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RESEARCH ARTICLE

Weed management with pre-emergent herbicides in soybean crops

Helis Marina Salomão[1]*, **Michelangelo Muzell Trezzi**[1], **Matheus Viecelli**[2], **Fortunato De Bortoli Pagnoncelli Junior**[2], **Felipe Patel**[2], **Leticia Damo**[3] and **Gilvane Frizzon**[2]

[1]Federal University of Technology, Pato Branco, PR, Brazil.
[2]Independent Agronomist, Brazil.
[3]Federal University of Viçosa, Viçosa, MG, Brazil.
Correspondence to: helissalomao@gmail.com

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ABSTRACT

The use of pre-emergent herbicides in soybean crops is fundamental, among other reasons, to maintain a clean crop in the initial stages, alter mechanisms, and consequently manage weed resistance. However, there is a considerable demand for information about the efficiency and selectivity of systems with residual herbicides applied in different modalities. This study evaluated the efficiency and selectivity of pre-emergent herbicides doses applied singly or mixed in a tank on soybean crops. The experiment was installed in randomized block design with 21 treatments and four repetitions. The treatments were composed of weeded and unweeded witnesses and pre-emergent application of isolated S-metolachlor or the herbicides diclosulam, flumioxazin, and sulfentrazone isolated or together with S-metolachlor in different doses with the addition of post-emergent S-metolachlor (soybean stage V2). Associations of residuals herbicides applied in pre-emergence or sequential mode increased the control levels of mono and dicotyledonous weeds. The treatments, including single or associated diclosulam and the systems with S-metolachlor sequentially, caused the most significant toxicity (up to 17%) for soybeans. High doses of S-metolachlor (2592.0 g ha^{-1}), diclosulam (33.6 g ha^{-1}), and the associations of S-metolachlor + diclosulam, S-metolachlor + flumioxazin, and S-metolachlor + diclosulam with sequential S-metolachlor should be avoided to obtain higher levels of soybean yield. The use of pre-emergent herbicides demonstrated to be an efficient and viable option to control weeds in soybean crops.

Highlighted Conclusions

1. The association of residual herbicides generally increases the control levels of mixed natural infestations of mono and dicotyledons weeds.
2. It is possible to associate the grain yield of a soybean crop with the control efficiency of weed species and the toxicity of herbicides in the crop.

INTRODUCTION

Soybean is one of the most important crops in world agribusiness. Brazil is this grain world's largest producer, with 114.27 million tons in the 2019 harvest, followed by the United States, producing 96.79 million tons (FAO 2020).

The increased technologies offered to soybean enabled its yield enlargement, although there are still high losses by competitions with weeds or pest attacks and diseases (Ferreira et al. 2012). The weeds interfere through competition for resources, such as water, light, nutrients, carbon dioxide, physical space, among other factors (Galon et al. 2018). They provoke mixed stress, causing biochemical and physiological alterations in competing plants (Rockenbach et al. 2018; Caverzan et al. 2019).

Herbicide application is the most common method for weed control due to its efficiency, speed, and lower cost compared with other control methods. However, its excessive and inappropriate use has caused several negative impacts, such as the toxicity to the crop, environmental impacts, and weeds resistance to herbicides (Acciaresi and Principiano 2020). New cases of weed resistance to herbicides are often reported (Heap 2021). The biological knowledge of weed species and resistance confirmation contribute to adequate preventive and curative management measures. The use of different management strategies must be planned and implemented to prevent new cases of resistance. The alternation of herbicides action mechanisms is a fundamental preventive strategy to which the use of pre-emergent herbicides has a significant contribution (Baucom 2019).

