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Herbicide alternative for *Conyza sumatrensis* control in pre-planting in no-till soybeans

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Abstract: Background: In the last two decades, herbicide-resistant biotypes of *Conyza bonariensis*, *Conyza canadensis*, and *Conyza sumatrensis* were identified. **Objective:** To evaluate herbicide alternatives for the control of *C. sumatrensis* to replace simplified management at soybean pre-sowing in the no-till system and assess the potential herbicide injury to soybeans. **Methods:** Four experiments were conducted in Palotina, PR, to evaluate alternative managements to the herbicides commonly used in *C. sumatrensis*, such as synthetic auxins, pre-emergent, and burndown herbicides. All consisted of applications in pre-sowing of soybeans and weed control evaluation. Experiments I and II included evaluations during the crop, such as injury and soybean yield. In all experiments, a randomized block design was used, with four repetitions. **Results:** The treatments with sequential applications were more effective in controlling *C. sumatrensis*. Triclopyr and dicamba were more effective than 2,4-D. **Conclusions:** Dicamba was the most effective synthetic auxins when applied only with glyphosate, without sequential. With sequential glufosinate, dicamba, and triclopyr application showed the highest efficacy. Glufosinate showed better control when applied sequentially compared to saflufenacil. Pre-emergent herbicides were effective only if combined with dicamba in the first application or with sequential glufosinate. Pre-emergent, synthetic auxins, and burndown herbicides were shown to be potentially selective for soybeans.

Keywords: Fleabane; Weeds; Herbicide resistance; Synthetic auxins; Dicamba; Glufosinate

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1. Introduction

The weed evolution of weed biotypes to herbicides is a major concern in agriculture today. For some years, biotypes of *Conyza bonariensis*, *Conyza canadensis,* and *Conyza sumatrensis* resistant to glyphosate have been identified in soybean farms since this is the most widely used herbicide in these areas, especially after the introduction of transgenic tolerance to this herbicide. Together, the three species present 106 cases of herbicide-resistant biotypes worldwide (Heap, 2021).

Among these, *C. sumatrensis* accounts for most cases of resistance to herbicides in Brazil, with seven records. With reports of multiple resistance to glyphosate and chlorimuron (Santos et al., 2014), to the previous and paraquat (Albrecht et al., 2020), as well as a case of resistance to 2,4-D (Queiroz et al., 2020), among others. These herbicides are among the most used for weed management in row crops, pre-sowing or post-emergence.

The factors that lead to the selection of herbicide-resistant weed biotypes include using the same herbicides; the intense selection pressure entails selecting resistant biotypes. Thus, the use of herbicides with different mechanisms of action, the combination of herbicides, and the adoption of other tools, in addition to chemical control, are essential in preventing the selection of resistant weed biotypes, as well as in their management (Gage et al., 2019). Studies show the effectiveness of dicamba (Flessner, Pittman, 2019), halauxifen (Krenchinski et al., 2019), glufosinate (Tahmasebi et al., 2018; Zobiole et al., 2018), saflufenacil (Budd et al., 2017), diclosulam (Braz et al., 2017, Krenchinski et al., 2019), especially in combinations, in the control of *Conyza* spp. and that can be used as control options in the cases of resistance.

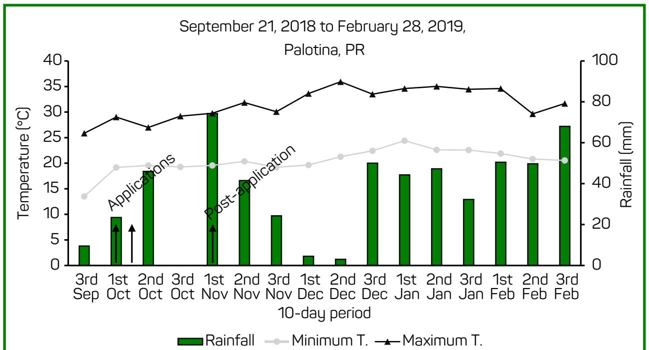
One of the most used control strategies is applying an auxinic herbicide (mainly 2,4-D) combined with glyphosate, followed by a sequential application of burndown herbicide accompanied by pre-emergent herbicide; these measures before soybean sowing. It is believed that dicamba and triclopyr may be equal or more effective to 2,4-D. Glufosinate and other burndown herbicides in mixtures with pre-emergent herbicides can be effective in controlling *C. sumatrensis*. Thus, constituting alternatives for the management of resistant *C. sumatrensis* and slowing the evolution of new resistant biotypes. In this context, this study aimed to evaluate the efficacy of alternative pre-planting herbicides for the control of *C. sumatrensis* and their selectivity to soybean.

