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RESEARCH ARTICLE

Management of glyphosate-resistant smooth pigweed and fleabane in burndown, pre-emergence and post-harvest in soybean

Manejo de Caruru-roxo e buva resistentes a glifosato na dessecação, pré-emergência e pós-colheita na soja

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Abstract: **Background**: The advance of smooth pigweed and fleabane in soybean-ryegrass systems is associated with the evolution of weed resistance.
Objective: Evaluate combinations of herbicides in burndown and pre-emergence for the control of smooth pigweed and fleabane in soybean, and the efficacy of herbicides in off-season management of smooth pigweed in ryegrass.
Methods: Two field trials carried out in a complete randomized block design with four blocks. The first trial tested burndown (carfentrazone, carfentrazone+saflufenacil, carfentrazone+diquat, and diquat) and pre-emergent (PRE) herbicides (sulfentrazone+diuron, S-metolachlor, flumioxazin+imazethapyr, S-metolachlor+metrobuzin, and without PRE. The second trial tested rates and tank mixes of herbicides 2,4-D, carfentrazone, metsulfuron and saflufenacil)on ryegrass at post-harvest soybean. The control and population of smooth pigweed and fleabane were evaluated, in addition to soybean yield. As in off-season, control (%) and dry weight of smooth pigweed plants, and phytotoxicity and dry weight of ryegrass were evaluated.
Results: The PRE sulfentrazone+diuron and S-metolachlor+metribuzin combined with carfentrazone+saflufenacil at burndown can be sprayed with selectivity and control efficacy to smooth pigweed and fleabane. In relation to fleabane the carfentrazone applied alone had lesser control, regardless of any pre-emergent herbicides. In the off-season management, the mixtures containing carfentrazone were efficient in the control, and not cause a significant phytotoxicity to ryegrass.
Conclusions: PRE herbicides are essential in the management of smooth pigweed and fleabane and those that promote better control are the combinations sulfentrazone+diuron and S-metolachlor+metribuzin. The tank mixture with carfentrazone demonstrate some phytotoxicity for ryegrass but can control smooth pigweed.

Keywords: *Amaranthus hybridus*, *Conyza* spp., control, herbicides, weed.

Resumo: **Introdução**: O avanço de caruru-roxo e buva no sistema soja-azevém é associada a evolução da resistência de plantas daninhas.
Objetivo: Avaliar combinações de herbicidas na dessecação e pré-emergência para o controle de caruru-roxo e buva na soja, e a eficácia de herbicidas no manejo de caruru no azevém na entressafra.
Métodos: Dois ensaios de campo foram realizados em delineamento em blocos casualizados com quatro repetições. O primeiro ensaio testou herbicidas na dessecação (carfentrazone, carfentrazone+saflufenacil, carfentrazone+diquat e diquat) e pré-emergência (PRE) (sulfentrazone+diuron, S-metolachlor, flumioxazin+imazethapyr, S-metolachlor+metribuzin e sem PRE). O segundo ensaio testou doses e misturas de 2,4-D, carfentrazone, metsulfuron e saflufenacil em azevém na pós-colheita da soja. O controle e a população de caruru-roxo e buva foram avaliados, além da produtividade da soja. Na entressafra, foram avaliados o controle e a massa seca das plantas de caruru-roxo, e a fitotoxicidade e massa seca do azevém.
Resultados: A combinação de sulfentrazone+diuron e S-metolachlor+metribuzin em PRE com carfentrazone+saflufenacil na dessecação pode ser aplicada com seletividade e eficácia no controle de caruru-roxo e buva. Para buva, o carfentrazone aplicado isoladamente apresentou menor controle, independentemente de quaisquer herbicidas pré-emergentes. No manejo na entressafra, as misturas contendo carfentrazone foram eficientes no controle e não causaram fitotoxicidade significativa ao azevém.
Conclusões: Herbicidas PRE são essenciais no manejo de caruru-roxo e buva, e os que promovem melhor controle são as combinações sulfentrazone + diuron e S-metolachlor + metribuzin. A mistura em tanque com carfentrazone demonstra alguma fitotoxicidade para o azevém, mas é eficiente para controlar caruru-roxo.

Palavras-chave: *Amaranthus hybridus*, *Conyza* spp., controle, herbicidas, plantas daninhas

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1. Introduction

Species of the genus *Amaranthus* are troublesome weeds of the Amaranthaceae family of world importance. Within the genus *Amaranthus*, 12 species are known in Brazil, with wide distribution throughout the national territory (Senna, 2020). Of the species characterized, six are commonly found weeds in the main agricultural fields, they are *A. deflexus* L., *A. hybridus* L., *A. retroflexus* L., *A. spinosus* L., *A. viridis* L. and the last one reported the occurrence in 2015 *A. palmeri* S. Among these species the *A. hybridus* (smooth pigweed) stands out recently, which presents morphological characteristics different from the others, with emphasis on the color, which can vary from green to purplish red on the stem, limb leaf and panicle. The constant morphological variation of the species occurs due to the hybridization factor (Costea et al. 2004) and edaphoclimatic conditions in the region of occurrence. The specie can cause a yield loss of 4.47 and 8.32% per unit of weed (Zandoná et al., 2022). Another problem with infestation of weeds of the *Amaranthus* genus in Brazil is the recent increase in reported cases of multiple herbicide resistance (Heap, 2024). Highlighting smooth pigweed with multiple resistance to acetolactate synthase inhibitor herbicides (ALS) (Heap, 2024) and Enolpyruvyl Shikimate Phosphate Synthase (EPSPs) with a mutation on EPSPS TAP-IVS (Mathioni et al., 2022), and Trp-574-Leu substitution in the ALS gene (Oliveira et al., 2024). The resistance makes control difficult and can cause more losses due to resource competition.

