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Efficacy of pre-emergence herbicides in controlling Sumatran fleabane (*Conyza sumatrensis*) in the off-season

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Abstract. Pre-emergence herbicides can be effective in controlling Sumatran fleabane (*Conyza sumatrensis* [Retz.] E.Walker) at soybean and other crops. The goal was to evaluate the effectiveness of sulfentrazone/diuron, imazethapyr/flumioxazin, flumioxazin, diclosulam, s-metolachlor, imazethapyr, clomazone and imazapic/imazapyr in controlling Sumatran fleabane for application in the off-season before soybean planting. Three experiments were conducted in the off season, with 9 treatments. The control of Sumatran fleabane was evaluated at 28, 42 and 49 days after application (DAA), at 49 DAA was performed counting of plants per m^2. In experiment 1, the worst performance was found for s-metolachlor (58.3% final control), in a situation of lower emergence flow of Sumatran fleabane, with equivalence for the other herbicides. In experiments 2 and 3, with greater emergence flow of Sumatran fleabane, clomazone efficacy stood out ($\geq$ 86.3% final control). A micro-encapsulated formulation of clomazone was used, which causes greater intoxication to this weed due to its slow release into the soil, and presents less loss to the environment. In conditions of lower emergence of Sumatran fleabane, sulfentrazone/diuron, imazethapyr/flumioxazin, flumioxazin, diclosulam, imazethapyr, clomazone and imazapic/imazapyr were effective in controlling it. Even in this condition, s-metolachlor was not effective in controlling Sumatran fleabane. The application of clomazone was effective in controlling Sumatran fleabane in the three experiments. Clomazone is characterized as an important herbicide for use in the off season in the management of this weed before soybean sowing.

Key words: clomazone, early management, *Erigeron sumatrensis*, weed, weed emergence.

INTRODUCTION

Sumatran fleabane (*Conyza sumatrensis* [Retz.] E.Walker sin.: *Erigeron sumatrensis* Retz.) is a species native to South America. It is highly adapted to no-till systems, and the correct identification helps to make the correct management decision and prevents the selection of herbicide-resistant biotypes (Bajwa et al., 2016). It can produce hundreds of thousands of viable seeds, which helps in its dispersal, since they are easily carried by the wind and animal fur (Dauer et al., 2006).

Another aspect that makes it difficult to control this weed is cases of resistance to herbicides, which can even increase production costs (Baccin et al., 2022). In Brazil, there are cases of Sumatran fleabane with multiple resistance to chlorimuron and glyphosate (Santos et al., 2014), simple resistance to paraquat (Zobiole et al., 2019), in addition to cases of single or multiple resistance to these and other herbicides (photosystem II inhibitors and synthetic auxins) (Albrecht et al., 2020a; Queiroz et al., 2020).

Off-season weed control is generally recommended in areas where the fallow period is long, and the soil is uncovered. The objective is to control the seed bank in the soil, to control weeds at the initial stages of development, mainly species that already show tolerance or resistance to the mechanisms of action of herbicides used in post-emergence. In areas after harvesting off season maize, this control is carried out mainly at the beginning of winter. This management is used in southern Brazil, mainly aiming at controlling *Conyza* spp. The combination of residual and non-selective herbicides is of great importance, since the period until planting the new crop is long (Oliveira Neto et al., 2010).

For *Conyza* spp. to be effectively controlled in the off-season, a set of strategies must be adopted, including herbicides with different mechanisms of action, cover crops with a high potential for leaving straw in the soil (Gerhards & Schappert, 2020; Oliveira et al., 2020), and crop rotation, among other techniques at integrated management (Sharma et al. 2021). The use of herbicides should be prioritized in the early stages of the plant and/or pre-emergence, to control the seed bank and small plants, as the larger they are, the more difficult the control (Santin et al., 2019; Bottcher et al., 2022).