2. Material and methods

2.1 Local description and experimental design

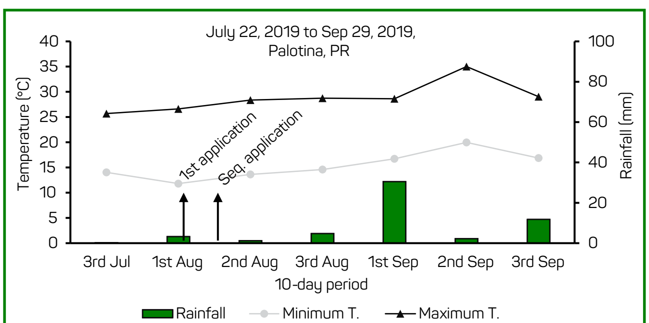
Experiments I and II were conducted in the 2018/19 season and experiments III and IV in the 2019 off-season, all in areas located in Palotina, state of Paraná (PR), Brazil (experiments I and II - 24º20’47.91’’S 53º51’53.54’’W; experiments III and IV - 24º18’33.75’’S 53º52’53.32’’W). Data for rainfall and minimum and maximum temperatures for 2018/2019 and 2019 off-season, during the experimental period, with soybean sowing and herbicide application dates, are shown below in Figures 1 and 2. In the 2018/19 growing season, there was low rainfall during the end of November and the first three weeks of December, associated with high temperatures. In the 2019 off-season, there was also low rainfall during the entire experimental period.

Experiments I and II were conducted for 140 days, which encompassed the entire soybean cycle (about 120 days) and the period of applications in pre-sowing burndown (about 20 days). Before applying the treatments, the area was grown with maize (2nd crop of 2018). It was sown the soybean cultivar Monsoy 5947 IPRO, in a no-tillage system with 12 seeds m^{-1} and rows were spaced 45 cm, with sowing five days after the second herbicide application Oct 15, 2018. Experiments III and IV were conducted during the 2019 off-season, between maize harvest (2nd crop of 2018) and the sowing of the soybean crop (season 2019/20), at pre-sowing burndown (about 60 days). For all, the soil was classified as very clayey. Soil analysis of experiments I and II, at a depth of 0 - 20 cm, showed CEC of 12.41 cmol$_c$ dm^{-3}, O.M. of 15.48 g dm^{-3}, and pH ($CaCl_2$) 4.6. In experiments, I and II, the initial infestation of *C. sumatrensis* was 21 plants m^{-2}, with an average height of 10 cm. For experiments III and IV, 15 plants m^{-2} and height of 16 cm.



Source: C.Vale - *Cooperativa Agroindustrial*.
Application at soybean post-emergence only to experiment I.

Figure 1 - Precipitation and medium temperatures (minimum and maximum), during the conduction period of experiments I and II in Palotina, PR, 2018/20 season.



Source: C.Vale - *Cooperativa Agroindustrial*.

Figure 2 - Precipitation and medium temperatures (minimum and maximum), during the conduction period of experiments III and IV in Palotina, PR, 2019 off-season.

The experiments were organized in randomized block design with four replications. The treatments of the four experiments are listed in Tables 1 to 4. In experiment I, glyphosate (Roundup® Original DI) + chlorimuron (Classic®) (1,080 g ae ha^{-1} + 20 g ai ha^{-1}) was applied in post-emergence of soybean, in experiment II, there was no application in post-emergence due to low weed emergence during the crop cycle. The plots measured 5x3 m, and to reduce the border effect, the evaluations were performed in the center of the plot (3x2 m).

Herbicides were applied with a CO_2 pressurized backpack sprayer equipped with a three-meter-long application boom, with six flat-fan nozzles (Teejet XR 110.02) spaced 50 cm. During application, the boom was placed at 50 cm height from the target, constant pressure of 2 bar, with a flow rate of 0.45 L min$^{-1,}$ and speed of 1 m s^{-1}, thus providing a volume of 150 L ha^{-1} of spray solution. The weather conditions at the time of the applications are shown in Table 5, with an interval of seven days between the first and sequential application.

2.2 Evaluations and data analysis

The control of *C. sumatrensis* was evaluated at 7, 21, and 35 days after the sequential application (DAA) in experiments I and III. In experiment II, evaluations were performed at 14 and 28 DAA and in experiment IV at 14, 28, and 42 DAA. At 28 and 35 DAA, injury symptoms in soybean plants were evaluated in experiments I and II. Visual injury scores were assigned to each experimental unit, where 0 represents no damage, and 100% indicates total plant death (Velini et al., 1995).

Experiments III and IV evaluated the emergence of plants of *C. sumatrensis*, using a metal square measuring 1 x 1 m, at 28, 35, and 42 DAA. The square was randomly launched in each plot, and the number of plants of *C. sumatrensis* inside the square was counted. With the same square, the number of plants of *C. sumatrensis* present in each experimental unit was counted immediately before the soybean harvest in experiments I and II.