Effective control not only of smooth pigweed but of broadleaf weed species at all times such as *Conyza* spp (fleabane) is essential for the economic sustainability of any row crop. The fleabane is one of the main weeds in Brazilian crops (Oliveira et al., 2021), including the species *C. bonariensis* and *C. sumatrensis* were recorded in Brazil (Kalsing et al., 2024). Characteristics such as easy dispersal, high seed production, autogamous reproduction, and discontinuous germination give fleabane a high capacity for infestation in various production systems (Bajwa et al., 2016). Additionally, it is one of the weeds with documented resistance to five mechanisms of action (Pinho et al. 2019), leading to challenges in management and increases in control costs. An alternative to reduce production costs and maintain efficacy to weed control is adoption of cultural methods, in which cover crops containing *Lolium multiflorum* (L.) (ryegrass) have potential to suppression of fleabane emergence (Lamego et al., 2013).

In the Southern Brazil use of cover crops are commonly in the soybean off-season (Grün et al., 2024), and ryegrass is one of the most used during autumn-winter season (Mario et al., 2024). Thus, understanding different management tools for smooth pigweed and fleabane in soybean-ryegrass agricultural systems is important for improving production conditions for these crops. We hypothesized that pre-emergence herbicides help control the smooth pigweed and fleabane, and that herbicide mixtures help off-season post-harvest. Therefore the objective was to evaluate the efficacy of different combinations of herbicides in burndown and pre-emergence (PRE) for the control of smooth pigweed and fleabane in soybean, and the efficacy of herbicides in off-season management of smooth pigweed in ryegrass.

2. Material and Methods

Two trials were carried out during the 2020/2021 season, under field conditions, in a commercial production area located in São Sepé, Rio Grande do Sul, Brazil (30°18'43.3"S 53°33'09.4"W). The trial were carried out in complete randomized blocks designs, with four replications. The soil in the area was classified as Argissolo Vermelho Distrófico típico (Dos Santos et al., 2018) with follow characteristics: pH = 4,6; orcanig matter = 2,9%; clay = 31%. The climate data during the trial are presented in Figure 1.

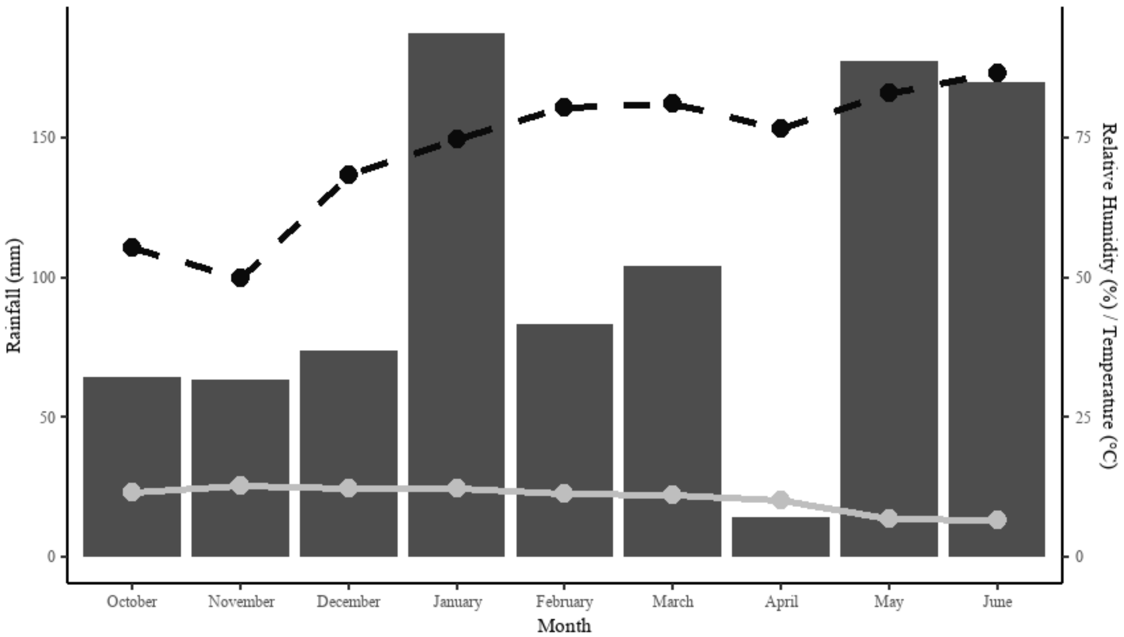


Figure 1. Mean Rainfall (mm) (bar), Temperature (ºC) (gray solid line) and Relative Humidity (%) (black dashed line) recorded during the 2020–2021 growing season. Source: Inmet (2021).