In soybeans, the biotype control of *Conyza* spp., *Digitaria insularis*, *Lolium multiflorum* resistant to glyphosate has led to the intensification of alternative herbicides belonging to the inhibitors of ACCase and ALS, with consequent cases of multiple resistance (Heap 2021). The application of pre-emergent herbicides in soybean crops is an efficient practice to control dicotyledonous weeds, such as flax-leaf fleabane (*Conyza* spp), blackjack (*Bidens* spp.), broadleaf buttonweed (*Borreria latifolia*), Brazil pusley (*Richardia brasiliensis*), among others (Agostinetto et al. 2015; Santin et al. 2019), and grassy weeds (Nunes et al. 2018; Coradin et al. 2019). The pre-emergent chemical management in soybeans becomes relevant for weeds of easy control in early applications. They affect the early development of seed germination, reducing the number of plants in the area, making positioning more accessible, and increasing post-emergency applications' efficiency. The application of pre-emergent herbicides must be prioritized in soybean crops. The use of ALS inhibitors, from Protox, and aerial part growth inhibitors, among others, can be intensified to reduce problems regarding glyphosate resistance.

Pre-emergent herbicides are frequently used to provide residual protection against weeds that germinate in the areas, reducing the selection pressure generated by post-emergent herbicides (Creamer and Dabney 2002; Rosario-Lebron et al. 2019). Sequential applications of different mechanisms can increment the control of weeds that grow in distinct flows, enabling higher levels of control. However, the residual effect may damage the crop, principally when using herbicide mixtures that can provoke synergism, additivity, or antagonism effects (Agostinetto et al. 2016; Kruse et al. 2006). Therefore, studies about management programs regarding efficiency and selectivity are necessary to evaluate different alternatives.

Then, this study aims to evaluate the efficiency and selectivity of pre-emergent herbicide doses applied singly or mixed in a tank in soybean crops.

MATERIAL AND METHODS

The experiment was conducted during the 2017/18 harvest in a rural area of the Nova Prata do Iguaçu, in the Southwest Region of the state of Paraná (25°38'8" S and 53°20'43" W, localized at 457m of altitude). The climate is classified as Cfa (Köppen and Geiger, 1985), subtropical climate, with hot summers, and temperatures above 22ºC in summer with more than 30 mm of rain in the driest months.

The randomized blocks experimental design was used with 21 treatments (Table 1) and four repetitions. The treatments were composed by the application of herbicides S-metolachlor (Met), diclosulam (Dic), flumioxazin (Flu), sulfentrazone (Sul), and associations of S-metolachlor + diclosulam, and S-metolachlor associated with flumioxazin and sulfentrazone, besides a weeded and unweeded witnesses. The treatments were made in two moments: in S1, during seeding (plant-apply system), and in S2 when plants reached the V2 stage (first trifoliate leaf fully expanded). Some treatments were made only in S1, while others occurred at both times. The applied doses of isolated and associated herbicides vary according to the application moment.

The cultivar BMX Elite was used in the density of 222,000 plants ha^{-1}, sown in the second half of October 2017. Each experimental unit comprised seven rows with 5 m of length and row spacing of 0.45 m. The studied area consisted of three center rows, and the 0.5 m ends were considered borders. Before sowing, the area was desiccated with glyphosate + clethodim (1440 + 180 g ha^{-1}) and sequential application of paraquat + diuron (400 + 200 g ha^{-1}) aiming to eliminate all plants present in the area, such as *D. insularis* and *B. pilosa*. The application of herbicides was conducted with a backpack CO_2 sprayer, with a bar containing six fan-type spray tips 110.02, resulting in a total spray volume of 200 L ha^{-1}. The environmental conditions during the application are described in Table 2.

Forty-three days after applying the sowing treatments (E1) (DAA), the weed count was conducted with two samples per plot with an area of 0.25 m^{-2} in each. This area was posteriorly extrapolated to 1 m^2. They were grouped in Monocotyledon (MN) (*Digitaria insularis, Eleusine indica, Uruchloa plantaginea, D. horizontalis Lolliun sp., Avena sativa*), Dicotyledon (DC) (*Raphanus sp., Amaranthus sp., Ipomoe sp., Sida sp., Euphorbia heterophylla, Commelina sp., Solanum americanum, Thalia geniculata, Stachys arvensis, Portulaca oleracea, Cyperus, Oxalys sp., Richardia brasiliensis, Borreria latifólia, Galinsoga parviflora)*, totals (TT), and *Bidens pilosa* (BP), the predominant species in the area. At 43 DAA, plant height (ALT) and toxicity on soybean plants (FT) were determined following the scale of Frans et al. (1986).