For experiments I and II, at R8, soybean was harvested by hand, on the four central rows over 2 m in length, totaling 3.6 m^{-2} area harvested in the plots. All the harvested material was cleaned with a stationary shredder and packed in paper bags, and weighted to estimate yield in kg ha^{-1}, with the values corrected to 13% moisture.

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Table 1 - Herbicide treatments, composed of two applications, for the control of *C. sumatrensis*. 2018/19 season, Palotina, PR (experiment I).

1st application		Sequential application	
Herbicide	**Rate**	**Herbicide**	**Rate**
Control (without weeding)	-	-	-
Control (with weeding)	-	-	-
glyphosate + saflufenacil[1]	1,080 + 35	glufosinate[2]	500
glufosinate[2]	500	glyphosate + saflufenacil[1]	1,080 + 35
glyphosate + 2,4-D + saflufenacil[1]	1,080 + 670 + 35	glufosinate[2]	500
2,4-D + glufosinate[3]	670 + 400	glyphosate + saflufenacil[1]	1,080 + 35
glyphosate + dicamba + saflufenacil[1]	1,080 + 288 + 35	glufosinate[2]	500
dicamba + glufosinate[3]	288 + 400	glyphosate + saflufenacil[1]	1,080 + 35
glyphosate + triclopyr + saflufenacil[1]	1,080 + 480 + 35	glufosinate[2]	500
triclopyr + glufosinate[3]	480 + 400	glyphosate + saflufenacil[1]	1,080 + 35
glyphosate + dicamba[1]	1,080 + 288	-	-
glyphosate + triclopyr[1]	1,080 + 480	-	-

Rates at g ai ha^{-1}, for glyphosate, 2,4-D and triclopyr at g ae ha^{-1}. Commercial products: Dicamba: Atectra®; glufosinate: Finale®; glyphosate: Roundup Original DI®; saflufenacil: Heat®; triclopyr: Triclon®; 2,4-D: DMA 806 BR®.

[1] Addition of Dash HC to 0.5% of the spray volume. [2] Addition of Assist to 0.5% of the spray volume. [3] Addition of Aureo to 0.5% of the spray volume.

Table 2 - Herbicide treatments, composed of two applications, for the control of *C. sumatrensis*. 2018/19 season, Palotina, PR (experiment II).

1st application		Sequential application	
Herbicide	**Rate**	**Herbicide**	**Rate**
Control (without weeding)	-	-	-
Control (with weeding)	-	-	-
glyphosate + 2,4-D	1,080 + 670	glyphosate + saflufenacil/imazethapyr[1]	1,080 + 35/100
glyphosate + 2,4-D	1,080 + 670	glufosinate[2]	500
glyphosate + 2,4-D	1,080 + 670	imazethapyr/flumioxazin	100/50
glyphosate + 2,4-D	1,080 + 670	diclosulam	25
glyphosate + 2,4-D	1,080 + 670	sulfentrazone/diuron	245/490
glyphosate + 2,4-D	1,080 + 670	glufosinate + imazethapyr/flumioxazin[2]	500 + 100/50
glyphosate + 2,4-D	1,080 + 670	glufosinate + diclosulam[2]	500 + 25
glyphosate + 2,4-D	1,080 + 670	glufosinate + sulfentrazone/diuron[2]	500 + 245 + 490

Rates at g ai ha^{-1}, for glyphosate, 2,4-D and imazethapyr for g ae ha^{-1}. Commercial products: diclosulam: Spider® 840 WG; imazethapyr/flumioxazin: Zethamaxx®; glufosinate: Finale®; glyphosate: Roundup® Original DI; saflufenacil/imazethapyr: Optill®; sulfentrazone/diuron: Stone®; 2,4-D: DMA® 806 BR.

Table 3 - Herbicide treatments, composed of two applications, for the control of *C. sumatrensis*. 2019 off-season, Palotina, PR (experiment III).

1st application		Sequential application	
Herbicide	**Rate**	**Herbicide**	**Rate**
Control (without weeding)	-	-	-
glyphosate + saflufenacil[1]	1,080 + 35	glufosinate[2]	500
glufosinate[2]	500	glyphosate + saflufenacil[1]	1,080 + 35
glyphosate + 2,4-D + saflufenacil[1]	1,080 + 670 + 35	glufosinate[2]	500
2,4-D + glufosinate[2]	670 + 400	glyphosate + saflufenacil[1]	1,080 + 35
glyphosate + dicamba+ saflufenacil[1]	1,080 + 288 + 35	glufosinate[2]	500
dicamba + glufosinate[2]	288 + 400	glyphosate + saflufenacil[1]	1,080 + 35
glyphosate + triclopyr + saflufenacil[1]	1,080 + 480 + 35	glufosinate[2]	500
triclopyr + glufosinate[2]	480 + 400	glyphosate + saflufenacil[1]	1,080 + 35
glyphosate + dicamba[1]	1,080 + 288	-	-
glyphosate + triclopyr[1]	1,080 + 480	-	-
glyphosate + 2,4-D	1,080 + 670	-	-
glyphosate + dicamba[1]	1,080 + 288	diquat[3]	400
glyphosate + triclopyr[1]	1,080 + 480	diquat[3]	400
glyphosate + 2,4-D	1,080 + 670	diquat[3]	400