Burndown and pre-emergence weed management of soybean

The experimental treatments consisted of a 4x5 bifactorial combination, whose factor A consisted of different herbicides in burndown, while factor B consisted of different herbicides in pre-emergence (Table 1) with a complete randomized block design (CRB). The experimental units consisted of plots 3 m wide and 5 m long, totaling 15 m^2. The sowing of the soybean cultivar NS 5906 was carried out on December 16, 2020, in the no-tillage system in ryegrass straw residue estimated 2 ton ha^{-1}. The spacing between rows was 0.45 m and sowing was done to obtain 14 plants m^{-1}. Soil fertility was corrected by applying 350 kg ha^{-1} of the 5-30-15 formulation at sowing. Forty days before the establishment of the experimental treatments, the area received application of glyphosate+2,4-D at rates of 1440 and 1005 g a.e. ha^{-1} to manage the existing vegetation and allow a new emergence flow of the target-plants. Weed control in post-emergence of soybean was done by the application of glyphosate, at a rate of 1080 g a.e. ha^{-1}.

Table 1. Herbicide treatments and respective rates utilized to control smooth pigweed (*Amaranthus hybridus*) and fleabane (*Conyza* spp.) in burndow and PRE of soybean.

Trade name	Active ingredient	Rate (mL/g c.p ha^{-1})	Rate (g a.i ha^{-1})
	Burndown[1]		
Aurora®	Carfentrazone	75	30
Aurora®+Heat®	Carfentrazone+Saflufenacil	50+50	20+53
Aurora®+Reglone®	Carfentrazone+Diquat	50+2000	20+400
Reglone®	Diquat	2000	400
	Pre-emergent herbicides (PRE)		
Stone®	Sulfentrazone+Diuron	1200	210+420
Dual Gold®	S-metolachlor	1500	1440
Zetamaxx®	Flumioxazin+Imazethapyr	600	120+60
Dual Gold®+Sencor®	S-metolachlor+Metribuzin	1500+700	1440+336
Without PRE herbicide	-	-	-

[1]DASH adjuvant was added at a rate of 500ml ha^{-1} for all burndown herbicides.

For the application of burndown and pre-emergence treatments, a backpack sprayer was used, pressurized with CO_2, equipped with flat fan nozzle model XR 110015, and calibrated to provide a carrier water volume equivalent to 150 L ha^{-1}. At the time of burndown application, smooth pigweed plants had an average height of 6 cm (2-6 leaves), with a variation of 2 to 10 cm, and with an average population of 15 plants m^{-2}, from the existing seed bank in the area. The population of fleabane plants was accounted for by 8 plants per m^{-2} with height lesser than 20 cm. The application of burndown was carried out 8 days before sowing, while the application of pre-emergence was carried out one day after sowing.

The variables analyzed in the present experiment were: visual control of smooth pigweed and fleabane at 18, 35 and 68 days after sowing, control of smooth pigweed and fleabane in pre-harvest, population of smooth pigweed and fleabane at 40 days after sowing; grain yield and soybean yield components (number of plants m^{-2}, number of grain pod^{-1}, number of pods $plant^{-1}$, and 1000-grain weigh - data not shown). The control visual evaluation was performed using a percentage scale, where zero (0) corresponds to the absence of injury and one hundred (100) to the death of the plants.

The quantification of the plant population was done by counting the number of plants in an area of 0.25 m^2 per experimental unit, with the value subsequently corrected for plants m^{-2}. Grain yield, on the other hand, was determined by harvesting 10 representative plants on a useful area of 3 m^2. Furthermore, the quantification of the weight of a thousand grains was carried out through five counts of one hundred grains each. At harvest time, the population of soybean plants per meter was quantified, in two lines of the useful area. After estimating the grain yield in kg ha^{-1}, based on yield components, grain moisture was corrected to 13%.

The data obtained were submitted to the test of assumptions of the mathematical model regarding the normality of errors and homogeneity of variances Shapiro-Wilk and Levene test, respectively. The analysis of variance was performed using the F test, and the means, when significant, were compared by the Scott-Knott test ($p \leq 0.05$) using the statistical software R (R Core Team, 2021). For the control variables at 18, 35 and 68 days after sowing, an orthogonal contrast analysis $p \leq 0.05$ was also performed.

Off-season management of smooth pigweed after harvest

The experiment was carried out to evaluate alternatives for chemical management of smooth pigweed regrowth in post-harvest soybean. The area where the experiment was carried out was cultivated with soybean in the summer crop, and during the soybean off-season there was the presence of ryegrass from the soil seed bank. The experimental units consisted of plots 3 m wide and 5 m long, totaling 15 m^2. The experimental treatments consisted of the application of 2,4-D herbicides (U-46 Prime, 1005 g e.a. ha^{-1}), 2,4-D+carfentrazone (Aurora, 40 g a.i. ha^{-1}), carfentrazone (30 g a.i. ha^{-1}), metsulfuron (Ally, 2.4 a.i. ha^{-1}), metsulfuron (2.4 g a.i. ha^{-1}) + carfentrazone (40 g a.i. ha^{-1}), saflufenacil (Heat, 35 g a.i. ha^{-1}) + carfentrazone (20 g a.i. ha^{-1}), saflufenacil (35 g a.i. ha^{-1}) + carfentrazone (30 g a.i. ha^{-1}), when necessary, mineral oil adjuvant was added to the spray (0.05 v/v).