Pre-emergence herbicides are critical in managing weed resistance as they allow rotation of herbicides and mechanisms of action (Knezevic et al., 2019). The use of pre-emergence herbicides is also fundamental in reducing weed emergence in the field, helping post-emergence control (Jovanović et al., 2020), which provides a competitive advantage to the crop due to the extension of the period prior interference (PPI) (Knezevic et al., 2019). Previous studies by Budd et al. (2016) and Barnes et al. (2017) highlight the effectiveness of pre-emergence herbicides in soybean weed control under different growing conditions. Examples of pre-emergence herbicides include imazapic, imazapyr, imazethapyr, diclosulam, sulfentrazone, diuron, clomazone, flumioxazin, s-metolachlor, among others. These herbicides can be effective in controlling Sumatran fleabane, for application in the off-season, which is normally dry, before soybean planting.

It was aimed to evaluate the effectiveness of sulfentrazone/diuron, imazethapyr/flumioxazin, flumioxazin, diclosulam, s-metolachlor, imazethapyr, clomazone and imazapic/imazapyr in controlling Sumatran fleabane for application in the off-season before soybean planting.

MATERIALS AND METHODS

Site description

Three experiments were conducted in the municipality of Ubiratã, state of Paraná, Brazil, in the off-season before soybean sowing. Experiment 1 was carried out in 2020 (24º33'S 52º58'W), experiment 2 in 2020, and experiment 3 in 2021, both in the same area (24º28'S 52º52'W). Soils at the sites were classified as clayey (Santos et al., 2018). The climate of the region is mesothermal humid subtropical - Cfa, according to the Koppen classification (Aparecido et al., 2016). Meteorological conditions during the experiments are illustrated in Fig. 1.

Prior to conducting the experiments, maize was cultivated in the three areas. 10 days before the treatments were applied, glufosinate (500 g ai ha^{-1}, Finale®) was applied to the total area, in addition to manual weeding, so that the experiment was installed in an area free from the presence of emerged weeds. In order to guarantee the evaluation of the effect of the treatments only in the pre-emergence of the weeds.

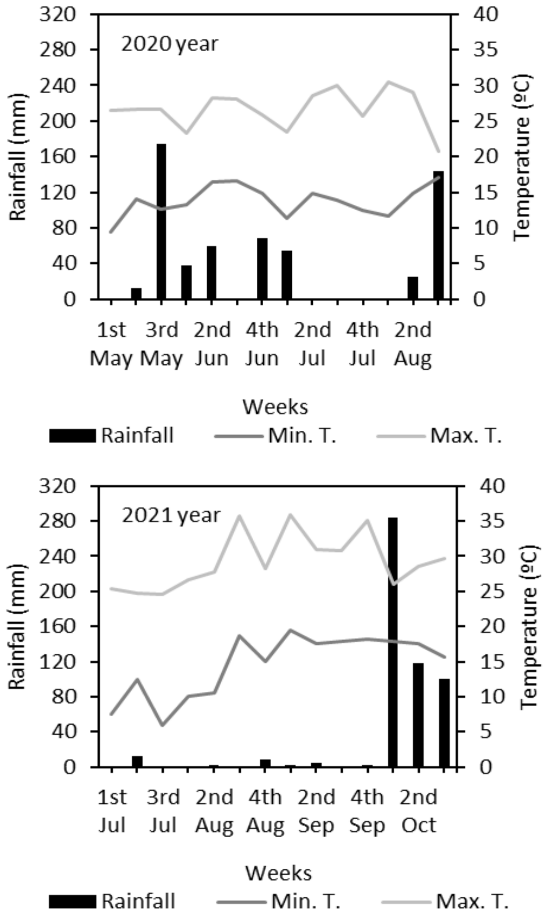

Figure 1. Rainfall, minimum and maximum temperatures during experiments conducted. Ubiratã, PR, Brazil, 2020 and 2021.

Experimental design

This was a randomized block design with four replications; the experimental units were composed of 3×5 m plots. The 9 treatments were composed by the application of the herbicides sulfentrazone/diuron (245/490 g active ingredient [ai] ha^{-1}, Stone®), imazethapyr/flumioxazin (120/60 g acid equivalent [ae]/ai ha^{-1}, Zethamaxx®), flumioxazin (60 g ai ha^{-1}, Flumyzin® 500 SC), s-metolachlor (1,920 g ai ha^{-1}, Dual Gold®), diclosulam (35 g ai ha^{-1}, Spider®), imazethapyr (100 g ae ha^{-1}, Vezir® 100), clomazone (1,080 g ai ha^{-1}, Reator® 360 CS), imazapic/imazapyr (78.75/26.25 g ae ha^{-1}, Amplexus™) and untreated control.