Rates at g ai ha^{-1}, for glyphosate, 2,4-D, dicamba and triclopyr at g ae ha^{-1}. Commercial products: dicamba: Atectra®; diquat: Reglone®; glufosinate: Finale®; glyphosate: Zapp® QI 620; saflufenacil: Heat®; triclopyr: Triclon®; 2,4-D: DMA® 806 BR.

[1] Addition of Dash HC to 0.5% of the spray volume. [2] Addition of Mess to 0.5% of the spray volume. [3] Addition of Agral to 0.5% of the spray volume.

[1] Addition of Mess to 0.5% of the spray volume. [2] Addition of Assist to 0.5% of the spray volume.

Table 4 - Herbicide treatments, composed of two applications, for the control of *C. sumatrensis*. 2019 off-season, Palotina, PR (experiment IV).

1st application		Sequential application	
Herbicide	Rate	Herbicide	Rate
Control (without weeding)	-	-	-
glyphosate + 2,4-D	1,080 + 670	glyphosate + saflufenacil/imazethapyr[2]	1,080 + 35/100
glyphosate + 2,4-D	1,080 + 670	glufosinate + imazethapyr/flumioxazin[2]	500 + 100/50
glyphosate + 2,4-D	1,080 + 670	glufosinate + diclosulam[2]	500 + 35
glyphosate + 2,4-D	1,080 + 670	glufosinate + sulfentrazone/diuron[2]	500 + 245/490
glyphosate + 2,4-D	1,080 + 670	glufosinate[2]	500
glyphosate + dicamba +imazethapyr/flumioxazin[1]	1,080 + 288 + 100/50	glufosinate[2]	500
glyphosate + dicamba + diclosulam[1]	1,080 + 288 + 35	glufosinate[2]	500
glyphosate + dicamba + sulfentrazone/diuron[1]	1,080 + 288 + 245/490	glufosinate[2]	500
glyphosate + dicamba + atrazine/mesotrione[1]	1,080 + 288 + 1,000/100	glufosinate[2]	500
glyphosate + imazethapyr/flumioxazin	1,080 + 100/50	glufosinate[2]	500
glyphosate + diclosulam	1,080 + 35	glufosinate[2]	500
glyphosate sulfentrazone/diuron	1,080 +245/490	glufosinate[2]	500
glyphosate + atrazine/mesotrione	1,080 + 1,000/100	glufosinate[2]	500
glyphosate + dicamba[1]	1,080 + 288	glufosinate[2]	500
glyphosate + triclopyr[1]	1,080 + 480	glufosinate[2]	500

Rates at g ai ha^{-1}, for glyphosate, 2,4-D, dicamba, triclopyr and imazethapyr at g ae ha^{-1}. Commercial products: atrazine/mesotrione: Calaris®; dicamba: Atectra®; diclosulam: Spider® 840 WG; sulfentrazone/diuron: Stone®; imazethapyr/flumioxazin: Zethamaxx®; glyphosate: Zapp® QI 620; glufosinate: Finale®; saflufenacil/imazethapyr: Optill®; triclopyr: Triclon®; 2,4-D: DMA® 806 BR.

[1] Addition of Dash HC to 0.5% of the spray volume. [2] Addition of Mess to 0.5% of the spray volume.

Table 5 - Weather conditions during herbicide applications.

	Exp. I and II		Exp. I	Exp. III and IV	
	1st application	Seq. application	Soybean post-emergence	1st application	Seq. application
Wind (km h^{-1})	7.0	9.0	6.5	8.0	9.0
T (°C)	29.0	27.0	29.5	21.0	19.0
RH (%)	62.0	58.0	57.5	61.0	52.0
Dates	Oct 03, 2018	Oct 10, 2018	Nov 05, 2018	Aug 08, 2019	Aug 15, 2019

Seq.: sequential. T: air temperature. RH: air relative temperature.

Data were tested by analysis of variance by the F-test ($p < 0.05$), and the mean values were separated by the Scott & Knott test at the 5% level. Analyses were run in Sisvar 5.6 software (Ferreira, 2011).