To apply the treatments, a backpack sprayer was used, pressurized with CO_2, equipped with flat-fan nozzle XR 110015, and calibrated to provide a carrier water volume equivalent to 150 L ha^{-1}. At the time of application, smooth pigweed plants were regrowth after soybean harvest in an average population of 94 plants m^{-2} and height less than 6 cm, while ryegrass had one to two leaves. The variables analyzed were: smooth pigweed control at 5, 10, 15 and 30 days after application (DAA) and ryegrass phytotoxicity at 5, 10, 15 and 30 DAA. After evaluation at 30 DAA, dry weight of the weed and ryegrass was harvested in a frame of 0.25 m^2 and transformed to 1 m^2.

The data obtained were submitted to the test of assumptions of the mathematical model regarding the normality of errors and homogeneity of variances Shapiro-Wilk and Levene test, respectively. The analysis of variance was performed using the F test, and the means, when significant, were compared using the Scott-Knott test ($p \leq 0.05$), using the ExpDes.pt package (Ferreira et al. 2014) and for graphical representation, the ggplot2 package was used, using the statistical software R (R Core Team, 2021). The smooth pigweed dry weight variable at 30 DAA was subjected to $\sqrt{x} + 1$ transformation.

3. Results and Discussion

Burndown and pre-emergence management of soybean

The Shapiro-Wilk's and Levene's test indicated compliance with the assumptions of normality of errors and homogeneity of residual variances. The analysis of variance did not show significance for the main effects of pré-emergent (PRE) herbicides for the smooth pigweed control variable at 18 days after sowing (DAS). For the control variables of smooth pigweed at 35 and 68 DAS, population of smooth pigweed plants at 40 DAS, there was an interaction between burndown and pre-emergence factors. For the evaluation of smooth pigweed control in pre-harvest, the main significance of the PRE herbicide factor was observed. For the variables of fleabane visual control at 18, 35, 68 DAS and pre-harvest and the variables of population of fleabane at 40 DAS, there was significance only for the effect of the burndown factor level. This result indicates that burndown management is extremely important in cases where the pre-emergence is not applied or is inefficient, and whenever possible, it should be used to smooth pigweed management.

For the visual control of smooth pigweed at 18 DAS, all treatments differed from the control without PRE application, showing the importance of this practice for weed management (Table 2). As for the visual control of smooth pigweed at 35 and 68 DAS, when comparing the burndown treatments within each PRE herbicide, it was found that when there was no used pre-emergent herbicides or when flumioxazin+imazethapyr was sprayed, the best control was obtained by treatment with carfentrazone+saflufenacil in both periods of evaluation, differing from the other treatments (Table 3). Still in the times of evaluation of smooth pigweed control at 35 and 68 DAS, for the treatments with diuron+sulfentrazone and S-metolachlor+metribuzin there was no difference between the levels of the burndown herbicide factor, due to a control close to 100% promoted by the herbicides utilized in PRE (Table 3). The below average control promoted by flumioxazin+imazethapyr (Table 3) may be due to the multiple resistance of the smooth pigweed present in the area to glyphosate and to acetolactate synthase (ALS) inhibitors, the mechanism of action of imazethapyr (Heap, 2024). It is noteworthy that, the comparison between the application of this herbicide with the control without pre-emergence did not show any difference, regardless of the time of control evaluation (Table 5).

For a better understanding of the treatments, the means were compared by orthogonal contrasts, the grouping of burndown and pre-emergence treatments. In all, 19 comparisons of orthogonal contrasts in Table 5 were carried out. The significative response of the treatment with sulfentrazone+diuron in relation to other pre-emergent at 68 DAS is highlighted and denotes the importance of PRE herbicides application of smooth pigweed. In similar work, the use of pre-emergence herbicide programs was a way to reduce the emergence of glyphosate-resistant *Amaranthus palmeri* (Whitaker et al. 2010). Meanwhile comparing the effects of burndown herbicides with and without the use of PRE herbicides. Overall, the best control of smooth pigweed described was with the application of burndown and PRE herbicides (Table 5). The application of diquat alone (contrast 2) resulted in lower control than the average of the other burndown treatments (Table 5). This can be attributed to the control promoted by the treatments where herbicide mixtures were used during the burndown spray, especially with carfentrazone+saflufenacil (Table 5). Therefore, this mixture can be considered the most efficient for the management of smooth pigweed (Table 5) and should be complemented by the application of pre-emergence herbicides.

For the density of smooth pigweed plants, it was found statistical interaction that when comparing the burndown treatments within herbicides sulfentrazone+diuron, S-metolachlor and S-metolachlor+metribuzin (Table 4). Therefore, when PRE treatments there was no significant difference when the pre-emergent used were no pre-emergent check. The treatment with carfentrazone+saflufenacil promoted a lower population of smooth pigweed plants in soybean, at 40 DAS (Table 4). However, an average population of smooth pigweed plants in the combination carfentrazone+saflufenacil without pre-emergence was 7 plants m^{-2}, indicating that even under these conditions there may be soybean yield loss up to 40% (Zandoná et al. 2022).