In experiment 1, treatments were applied on June 29, 2020, under a temperature (T) of 15.5 °C, relative humidity (RH) of 73% and wind of 14 km h^{-1}. For experiment 2, the application was carried out on July 10, 2020, under T of 13.8 °C, air RH of 63% and wind of 15 km ha^{-1}. Experiment 3 was applied on August 27, 2021, under T of 15 °C, air RH of 92% and wind of 13 km h^{-1}. Herbicides were applied using a CO_2 pressurized backpack sprayer at a constant pressure of 2 bar, equipped with hand boom with 6 fan nozzles (XR 110.02, Teejet®) at a height of 50 cm from the target, with a spray volume of 150 L ha^{-1}.

Evaluations and data collection

Sumatran fleabane control was evaluated at 28, 42 and 49 days after application (DAA), using a visual scale from 0 (no symptoms) to 100% (plant death) (Velini et al., 1995). Weeds of other species were eliminated by manual weeding, with control notes referring only to Sumatran fleabane. At 49 DAA, the number of Sumatran fleabane plants m^{-2} was counted in 0.25 m^2 per plot.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) by F-test ($P \leq 0.05$), the experiments were analyzed separately. The mean values of the treatments were subjected to Tukey's test, at the 5% level. These tests were run in the Sisvar 5.6 software (Ferreira, 2011).

RESULTS AND DISCUSSION

ANOVA indicated a significant effect by *F*-test ($P \leq 0.05$) for treatments on all variables (Table 1). Thus, the Tukey's test at the 5% level was applied and the results for each experiment are presented in sequence.

Table 1. Summary of the ANOVA for the variables of the three experiments

		Control			Density (Plants m^{-2})
		28 DAA (%)	42 DAA	49 DAA	
Exp. 1	F (treatments)	89.6	64.4	51.6	749.6
	P	*	*	*	*
	CV (%)	8.3	9.8	11.2	8.8
	Mean	78.2	76.6	75.9	2.5
Exp. 2	F (treatments)	22.1	13.4	72.8	3.4
	P	*	*	*	*
	CV (%)	22.5	32.4	17.1	21.1
	Mean	54.3	44.0	34.7	8.7
Exp. 3	F (treatments)	6.1	12.7	16.7	13.0
	P	*	*	*	*
	CV (%)	36.0	30.2	33.2	31.5
	Mean	49.3	51.7	38.1	10.1

Degrees of freedom: 8 for treatments, 3 for block replication. * $P \leq 0.05$, means of the treatments differ from each other.

In experiment 1, the application of sulfentrazone/diuron, imazethapyr/flumioxazin, flumioxazin, diclosulam, imazethapyr, clomazone presents efficacy ≥ 81.3% in all evaluations. At 49 DAA, the efficacy of s-metolachlor in controlling Sumatran fleabane was 58.3%, being the least effective and superior only to the untreated control (0%), other herbicides did not differ from each other, with efficacy of 81.3–95%. The control results corroborate what was verified for plant density m^{-2}, with higher density for the untreated control (9.3 plants m^{-2}). Among the herbicide treatments, the highest number of plants m^{-2} was observed for s-metolachlor (6 plants), only lower than the untreated control, for the other treatments no differences were detected with a maximum of 1.3 plants m^{-2} (Table 2).

Table 2. Pre-emergence control of Sumatran fleabane at 28, 42, 49 days after application (DAA) and plant density (experiment 1).