3. Results and discussion

3.1 Experiment I

In experiment I, all treatments, except the single application of glyphosate + diclosulam and glyphosate + triclopyr, promoted a high level of control of *C. sumatrensis*. The number of *C. sumatrensis* plants confirms the effectiveness of all treatments in controlling this weed at 35 DAA and throughout the soybean cycle since all treatments had a low number of plants per m^{-2}, while the control showed an average of 43 plants per m^{-2} (Table 6).

The sequential application, either saflufenacil + glyphosate or glufosinate, proved effective in controlling *C. sumatrensis*. That strategy is characterized as important management alternatives based on the rotation of herbicides with different mechanisms of action, which helps to fight against resistance. Other studies have also shown an equal level of control with the application of glufosinate in *Conyza* spp. smaller than 10 cm in height (Santos et al., 2015). The application of saflufenacil + glyphosate also showed complete control of *Conyza* spp., with a synergistic effect for the mixture (Dalazen et al., 2015). This mixture also had a similar effect on controlling other weeds, such as *Amaranthus palmeri* (Takano et al., 2020). The high control over *Conyza* spp. is mainly due to the low development of these plants at the time of application, since the development

Table 6 - Control, plants of *C. sumatrensis* m^{-2} at harvest, and soybean yield (kg ha^{-1}). 2018/19 season, Palotina, PR (experiment I).

1st application	Sequential application	Control (%) at DAA			Plants m^{-2}	Yield
		7	21	35		kg ha^{-1}
Control (without weeding)	-	0.0 e	0.0 c	0.0 d	43.0 b	0 b
Control (with weeding)	-	100.0 a	100.0 a	100.0 a	0.0 a	1,420 a
glyphosate + saflufenacil	glufosinate	85.8 b	98.3 a	98.8 a	0.5 a	1,278 a
glufosinate	glyphosate + saflufenacil	85.8 b	92.0 a	92.3 a	1.0 a	1,255 a
glyphosate + 2,4-D + saflufenacil	glufosinate	85.5 b	97.3 a	98.8 a	0.0 a	1,253 a
2,4-D + glufosinate	glyphosate + saflufenacil	86.5 b	97.5 a	98.3 a	0.0 a	1,168 a
glyphosate + dicamba + saflufenacil	glufosinate	85.0 b	99.0 a	99.0 a	0.0 a	1,266 a
diclosulam + glufosinate	glyphosate + saflufenacil	87.0 b	98.5 a	99.3 a	0.0 a	1,331 a
glyphosate + triclopyr + saflufenacil	glufosinate	86.5 b	97.5 a	98.8 a	0.3 a	1,298 a
triclopyr + glufosinate	glyphosate + saflufenacil	85.5 b	98.0 a	99.0 a	0.5 a	1,345 a
glyphosate + dicamba	-	56.3 c	73.3 b	79.3 b	0.0 a	1,210 a
glyphosate + triclopyr	-	51.0 d	66.3 b	72.5 c	2.3 a	1,240 a
	Mean	74.6	84.8	86.3	4.0	1,172
	F	*	*	*	*	*

DAA: days after sequential application.

* Means followed by the same letter in the column do not differ by Scott & Knott's test, at the 5% probability level.

stage influences the performance of the herbicide and the control spectrum, which is better in plants at early stages, as in this case, in which the treatments did not differ from the weeded control (Oliveira Neto et al., 2010).

For yield (Table 6), the control showed zero for soybeans, the high infestation of *C. sumatrensis* at the end (43 plants m^{-2}), resulting in total plant death due to the high competition with the crop. It should be noted that only 2.7 *C. bonariensis* plants m^{-2} can reduce soybean yield by up to 50% (Trezzi et al., 2015). Notably, there were no differences between herbicidal treatments for yield. In contrast, the injury symptoms in soybean plants were at most 2.75% (data not shown). The low soybean yield, an average of 1,172 kg ha^{-1} (Table 6), may have been a consequence of low rainfall and high temperatures during late November and almost the entire month of December (Figure 1).

3.2 Experiment II

In the second experiment, better results (≥ 86%) were found for treatments with sequential application of glyphosate + saflufenacil/imazethapyr, glufosinate, glufosinate + imazethapyr/flumioxazin, glufosinate + diclosulam, glufosinate + sulfentrazone/diuron. These treatments are also among the ones that reduced most the number of *C. sumatrensis* plants, while a final infestation of 34.3 plants m^{-2} was observed for the control. Such results reflect that observed for soybean yield, with the least effective control treatments and lower soybean yield (Table 7). The low soybean yield, an average of 1,005 kg ha^{-1}, can be explained by low rainfall and high temperatures during late November and almost the entire month of December (Figure 1).