Table 2. Control (%) of smooth pigweed at 18 days after sowing (18 DAS) and in the pre-harvest of soybean.

Pre-emergent herbicides (PRE)	18 DAS	Pre-harvest
Diuron+Sulfentrazone	98 a	95 a
Flumioxazyn+Imazethapyr	90 a	45 c
Metolachlor	97 a	63 b
Metolachlor+Metribuzin	98 a	85 a
Without PRE herbicide	75 b	22 d
CV (%)	11.81	38.47

[1]Means followed by the same lowercase letter do not differ by the Scott-Knott test ($p \leq 0.05$).

Table 3. Smooth pigweed control (%) at 35 and 68 days after soybean sowing, as a function of burndown and PRE herbicides treatments.

Pre-emergent herbicides (PRE)	Burndown herbicides			
	Carfentrazone	Carfentrazone+Diquat	Carfentrazone+Saflufenacil	Diquat
	35 DAS			
Diuron+Sulfentrazone	99 aA	97 aA	99 aA	99 aA
Flumioxazyn+Imazethapyr	60 bB	50 cB	80 bA	62 bB
S-Metolachlor	88 aB	80 bB	99 aA	93 aA
S-Metolachlor+Metribuzin	99 aA	99 aA	99 aA	98 aA
Without PRE herbicide	53 bB	35 cC	83 bA	39 cC
CV (%)	10.48			
	68 DAS			
Diuron+Sulfentrazone	93 aA	96 aA	98 aA	99 aA
Flumioxazyn+Imazethapyr	45 bB	22 cC	77 bA	20 bC
S-Metolachlor	83 aA	52 bB	72 bA	77 aA
S-Metolachlor+Metribuzin	98 aA	91 aA	90 aA	93 aA
Without PRE herbicide	37 bA	14 cB	55 bA	20 bB
CV (%)	20.58			

[1]Means followed by the same lower-case letter, comparing different pre-emergences for each burndown treatment, and upper-case means, comparing burndown treatments for each pre-emergence, do not differ from each other by the Scott-Knott test (p≤0.05).

Table 4. Density (plants m^{-2}) of Smooth Pigweed, evaluated 40 days after soybean sowing, as a function of burndown and PRE herbicides treatments.

PRE herbicides	Burndown herbicides			
	Carfentrazone	Carfentrazone+Diquat	Carfentrazone+Saflufenacil	Diquat
	40 DAS			
Diuron+Sulfentrazone	1 bA	0 cA	0 aA	0 cA
Flumioxazyn+Imazethapyr	7 bB	14 bB	9 aB	23 bA
S-Metolachlor	5 bA	4 cA	12 aA	3 cA
S-Metolachlor+Metribuzin	0 bA	1 cA	1 aA	1 cA
Without PRE herbicide	19 aB	31 aA	7 aC	37 aA
CV (%)	81.15			

[1]Means followed by the same lower-case letter, comparing different pre-emergences for each burndown treatment, and upper-case means, comparing burndown treatments for each PRE herbicide, do not differ from each other by the Scott-Knott test (p≤0.05).

Table 5. Orthogonal contrasts for the control (%) at 18, 35 and 68 days after sowing (DAS) and density (plants m^{-2}) of smooth pigweed (*Amaranthus hybridus*) at 40 DAS as a function of different treatments in burndown and PRE herbicides.

N	Contrasts	18 DAS		35 DAS		68 DAS		Population	
1	Carfentrazone x all	94 x	91 ns[1]	80 x	81 ns	71 x	65 *	6 x	10 ns
2	Carfentrazone+Diquat x all	88 x	93 ns	72 x	85 *	55 x	70 ns	10 x	9 ns
3	Carfentrazone+Saflufenacil x all	96 x	90 ns	92 x	77 *	78 x	63 ns	6 x	10 ns
4	Diquat x all	89 x	93 ns	78 x	81 *	62 x	68 *	13 x	7 ns
5	Carfentrazone x Carfentrazone+Saflufenacil	94 x	96 ns	80 x	92 *	71 x	78 ns	6 x	6 ns
6	Carfentrazone x Carfentrazone+Diquat	94 x	88 ns	80 x	72 *	71 x	55 ns	6 x	10 *
7	Carfentrazone x Carfentrazone+Diquat plus Carfentrazone+Saflufenacil	94 x	92 ns	80 x	82 ns	71 x	67 ns	6 x	8 ns
8	Carfentrazone+Diquat x Diquat	88 x	89 ns	72 x	78 *	55 x	62 *	10 x	13 ns
9	Carfentrazone+Diquat x Carfentrazone+saflufenacil	88 x	96 ns	72 x	92 *	55 x	78 ns	10 x	6 ns
10	Carfentrazone with PRE x Carfentrazone without PRE	97 x	80 *	86 x	53 *	80 x	37 ns	3 x	19 ns
11	Carfen.[2]+Diquat+PRE x Carfen.[2]+Diquat without PRE	95 x	62 ns	81 x	35 *	65 x	14 ns	5 x	31 ns
12	Carfen.[2]+Safluf.[3]+PRE x Carfen.[2]+Safluf.[3] without PRE	98 x	87 ns	94 x	83 *	84 x	55 *	6 x	7 *
13	Diquat wit PRE x Diquat without PRE	94 x	72 ns	88 x	39 *	72 x	20 *	7 x	37 *
14	Diuron+Sulfentrazone x all	98 x	90 ns	98 x	76 *	97 x	59 *	0 x	11 *
15	Diuron+Sulfentrazone x S-metolaclhor	98 x	97 ns	98 x	90 *	97 x	71 *	0 x	6 *
16	Diuron+Sulfentrazone x S-metolachlor+Metribuzin	98 x	99 ns	98 x	99 *	97 x	93 *	0 x	1 *
17	Diuron+Sulfentrazone x flumioxazin+Imazethapyr	98 x	90 *	98 x	63 *	97 x	41 *	0 x	13 *
18	S-metolachlor x S-metolachlor+Metribuzin	97 x	99 ns	90 x	99 *	71 x	93 ns	6 x	1 ns
19	Without PRE x with PRE	75 x	96 *	53 x	87 *	31 x	75 *	23 x	5 *