When soybean plants reached physiological maturation, the final stand (EF) was determined. Ten plants randomly removed from each plot were used to determine the yield components: number of pods per plant (NVP), number of grains per pod (NGV), and 1000-grain weight (MMG). In the useful area of each plot, the grain yield (RF) was determined.

The normality analysis of residuals and homogeneity of variances was conducted using the methods of Shapiro-Wilk and O'Neill-Mathews. The weeds' density variables (MN, DC, TT, and BP) were transformed through the square root plus a constant due to the absence of weeds in some treatments (value zero). The variable GY was transformed by the Box-Cox method. Posteriorly, data were submitted to ANOVA, and, if significant, the averages were grouped by the Scott-Knott test ($p \leq 0,05$). Posteriorly, Pearson correlation analysis was conducted with the software RStudio.

Table 1. Treatments used, doses (g.i.a. ha^{-1}), comercial product and dose of the commercial product used in the experiment to control natural weed infestation in soybean crop. Pato Branco, 2020.

	Trataments	Dose g.i.a ha^{-1}	Commercial product	Dose L or g ha^{-1}
1	Control	-	-	-
2	Control weeded	-	-	-
3	S-metolachlor (Met) in E1[1/]	1728	Dual Gold	1,8 L (1x)[3/]
4	S-metolachlor in E1	2592	Dual Gold	2,7 L (1,5x)
5	Diclosulam (Dic) in E1	25,2	Spider	30 g (1x)
6	Diclosulam in E1	33,6	Spider	40 g (1,3x)
7	S-metolachlor in E1 and in E2[2/]	1728/ 1440	Dual Gold/ Dual Gold	1,8L / 1,5L (0,8x)
8	S-metolachlor + diclosulam in E1	1728 + 25,2	Dual Gold + Spider	1,8L + 30g
9	S-metolachlor + diclosulam in E1	1728 + 33,6	Dual Gold + Spider	1,8L + 40g
10	S-metolachlor + diclosulam in E1	2592 + 25,2	Dual Gold + Spider	2,7L + 30g
11	S-metolachlor + diclosulam in E1	2592 + 33,6	Dual Gold + Spider	2,7L + 40g
12	S-metolachlor + diclosulam in E1 / metolachlor in E2[3/]	1920 + 25,2 / 1440	Dual Gold + Spider / Dual Gold	1,8L+ 30g / 1,5L
13	S-metolachlor + diclosulam in E1 / metolachlor in E2	1920 + 33,6 / 1440	Dual Gold + Spider / Dual Gold	1,8L+ 40g / 1,5L
14	Flumioxazin (Flu) in E1	45,0	Sumisoya	90g (1x)
15	S-metolachlor + flumioxazin in E1	1728 + 45,0	Dual Gold + Sumisoya	1,8L + 90g
16	S-metolachlor + flumioxazin in E1	2592 + 45,0	Dual Gold + Sumisoya	2,7L + 90g
17	S-metolachlor + flumioxazin in E1 / metolachlor in E2	1920 + 45,0 / 1440	Dual Gold + Sumisoya/ Dual Gold	1,8L+ 90g / 1,5L
18	Sulfentrazone (Sul) in E1	600	Boral	1,2L (1x)
19	S-metolachlor + sulfentrazone in E1	1728 + 600	Dual Gold + Boral	1,8L + 1,2L
20	S-metolachlor + sulfentrazone in E1	2592 + 600	Dual Gold + Boral	2,7L + 1,2L
21	S-metolachlor + sulfentrazone in E1 / S-metolachlor in E2	1920 + 600 / 1440	Dual Gold + Boral/ Dual Gold	1,8L+ 1,2L / 1,5L

[1/]E1: application at sowing time; [2/]E2: soybean V2 application; [3/] x: commercial dose.

Table 2. Temporal conditions at the time of application of treatments at times E1 and E2. Pato Brando, 2020.