Greater efficacy of glufosinate has been reported in a sequential application to control *Conyza* spp. compared to saflufenacil and paraquat at 35 DAA, in treatments with glyphosate + 2,4-D in the first application (Zobiole et al., 2018), as well as in this experiment. The satisfactory performance of saflufenacil and glufosinate in this experiment is because the population of *C. sumatrensis* showed little development at the time of application (10 cm height). Takano et al. (2013) observed total control with glyphosate + 2,4-D in plants up to 15 cm high at 28 DAA.

In some regions, especially in the western region of Paraná state, the effectiveness of this mixture has been declining in recent years due to the rapid necrosis that 2,4-D causes on this weed, visible two to three hours after application. This effect is related to a mechanism of resistance of *C. sumatrensis* to 2,4-D, which regrows a few days after treatment with this herbicide, since, under the effect of necrosis, there is less absorption of herbicides used in sequence, reducing the performance of these molecules. In this case, there is a need to replace 2,4-D with another auxinic herbicide in the management of *Conyza* spp., such as dicamba and triclopyr (Queiroz et al., 2020). These same authors reported resistance to 2,4-D in *C. sumatrensis* biotypes; however, there were no reports of cross-resistance since other auxinic herbicides such as dicamba, triclopyr, halauxifen, and fluroxypyr did not cause necrosis.

Table 7 – Control, plants of *C. sumatrensis* m^{-2} and soybean yield (kg ha^{-1}). 2018/19 season, Palotina, PR (experiment II).

1st application	Sequential application	Control (%) at DAA		Plants m^{-2}	Yield
		7	21		kg ha^{-1}
Control (without weeding)	-	0.0 e	0.0 d	34.3 c	0 b
Control (with weeding)	-	100.0 a	100.0 a	0.0 a	1,424 a
glyphosate + 2,4-D	glyphosate + saflufenacil/imazethapyr	86.3 b	90.3 a	0.0 a	1,336 a
glyphosate + 2,4-D	glufosinate	85.0 b	86.0 a	3.0 a	1,339 a
glyphosate + 2,4-D	imazethapyr/flumioxazin	49.0 c	43.8 c	16.3 b	363 b
glyphosate + 2,4-D	diclosulam	41.0 d	35.8 c	16.3 b	325 b
glyphosate + 2,4-D	sulfentrazone/diuron	56.3 c	59.5 b	7.8 a	374 b
glyphosate + 2,4-D	glufosinate + imazethapyr/flumioxazin	86.5 b	89.5 a	3.5 a	1,500 a
glyphosate + 2,4-D	glufosinate + diclosulam	83.5 b	96.8 a	0.0 a	1,483 a
glyphosate + 2,4-D	glufosinate + sulfentrazone/diuron	86.3 b	93.0 a	0.0 a	1,901 a
	Mean	67.4	69.5	8.1	1,005
	F	*	*	*	*

DAA: days after sequential application.

* Means followed by the same letter in the column do not differ by Scott & Knott's test, at the 5% probability level.

As in experiment I, low injury was observed in soybean plants (≤3.5%) (data not shown). The diclosulam, sulfentrazone, and chlorimuron application caused a 2% injury to soybeans (Osipe et al., 2014). The application of diclosulam, sulfentrazone, flumioxazin, imazethapyr, chlorimuron, and s-metolachlor do not reduce the yield of soybean crops but can cause injury in some situations. Depending on the herbicide and the species, their residual can be equivalent to two applications of glyphosate and reduce the initial competition with the crop, especially in high infestations (Lopes-Ovejero et al., 2013).

3.3 Experiment III

For experiment III, better results were observed for the application of glyphosate + 2,4-D + saflufenacil sequential (seq.) glufosinate, glyphosate + dicamba, dicamba + saflufenacil seq. glufosinate, glyphosate + triclopyr + saflufenacil seq. glufosinate and triclopyr + glufosinate seq. glyphosate + saflufenacil, with scores ≥ 85.5% at 35 DAA. Added to these, the treatments glufosinate seq. glyphosate + saflufenacil, 2,4-D + glufosinate seq. glyphosate + saflufenacil, dicamba + glufosinate seq. glyphosate + saflufenacil, glyphosate + dicamba, glyphosate + dicamba seq. diquat, as those that reduced most the emergence of *C. sumatrensis* (Table 8).

Other studies also indicated *Conyza* spp. control above 90% (Byker et al., 2013), until 97% at 28 DAA in the combination of dicamba, saflufenacil, and glyphosate (Budd et al. 2016). This and other studies show that dicamba is highly efficient in controlling this weed and can be an excellent auxinic herbicide alternative for *Conyza* spp. resistant to 2,4-D.

3.4 Experiment IV

In experiment IV, in the last evaluation at 42 DAA, the treatments glyphosate + dicamba + imazethapyr/flumioxazin seq. glufosinate, glyphosate + dicamba + diclosulam seq. glufosinate, glyphosate + dicamba seq. glufosinate and glyphosate + triclopyr seq. glufosinate, with scores > 90% in the control and ≤ 0.5 plants m^{-2} (Table 9).