[1]* and [ns] represent a significant and non-significant difference, respectively (p≤0.05). [2] Carfentrazone. [3] Saflufenacil. N = contrast number.

In relation to the smooth pigweed control evaluated in the pre-harvest of soybean, a control close to 100% was observed when sulfentrazone+diuron was sprayed, which did not differ from the mixture of S-metolachlor+metribuzin (Table 2). These results indicate the good residual control promoted by these herbicides, preventing reinfestation of smooth pigweed in field. There are reports in the literature on the efficacy of metribuzin to control *Amaranthus retroflexus* and *Chenopodium album* in pre- and post-weed emergence (Alebrahim et al. 2012). Also, the efficacy of sulfentrazone to control *Amaranthus tuberculatus* in emergence and diuron to reduce the population density of *Amaranthus palmeri* in production areas (Hausman et al. 2013; Inman et al. 2016). Furthermore, the sulfentrazone+diuron mixture was also efficient for the pre-emergence management of smooth pigweed in different desiccation systems (Martins et al. 2020).

For the control of fleabane, where there was an effect for the burndown factor, the treatment with carfentrazone alone promoted bad control, differing from the others in the evaluations at 18, 35 and 68 DAS (Table 6), not differing from carfentrazone+saflufenacil in the pre-harvest assessment (Table 6). As for the population variable of fleabane plants, at 40 DAS, treatments with carfentrazone+saflufenacil and diquat promoted the greatest reduction in the number of fleabane plants (Table 6). It is noteworthy that in seeding work, the use of sequential applications, combined with the use of herbicides with residual effect, helps control fleabane and reduces infestation after sowing soybean (Albrecht et al. 2020). Thus far the analysis of orthogonal contrasts for the control of fleabane indicated the relevance of weed burndown management, with no difference between PRE treatments, except at 18 DAS in contrast 16, when metribuzin was sprayed (Table 7). For burndown management, contrast 3, compared to the others, in all control evaluations, promoted greater fleabane control (Table 7), highlighting the importance and spectrum of control promoted by the burndown mixture prior soybean sow. The use of saflufenacil, mainly in mixture with glyphosate, has an important role in the control of fleabane, also being of great importance for the reduction of the weed population (Mellendorf et al. 2013).

Table 6. Control (%) of fleabane at 18, 35 and 68 days after sowing (DAS), pre-harvest and density (pl m^{-2}) at 40 DAS in soybean as a function of burndown treatments.

Burndown	18 DAS	35 DAS	68 DAS	Pre-harvest	Density 40 DAS
Carfentrazone	82 b	80 b	70 b	77 b	2 a
Carfentrazone+Diquat	91 ab	90 ab	91 a	90 a	2 a
Carfentrazone+Saflufenacil	97 a	96 a	97 a	73 b	0 a
Diquat	93 a	92 a	95 a	95 a	0 a
CV (%)	12.12	15.45	20.77	24.57	66.54

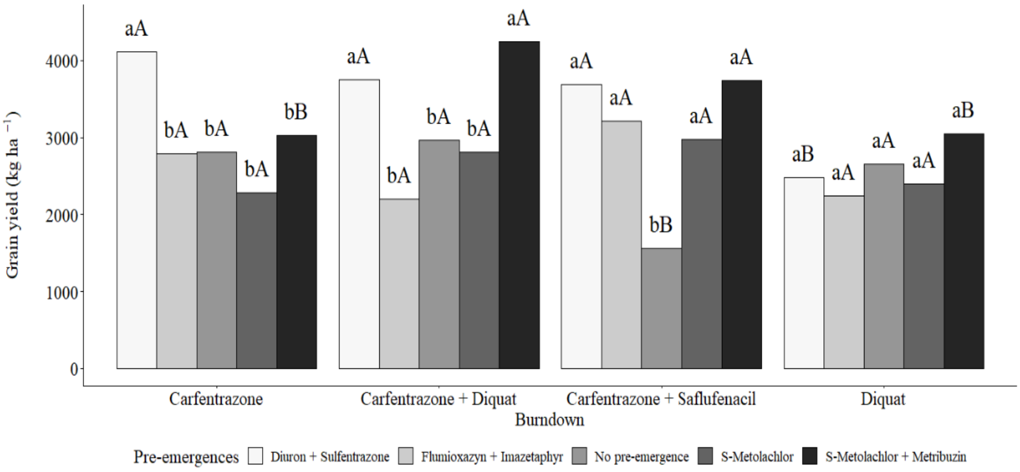
[1]Means followed by the same lowercase letter do not differ by the Scott-Knott test (p<0.05).