Herbicide	Rate[1] (g ia ha^{-1})	28 DAA (%)	42 DAA	49 DAA	Density (Plants m^{-2})
Untreated control	-	0.0 c	0.0 c	0.0 c	9.3 c
Sulfentrazone/diuron	245/490	87.5 a	86.3 a	90.0 a	1.0 a
Imazethapyr/flumioxazin	120/60	95.0 a	95.0 a	95.0 a	1.0 a
Flumioxazin	60	92.5 a	91.3 a	91.3 a	1.0 a
S-metolachlor	1,920	66.3 b	64.8 b	58.3 b	6.0 b
Diclosulam	35	93.8 a	86.3 a	92.5 a	1.0 a
Imazethapyr	100	85.0 a	81.3 ab	81.3 a	1.3 a
Clomazone	1,080	87.5 a	88.8 a	85.0 a	1.0 a
Imazapic/imazapyr	78.75/26.25	90.0 a	90.0 a	90.0 a	1.0 a

[1] Rates at g ae ha^{-1} for imazethapyr, imazapic, and imazapyr. Means with same letter do not differ each other by Tukey's test ($P \leq 0.05$).

The effectiveness of clomazone in experiment 2 stood out, it was the only treatment among the most effective in all evaluations of control of Sumatran fleabane. At 49 DAA, clomazone showed an efficacy of 91.3%, in absolute values the second highest efficacy was observed for the application of imazethapyr/flumioxazin, with 46.3%, while the least effective herbicides were flumioxazin (26.3%), imazethapyr (25%), and imazapic/imazapyr (15%), that were superior only to the untreated control (0%). The effectiveness of clomazone was also observed in plant density, with 1.5 Sumatran fleabane plants m^{-2}, which differed from untreated control and sulfentrazone/diuron application with 14.3 and 13.5 plants m^{-2}, respectively (Table 3).

Table 3. Pre-emergence control of Sumatran fleabane at 28, 42, 49 days after application (DAA) and plant density (experiment 2)

Herbicide	Rate[1] (g ia ha^{-1})	28 DAA (%)	42 DAA	49 DAA	Density (Plants m^{-2})
Untreated control	-	0.0 e	0.0 e	0.0 e	14.3 b
Sulfentrazone/diuron	245/490	82.5 a	42.5 cd	33.8 bc	13.5 b
Imazethapyr/flumioxazin	120/60	62.5 abc	40.0 cd	46.3 b	4.8 ab
Flumioxazin	60	25.0 de	32.5 cde	26.3 cd	10.8 ab
S-metolachlor	1,920	50.0 bcd	45.0 cd	32.5 bc	7.8 ab
Diclosulam	35	65.0 abc	65.0 ab	42.5 b	7.3 ab
Imazethapyr	100	40.0 cd	62.5 ab	25.0 cd	10.0 ab
Clomazone	1,080	88.8 a	88.8 a	91.3 a	1.5 a
Imazapic/imazapyr	78.75/26.25	75.0 ab	20.0 de	15.0 d	8.3 ab

[1] Rates at g ae ha^{-1} for imazethapyr, imazapic, and imazapyr. Means with same letter do not differ each other by Tukey's test ($P \leq 0.05$).

In experiment 3, at 28 DAA, no differences were detected between the herbicides in the control of Sumatran fleabane. Diclosulam and clomazone were among the most effective in all control evaluations. At 49 DAA, the effectiveness of clomazone was 86.3%, superior to the other treatments, except for diclosulam, with 57.5% control. In agreement with the observed for the control efficacy, for the application of clomazone at 49 DAA, 1.8 Sumatran fleabane plants m^{-2} were observed, while for the untreated control, 17.5 plants m^{-2} were observed (Table 4).

Table 4. Pre-emergence control of Sumatran fleabane at 28, 42, 49 days after application (DAA) and plant density (experiment 3)

Herbicide	Rate[1] (g ia ha^{-1})	28 DAA (%)	42 DAA	49 DAA	Density (Plants m^{-2})
Untreated control	-	0.0 b	0.0 d	0.0 d	17.5 d
Sulfentrazone/diuron	245/490	63.8 a	75.0 ab	37.5 bc	5.0 ab
Imazethapyr/flumioxazin	120/60	67.0 a	58.8 ab	37.5 bc	16.3 cd
Flumioxazin	60	47.5 a	16.3 cd	17.5 cd	11.3 bcd
S-metolachlor	1,920	45.0 a	47.5 bc	37.5 bc	15.8 cd
Diclosulam	35	55.0 a	67.5 ab	57.5 ab	4.0 ab
Imazethapyr	100	52.5 a	61.3 ab	53.8 b	8.8 abc
Clomazone	1,080	75.0 a	87.5 a	86.3 a	1.8 a
Imazapic/imazapyr	78.75/26.25	37.5 ab	51.3 abc	15.0 cd	10.3 bcd

[1] Rates at g ae ha^{-1} for imazethapyr, imazapic, and imazapyr. Means with same letter do not differ each other by Tukey's test ($P \leq 0.05$).

