 Aa*	99.3 Aa*	100.0 Aa*	99.8 Aa*
Check without herbicide	0.0		0.0	
CV (%)	7.66		11.22	

[1] Mineral oil (Assist®) 0.5% $v.v^{-1}$; [2] Anionic surfactant (Iharaguen®) 0.2% $v.v^{-1}$; [3] Vegetal oil (Aureo®) 0.2% $v.v^{-1}$. [4] D100 - Higher dose recorded for use in crops for which the herbicide is recorded (Rodrigues and Almeida, 2011); D75 - 75% of the recommended dose. * Differ from the check by the Dunnett's test ($p \leq 0.05$); Means followed by different uppercase letters in the lines and lowercase letters in the column differ by the Scott-Knott test ($p \leq 0.05$).

In evaluation performed at 28 DAA, diuron applied at both doses and fomesafen at the 187.5 g ha^{-1} dose, were the only treatments that did not reach at least 80% control over showy crotalaria plants when used in post-emergence (Table 6). It is possible to highlight that for fomesafen there was a difference in the performance of the two evaluated doses; it was possible to reach control effectiveness on showy crotalaria by the application of the full dose of this herbicide (D100).

In the final control evaluation, it is possible to observe that more than 80% of the tested treatments (13 out of 16) were effective in the chemical management of post-emerged showy crotalaria, in applications performed over plants with 6 to 8 real leaves (Stage II). Differently from the first evaluated application stage, where only the lowest dose of diuron was not effective in controlling this leguminous plant, for Stage II, there was an addition of diuron at full dose (2000 g ha^{-1}) and fomesafen at the lowest dose (187.5 g ha^{-1}).

Comparing the two stages where showy crotalaria plants received the application of herbicides, they tended to be more tolerant to the herbicides applied later, where the control average among all treatments in the final evaluation demonstrated numbers like 94.48 and 85.37% for Stage I and II, respectively.

These differences may be related to the higher metabolism capacity or to the lower absorption according to the cuticle deposition increase on the leaves at more advanced development stages (Braz et al., 2013).

Aiming at the control of showy crotalaria in applications performed in post-emergence on plants with 2 to 4 leaves (Stage I), with the exclusion of diuron at the lowest dose, all the other treatments were effective in controlling this species. In the second application stage (6 to 8 leaves), in addition to diuron, now at both doses, fomesafen (187.5 g ha^{-1}), was not effective in controlling showy crotalaria, either.

Herbicides to be used in the control of showy crotalaria volunteer plants

As for the herbicides applied in pre-emergence, it becomes evident that, on clayey soils, the best alternatives consist in herbicides inhibiting the photo system II, atrazine and diuron. In spite of the fact that in this work the other treatments did not reach the satisfactory effectiveness to be recognized as herbicides for the management of showy crotalaria volunteer plants, it is necessary to perform works on soils with different textures, since there were different behaviors among the results obtained in this experiment and the ones conducted in greenhouses on loamy-sandy soils (Braz et al., 2015). This precaution of not excluding options that may be positioned in the management of these volunteer plants becomes even more important when it is verified that currently there is no registered product in Brazil for the management of this species.

Herbicides such as flumioxazin and fomesafen, applied in pre-emergence, in spite of not having provided control levels above satisfaction (>80%), had great influence in the development of showy crotalaria plants, leaving them with severe intoxication symptoms, as well as causing great reduction in the emergence of plants from this species.

As for post-emergent herbicides, it is possible to observe that applications at more precocious development stages provide better herbicide control. For atrazine, glyphosate and ammonium-glufosinate, this behavior was not so evident within the two evaluated application stages, becoming more evident for PROTOX-inhibiting herbicides, together with diuron. Summing up the results obtained in both experiments, it is possible to verify that the main herbicide, within the evaluated ones, for the management of volunteer plants of showy crotalaria probably is atrazine, since it was able to impose high effectiveness, regardless of the used application dose or modality.

Conclusions

The best option to control volunteer plants of showy crotalaria (*C. spectabilis*) in pre-emergence consists in the application of atrazine and diuron, be it with 100 or 50% of the recommended doses (2500 and 2000 g ha^{-1}, respectively). Other herbicides that may be used with this aim were flumioxazin (60 g ha^{-1}) and fomesafen (375 g ha^{-1}).

With the exception of diuron at the lowest dose (1500 g ha^{-1}), all the other treatments were effective in controlling showy crotalaria in applications performed on plants with 2 to 4 leaves. As for the second application stage (6 to 8 leaves), in addition to diuron, fomesafen applied at the lowest dose (187.5 g ha^{-1}), was not effective in controlling showy crotalaria, either.

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