Table 7. Orthogonal contrasts for the control (%) at 18, 35 and 68 days after sowing (DAS) and density (plants m^{-2}) of fleabane (*Conyza* spp.) at 40 DAS as a function of different treatments in burndown and PRE herbicides.

N	Contrasts	18 DAS		35 DAS		68 DAS		Population	
1	Carfentrazone x all	82 x	94 ns[1]	80 x	93 ns	70 x	95 ns	2 x	1 ns
2	Carfentrazone+Diquat x all	91 x	95 *	90 x	94 ns	91 x	96 *	2 x	0 ns
3	Carfentrazone+Saflufenacil x all	97 x	89 *	96 x	87 *	97 x	85 *	0 x	1 ns
4	Diquat x all	93 x	90 ns	92 x	89 ns	95 x	86 ns	0 x	1 ns
5	Carfentrazone x Carfentrazone+Saflufenacil	82 x	97 *	80 x	96 ns	70 x	97 ns	2 x	0 ns
6	Carfentrazone x Carfentrazone+Diquat	82 x	91 ns	80 x	90 ns	70 x	91 *	2 x	2 ns
7	Carfentrazone x Carfentrazone+Diquat plus Carfentrazone+Saflufenacil	82 x	94 ns	80 x	93 ns	70 x	94 ns	2 x	1 ns
8	Carfentrazone+Diquat x Diquat	91 x	93 ns	90 x	92 ns	91 x	95 ns	2 x	0 ns
9	Carfentrazone+Diquat x Carfentrazone+Saflufenacil	91 x	97 *	90 x	96 *	91 x	97 *	2 x	0 ns
10	Carfentrazone with PRE x Carfentrazone without PRE	79 x	94 ns	78 x	89 ns	70 x	68 ns	3 x	1 ns
11	Carfen.[2]+Diquat+PRE x Carfen.[2]+Diquat without PRE	90 x	92 ns	92 x	85 ns	95 x	75 ns	2 x	1 ns
12	Carfen.[2]+Safluf.[3]+PRE x Carfen.[2]+Safluf.[3] without PRE	97 x	99 ns	95 x	99 ns	98 x	96 ns	0 x	1 ns
13	Diquat wit PRE x Diquat without PRE	94 x	92 ns	92 x	92 ns	96 x	93 ns	0 x	0 ns
14	Diuron+Sulfentrazone x all	91 x	91 ns	89 x	90 ns	89 x	88 ns	2 x	1 ns
15	Diuron+Sulfentrazone x S-metolaclhor	91 x	87 ns	89 x	90 ns	89 x	89 ns	2 x	1 ns
16	Diuron+Sulfentrazone x S-metolachlor+Metribuzin	91 x	94 *	89 x	91 ns	89 x	91 ns	2 x	1 ns
17	Diuron+Sulfentrazone x flumioxazin+Imazethapyr	91 x	88 ns	89 x	86 ns	89 x	90 ns	2 x	2 ns
18	S-metolachlor x S-metolachlor+Metribuzin	87 x	94 *	90 x	91 ns	89 x	91 ns	1 x	1 ns
19	Without PRE x with PRE	94 x	90 ns	91 x	89 ns	83 x	90 ns	1 x	1 ns

[1] * and ns represent a significant and non-significant difference, respectively ($p \leq 0.05$). [2] Carfentrazone. [3] Saflufenacil. N = contrast number.

For soybean grain yield, it was found that for the comparison of pre-emergents within the level of burndown herbicides, the application of sulfentrazone+diuron showed no difference in the mixture of S-metolachlor+metribuzin, except in relation to the application of carfentrazone where it was higher (Figure 2). When comparing burndown treatments, it was observed overall, that management with diquat reduced yield when the aforementioned PRE herbicides were applied. Still, it is noteworthy that, in general, the lowest yield for all the burndown herbicides tested occurred when there was no application in PRE. The yield responses observed in the present work are considered as a result of the negative interference of weeds, disregarding the effects of phytotoxicity to the crop, which were not observed. The management with pre-emergence herbicides was an alternative to avoid the productivity losses promoted by *A. palmeri* (Whitaker et al. 2010), in a similar way to what was observed in the present work.



[1]Means followed by the same lowercase letter comparing different pre-emergents for each burndown treatment, and uppercases comparing desiccation treatments for each pre-emergence, do not differ from each other by the Scott-Knott test (p≤0.05). CV (%) = 18.

Figure 2. Soybean [*Glycine max* (L.) Merr.] grain yield (kg ha^{-1}) as a function of burndown and PRE herbicides treatments.