Moments	Start time (h)	UR (%)	Wind speed (km h^{-1})	Temperature (°C)
E1	10:20	78	4	28
E2	9:30	84	3	25

E1: application at sowing time; E2: soybean V2 application.

RESULTS AND DISCUSSION

The variables that presented no significance to the treatment were plant height (ALT), final stand (EF), number of grains per pod (NGV), and number of pods per plant (NVP) (Table 3). For weeds' density evaluations, high values of CV were observed due to the area's natural infestation, which is often uneven.

Table 3. Variation factors (FV) and mean square error (QME) for weed variables, with density of monocotyledonous weeds (MN), dicotyledons (DC), *Bidens pilosa* (BP) and totals (TT), and for soybean plants, with plant height (ALT), phytotoxicity (FT), final stand (EF), number of pods per plant (NVP), weight of a thousand grains (PMS), number of grains per pod (NGV) and final yield (RF) in response to the application of pre-emergent herbicides isolated, mixed and sequentially with different doses in the soybean crop. Pato Branco, 2020.

FV	Mean square error (QME)										
	MN	DC	BP	TT	ALT	FT	EF	NVP	MMG	NGV	RF
Treatment	5.73**	13.5**	6.5**	20.8**	2.4	3618.0**	300.6	65.3	39.8**	0.05	2966 .10^{9*}
Block	4.6	61.1**	76.8**	58.6**	37.6	176.4*	60.2	67.2	61.7**	0.01	4545.7 .10^{9*}
Residue	2.4	3.9	3.5	4.3	2.8	1275.3	281.5	65.2	20.5	0.01	1514.6 .10^{9}
CV (%)[1/]	78.6	54.4	49.6	33.1	4.7	62.8	9.0	14.04	3.12	4.83	23.07

* Significant by F test (p≤0,05). ** Significant by F test (p≤0,01). [1/] Coefficient of variation.

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All the treatments showed efficiency to control the monocotyledonous weeds (MN), not differing from the weeded witness (Table 4). Regarding the density of dicotyledonous weeds (DC) and total (TT), the treatments with better results were those with S-metolachlor + diclosulam, S-metolachlor + sulfentrazone, and when were added to these treatments and S-metolachlor + flumioxazin in S1 a sequential application with S-metolachlor in E2.

Table 4. Density of monocotyledonous (MN), dicotyledonous (DC), total (TT) and Bidens pilosa (BP) weeds of the soybean cultivar BMX Elite in response to the application of pre-emergent herbicides isolated, in mixture and in sequential with different doses. Pato Branco, 2020.

Treatment	MN(m^{-2})		DC(m^{-2})		TT(m^{-2})		BP(m^{-2})	
Control	51.86	a	86.43	a	138.29	a	38.00	a
Control weeded	0.00	b	0.00	c	0.00	c	0.00	b
Met 1x	7.41	b	29.64	b	37.05	b	12.00	a
Met 1,5x	2.47	b	32.11	b	34.58	b	8.00	b
Dic 1x	9.88	b	24.70	b	34.58	b	24.00	a
Dic 1,3x	7.41	b	27.16	b	34.57	b	16.00	a
Met 1x / Met 0,8x	7.41	b	12.35	c	19.76	b	4.00	b
Met ,1x + Dic 1x	7.41	b	44.45	b	51.86	b	30.00	a
Met 1x + Dic 1,3x	0.00	b	4.94	c	4.94	c	2.00	b
Met 1,5x + Dic 1x	4.94	b	19.75	c	24.69	c	22.00	a
Met 1,5x + Dic 1,3x	0.00	b	7.41	c	7.41	c	4.00	b
Met 1x + Dic 1x / Met 0,8x	4.94	b	7.41	c	12.35	c	6.00	b
Met 1x + Dic 1,3x / Met 0,8x	2.47	b	14.81	c	17.28	c	14.00	b
Flu 1x	4.94	b	37.04	b	41.98	b	12.00	b
Met 1x + Flu 1x	2.47	b	12.35	c	14.82	c	14.00	a
Met 1,5x + Flu 1x	7.41	b	24.70	b	32.11	b	18.00	a
Met 1x + Flu 1x / Met 0,8x	2.47	b	9.88	c	12.35	c	4.00	b
Sulf 1x	7.47	b	14.82	c	22.29	b	4.00	b
Met 1x + Sulf 1x	0.00	b	14.82	c	14.82	c	12.00	b
Met 1,5x + Sulf 1x	0.00	b	0.00	c	0.00	c	0.00	b
Met 1x + Sulf 1x / Met 0,8 x	0.00	b	4.94	c	4.94	c	6.00	b