One of the known characteristics of auxinic herbicides is their persistence in the soil (Silva et al., 2011), which mentions the residual effect of 2,4-D on soybeans. Dicamba has also shown excellent residual for pre-emergence with control of 97% to *Kochia scoparia* with pre-emergence application and only 10% control in post-emergence since the species in question is resistant to dicamba (Ou et al., 2018). Also, total control of *Conyza* spp. with glyphosate, halauxifen, and diclosulam indicates that this auxinic herbicide is also highly effective for the management of *Conyza* spp., which may be an alternative to the use of 2,4-D (Braz et al., 2017).

In isolated application, among those pre-emergent with glyphosate, atrazine/mesotrione stands out. Matte et al. (2018) reported that atrazine/mesotrione provided complete control of *C. bonariensis* at 14 DAA. Nevertheless, the residual period of this herbicide for implanting soybeans is quite long, which may hinder its use in the management of *Conyza* spp. at pre-sowing, since there was a reduction in dry matter and yield of soybeans with sowing at 120 DAA of this herbicide (Gonçalves et al., 2018).

3.5 Final remarks

All treatments with sequential applications were more effective in controlling *C. sumatrensis* than single herbicide applications. At higher development stages, combining different herbicides is essential, especially with pre-emergent ones, which are shown as the ideal tool to reduce infestation of plants that are difficult to control and with reports of resistance to herbicides. The anticipation of herbicide applications in the off-season can significantly contribute to the success in weed control, at the early-plant stage when the weeds are more sensitive to the herbicides, a fact also confirmed in this research. However, the best control practice is Integrated Weed Management, and chemical control is only one of the pillars of this management. The use of soil cover, for example, can be as efficient as herbicides, the use of pre-emergent herbicides to reduce the emergence flows of weeds, and the monitoring of crops, to adopt the best strategy and the ideal time to perform the control. The management strategies studied in this study with dicamba, triclopyr, glufosinate and saflufenacil were highly efficient in controlling *C. sumatrensis* and capable of replacing the herbicides 2,4-D and paraquat.

Table 8 - Control and emergence (plants m^{-2}) of *C. sumatrensis* m^{-2}. 2019 off-season, Palotina, PR (experiment III).

1st application	Sequential application	Control (%) at DAA			Plants m^{-2} at DAA		
		7	21	35	28	35	42
Control (without weeding)	-	0.0 f	0.0 f	0.0 g	8.3 d	8.8 c	9.8 c
glyphosate + saflufenacil	glufosinate	73.3 a	63.8 c	53.0 d	1.8 b	2.5 a	3.5 b
glufosinate	glyphosate + saflufenacil	76.3 a	74.3 b	65.0 c	0.0 a	0.0 a	0.8 a
glyphosate + 2,4-D + saflufenacil	glufosinate	74.3 a	83.5 a	85.5 a	0.3 a	0.8 a	1.3 a
2,4-D + glufosinate	glyphosate + saflufenacil	76.5 a	86.8 a	78.5 b	0.3 a	0.8 a	1.3 a
glyphosate + dicamba+ saflufenacil	glufosinate	76.5 a	85.8 a	89.3 a	0.0 a	0.0 a	0.0 a
dicamba + glufosinate	glyphosate + saflufenacil	77.0 a	86.8 a	80.3 b	0.3 a	0.3 a	0.5 a
glyphosate + triclopyr + saflufenacil	glufosinate	75.8 a	85.8 a	92.3 a	0.5 a	0.5 a	0.8 a
triclopyr + glufosinate	glyphosate + saflufenacil	76.8 a	86.8 a	90.5 a	0.8 a	1.3 a	1.8 a
glyphosate + dicamba	-	52.0 c	61.8 c	68.8 c	0.0 a	0.0 a	0.0 a
glyphosate + triclopyr	-	41.8 e	50.5 d	52.3 d	4.3 c	4.5 b	5.0 b
glyphosate + 2,4-D	-	48.3 d	43.3 e	32.8 f	2.3 b	4.5 b	5.3 b
glyphosate + dicamba	diquat	58.3 b	65.8 c	73.0 c	0.0 a	0.0 a	0.0 a
glyphosate + triclopyr	diquat	55.8 b	62.5 c	66.3 c	3.0 b	3.3 b	3.8 b
glyphosate + 2,4-D	diquat	54.5 c	53.0 d	44.3 e	1.3 b	3.0 b	4.0 b
	Mean	61.1	66.0	64.8	1.5	2.0	2.5
	F	*	*	*	*	*	*

DAA: days after sequential application.

* Means followed by the same letter in the column do not differ by Scott & Knott's test, at the 5% probability level.