Off-season management of smooth pigweed after harvest

The Shapiro-Wilk and Levene tests indicated that it was only necessary to transform the data for the dry weight variable in the smooth pigweed control. The analysis of variance showed significance for the phytotoxicity variable on the ryegrass, those with greater phytotoxicity, at 5 and 10 DAA, had the presence of carfentrazone, differing from the check without spray (Table 8). However, from 15 DAA onwards, the treatments with the greatest phytotoxicity were the mixture of that herbicide with saflufenacil, regardless of the rate, or the mixture with metsulfuron. As for the control variables (%) of smooth pigweed regrowth at 5, 10, 15 and 30 days after application (DAA) and dry weight at 30 DAA (Table 9) and for the ryegrass phytotoxicity variables at 5, 10, 15 and 30 days after application (DAA), the dry weight (DW) variable (Table 8) showed no statistical difference between treatments. However, it can be affirmed that the verified injuries did not compromise the ryegrass development and growth, evidenced by the no significance for the dry weight variable at 30 DAA. It is noteworthy that it is of great importance that chemical management does not cause phytotoxic effects on cover crops, as the reduction of soil cover and biomass can reduce the suppression effect of cover crops on weeds (Osipitan et al. 2019). Which is also demonstrated for the control of *A. palmeri*, it was observed that the greater the mass of cover crops, the greater the reduction in weed establishment (Webster et al. 2013). Also, we want to empathize that in the present study, the greatest phytotoxicity is attributed to the ryegrass development stage (with only five to six expanded leaves).

Table 8. Phytotoxicity to ryegrass at 5, 10, and 15 and 30 days after application (DAA) and shoot dry weight (DW) per m^2 in grams at 30 DAA.

Treatments	5 DAA	10 DAA	15 DAA	30 DAA	DW (g)
Untreated check	0 a[1]	0 a	0 a	0 a	3.64^{ns}
2,4-D	5 a	14 a	2 a	1 a	4.92
2,4-D+Carfentrazone (75)	9 b	9 a	2 a	0 a	2.32
2,4-D+Carfentrazone (100)	18 c	32 b	5 a	1 a	4.84
Metsulfuron	11 b	5 a	3 a	0 a	3.24
Metsulfuron+Carfentrazone (100)	18 c	23 b	22 b	6 b	2.68
Saflufenacil+Carfentrazone (50)	31 d	36 b	33 b	9 b	1.96
Saflufenacil+Carfentrazone (75)	29 d	36 b	37 b	7 b	6.12
CV (%)	10	77	50	32	63

[1]Means followed by the same lowercase letter do not differ by the Scott-Knott test (p≤0.05).

Table 9. Smooth Pigweed control (%) at 5, 10, and 15 and 30 days after application (DAA) and shoot dry weight (DW) per m^2 in grams at 30 DAA.

Treatments	5 DAA	10 DAA	15 DAA	30 DAA	DW (g)
Untreated check	0 d	0 d	0 d	0 d	29 b
2,4-D	34 b	61 b	76 b	84 b	11 b
2,4-D+carfentrazone (75)	84 b	95 b	96 a	95 a	4.2 a
2,4-D+carfentrazone (100)	87 a	96 a	99 a	96 a	6.9 a
Metsulfuron	14 c	21 c	27 c	45 c	33 b
Metsulfuron+carfentrazone (100)	91 a	93 a	97 a	94 a	8 a
Saflufenacil+carfentrazone (50)	90 a	92 a	93 a	97 a	8.2 a
Saflufenacil+carfentrazone (75)	95 a	97 a	98 a	98 a	5.7 a
CV (%)	8	77	8	32	26.74[2]

[1]Means followed by the same lowercase letter do not differ by the Scott-Knott test (p≤0.05). [2] CV related to transformation $\sqrt{x}$ +1.

The best control (%) of smooth pigweed regrowth were observed, overall, in those treatments with the presence of carfentrazone (Table 9). As for the variable of dry weight, only the treatments with 2,4-D and metsulfuron alone did not differ statistically from the check without herbicide application, showing low control efficacy under the conditions of the trial. Also, due to the low levels of metsulfuron control efficacy, we can assume that the ecotype present in the area has resistance to ALS-inhibiting herbicides, which is already widely proven in Brazil (Heap, 2024). Therefore, the efficient postharvest control in off-season management can reduce weed infestation in later season by reducing the weed seed bank (Bagavathiannan and Norswhorty, 2012). In a similar work, the control of *Amaranthus palmeri* with paraquat alone and mixed with several pre-emergent herbicides after soybean harvest, reduced the entry of weed seeds into the seed bank, preventing their appearance in the later crop (Crow et al. 2015). Consequently, the control results found in this work made by the mixtures with carfentrazone can prevent regrowth and suppress the emergence of smooth pigweed in subsequent crops.

4. Conclusions

Pre-emergence herbicide treatments are essential in the management of smooth pigweed and fleabane and those that promote better weed control are the combinations sulfentrazone+diuron and S-metolachlor+metribuzin.

The use burndown herbicide management with carfentrazone+saflufenacil is important to help in the management of smooth pigweed, allowing to broaden the control spectrum for the fleabane.

Treatments with the herbicide carfentrazone demonstrate some phytotoxicity for the ryegrass crop, but do not change its dry weight. And all the mixtures with carfentrazone proved to be efficient for the control of smooth pigweed in post-harvest off-season management.

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