In experiment 1, there were no new emergence flows of Sumatran fleabane before 28 DAA. Thus, with lower plant density all herbicide treatments were effective in controlling this weed in the off-season, except for s-metolachlor. Studies suggest that *Conyza* seeds are prone to be positive photoblastic and easily emerge from the soil surface without crop residues (Yamashita et al., 2016; Loura et al., 2020). The high retention of crop residues on the soil surface in no-till systems can inhibit the germination of Sumatran fleabane (Mahajan et al., 2021). Rotation with cover crops that leave straw in sufficient quantity and/or uniformity on the soil is a way to reduce the emergence of *Conyza* spp. (Lamego et al., 2013). This helps to explain the lower germination of Sumatran fleabane in the area of experiment 1, added to the smaller seed bank present in this area, under these conditions the combination of soil cover with pre-emergence herbicides is very effective in controlling this weed.

Pre-emergence herbicides can show variable effectiveness depending on the weed species. Diclosulam, for example, is effective in controlling broadleaf species, such as *Conyza* spp., but with the worst performance in controlling grasses (Golubev, 2021), and the opposite can be observed for s-metolachlor (Soltani et al., 2019). This helps to explain the effectiveness of some of the herbicides tested and the low effectiveness of s-metolachlor in controlling Sumatran fleabane in this study.

Experiments 2 and 3 were conducted at the same site in the years 2020 and 2021, respectively. A greater emergence flow of Sumatran fleabane was verified, in a condition of higher incidence of plants, clomazone was the most effective. Other studies highlight the effectiveness of clomazone, especially in the control of grasses (Bond et al., 2014; Correia & Resende, 2018; Ghirardello et al., 2022). Clomazone is a member of the F3 group (isoxazolidinone), carotenoid biosynthesis inhibitors. Herbicides of this group act on enzymatic sites of the carotenoid synthesis pathway, the inhibition of these pigments results in the characteristic symptom of depigmentation (Ferhatoglu & Barrett, 2006; Dayan & Zaccaro, 2012). These herbicides have a broad spectrum of action, but with greater action on grasses.

Few studies have observed the effectiveness of clomazone for *Conyza* spp., when detected, it is mainly in mixtures with other herbicides or in low infestations. Santiago et al. (2018) reported the effectiveness of clomazone (1,080 g ai ha^{-1}) in mixtures with ametryn (2,000 g ai ha^{-1}), metribuzin (480 g ai ha^{-1}), or flumioxazin (80 g ai ha^{-1}) in pre- or early post-emergence of *Conyza* spp., at cassava crop. This demonstrates the relevance of the present study and suggests clomazone (micro-encapsulated formulation) as an important herbicide in the pre-emergence control of Sumatran fleabane at off-season.

A relevant point in this result is the formulation of clomazone used. The micro-encapsulated formulation causes greater weed intoxication due to its slow release into the soil. This formulation has a greater movement capacity in the straw on the soil and is more concentrated on the surface, which results in less loss to the environment (Mendes et al., 2020). Common formulations used in other treatments are readily available molecules and are more susceptible to degradation and leaching losses. In dry conditions, the micro-encapsulated formulation has better control than other formulations and is safer for the environment and for the subsequent crop (Tropaldi, et al., 2019).

CONCLUSIONS

In conditions of lower emergence flow of Sumatran fleabane, sulfentrazone/diuron, imazethapyr/flumioxazin, flumioxazin, diclosulam, imazethapyr, clomazone and imazapic/imazapyr were effective in controlling it. Even in this condition, s-metolachlor was not effective in controlling Sumatran fleabane.

The application of clomazone was effective in controlling Sumatran fleabane in the three experiments, especially in areas with high infestation and in the dry period. Clomazone is characterized as an important herbicide for use in the off-season in the management of this weed before soybean sowing.

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