Table 9 - Control and emergence (plants m^{-2}) of *C. sumatrensis* m^{-2}. 2019 off-season, Palotina, PR (experiment IV).

1st application	Sequential application	Control (%) at DAA			Plants m^{-2} at DAA		
		14	28	42	28	35	42
Control (without weeding)	-	0.0 e	0.0 c	0.0 d	9.5 b	9.8 c	11.3 c
glyphosate + 2,4-D	glyphosate + saflufenacil/imazethapyr	81.0 a	82.0 a	71.8 b	0.5 a	0.5 a	1.3 b
glyphosate + 2,4-D	glufosinate + imazethapyr/flumioxazin	81.3 a	87.0 a	83.0 a	0.3 a	0.5 a	3.0 b
glyphosate + 2,4-D	glufosinate + diclosulam	78.8 b	80.8 a	73.8 b	0.0 a	0.3 a	1.0 a
glyphosate + 2,4-D	glufosinate + sulfentrazone/diuron	79.5 b	86.5 a	84.3 a	0.3 a	0.5 a	1.8 b
glyphosate + 2,4-D	glufosinate	79.5 b	88.5 a	84.5 a	0.0 a	1.0 b	2.0 b
glyphosate + dicamba + imazethapyr/flumioxazin	glufosinate	78.8 b	88.5 a	93.0 a	0.0 a	0.0 a	0.3 a
glyphosate + dicamba + diclosulam	glufosinate	77.3 c	86.0 a	90.8 a	0.0 a	0.0 a	0.0 a
glyphosate + dicamba + sulfentrazone/diuron	glufosinate	77.8 c	88.0 a	87.5 a	0.0 a	0.0 a	0.0 a
glyphosate + dicamba + atrazine/mesotrione	glufosinate	77.0 c	84.3 a	85.3 a	0.0 a	0.0 a	0.3 a
glyphosate + imazethapyr/flumioxazin	glufosinate	74.5 d	68.3 b	57.5 c	0.0 a	1.3 b	2.3 b
glyphosate + diclosulam	glufosinate	77.5 c	69.8 b	58.8 c	0.0 a	0.0 a	0.3 a
glyphosate sulfentrazone/diuron	glufosinate	76.5 c	66.5 b	56.8 c	0.0 a	1.3 b	2.3 b
glyphosate + atrazine/mesotrione	glufosinate	77.5 c	75.0 b	67.5 b	0.0 a	0.0 a	0.0 a
glyphosate + dicamba	glufosinate	79.8 b	89.8 a	95.8 a	0.0 a	0.0 a	0.0 a
glyphosate + triclopyr	glufosinate	78.8 b	87.8 a	93.8 a	0.0 a	0.3 a	0.5 a
	Mean	73.5	76.8	74.0	0.7	1.0	1.7
	F	*	*	*	*	*	*

DAA: days after sequential application.

* Means followed by the same letter in the column do not differ by Scott & Knott's test, at the 5% probability level.

Pre-emergent herbicides are fundamental in weed resistance management as they allow the rotation of herbicides and mechanisms of action (Knezevic et al., 2019). In addition, they have proved to be selective and highly safe for soybean cultivation in this and several other studies. Nevertheless, the carryover potential depends on several factors related to the herbicide, the soil, environmental conditions, and subsequent crop. The planning of crop rotation should be meticulous to avoid damage and allow the pre-emergent herbicides to show residual activity until closing the interrow of the crop, controlling weed emergence flows, especially of *Conyza* spp. when considering that the Period Before Interference of this species for soybeans is 24 days (Silva et al., 2014).

4. Conclusions

Dicamba was the most effective among synthetic auxins, when applied only with glyphosate, without sequential application. With sequential application of glufosinate, dicamba and triclopyr showed the highest efficacy among all treatments. Glufosinate showed better control when applied sequentially compared to saflufenacil.

Pre-emergent herbicides were effective only if combined with dicamba in the first application or with sequential glufosinate. All reduced the emergence of *C. sumatrensis*, with emphasis on diclosulam and atrazine/mesotrione.

Pre-emergent, synthetic auxins, and burndown herbicides were shown to be potentially selective for soybeans, with low symptoms of injury.

Authors'contributions

Conceptualization of the manuscript and development of the methodology: R.M.C., L.P.A., and A.J.P.; data collection and curation: R.M.C., M.T.Y.D., and J.B.L.; data analysis: R.M.C., M.T.Y.D. and J.B.L.; data interpretation: R.M.C. and L.P.; funding acquisition and resources: L.P.A. and A.J.P.; project administration: R.M.C.; supervision: L.P.A.; writing the original draft of the manuscript: R.M.C. and A.F.M.S.; writing, review and editing: L.P.A., A.F.M.S., and L.P.A. All authors read and agreed to the published version of the manuscript.

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