Means followed by the same letter in the column do not differ by Scott-Knott test ($p \leq 0.05$).

The associations of herbicides or sequential applications generally provided higher levels of control than the isolated products tested, revealing the importance of using herbicides with more than one action mechanism. This type of application broadens the spectrum and improves weed control efficiency, hindering the occurrence of resistance (Vidal et al. 2016).

The treatments that presented a higher reduction in plant density of *Bidens pilosa* (BP) (Table 4), the species abundant in the area, were the use of isolated S-metolachlor in its higher dose (1.5x) and the sequential treatments with S-metolachlor (0.8x). The treatments with the higher dose of diclosulam (1.3x) associated with S- metolachlor demonstrated high efficiency. The same occurred with the use of isolated flumioxazin and isolated sulfentrazone or associated with S-metolachlor.

The height of soybean plants (ALT) did not differ between treatments, showing an overall average of 36.04 cm (data not presented). Phytotoxicity (FT) (Table 5) was absent only in the treatment of isolated flumioxazin. However, this treatment was not efficient in controlling dicotyledonous weeds and totals. The treatments that provided higher levels of phytotoxicity to soybean plants were the ones with diclosulam and sequential applications of S-metolachlor herbicide, independently of their doses. The association of S-metolachlor (1x) with flumioxazin (1x), followed by one application of S-metolachlor (0.8x), besides being superior in weed control, was selective regarding the crop, revealing that, although there was some phytotoxic effect, it not impacted the final yield negatively.

Tabela 5. Phytotoxicity (FT), weight of a thousand seeds (PMS) and final yield (RF) of the soybean cultivar BMX Elite in response to the application of pre-emergent herbicides isolated, in mixture and in sequential with different doses. Pato Branco, 2020.

Treatment	Variables					
	FT(Visual)		MMG (g)		RF (kg ha^{-1})	
Control	0.00	c	142.79	b	2800.00	b
Control weeded	0.00	c	149.88	a	3457.02	a
Met 1x	10.75	b	145.20	a	3363.58	a
Met 1,5x	8.75	b	146.28	a	3025.93	b
Dic 1x	20.00	a	149.98	a	3503.09	a
Dic 1,3x	20.00	a	139.49	b	2841.98	b
Met 1x / Met 0,8x	18.75	a	142.78	b	2870.80	b
Met ,1x + Dic 1x	15.00	a	147.20	a	3372.47	a
Met 1x + Dic 1,3x	17.50	a	151.08	a	3774.07	a
Met 1,5x + Dic 1x	16.25	a	142.08	b	3452.47	a
Met 1,5x + Dic 1,3x	18.75	a	143.22	b	3094.06	b
Met 1x + Dic 1x / Met 0,8x	20.00	a	146.14	a	3213.58	b
Met 1x + Dic 1,3x / Met 0,8x	20.00	a	142.13	b	2878.40	b
Flu 1x	2.50	c	147.59	a	3668.52	a
Met 1x + Flu 1x	9.25	b	142.82	b	2998.02	b
Met 1,5x + Flu 1x	7.50	b	146.46	a	3109.81	b
Met 1x + Flu 1x / Met 0,8x	17.50	a	146.22	a	3343.21	a
Sulf 1x	9.75	b	144.43	b	3385.80	a
Met 1x + Sulf 1x	11.25	b	150.77	a	3306.15	a
Met 1,5x + Sulf 1x	6.75	b	144.95	b	3259.88	a
Met 1x + Sulf 1x / Met 0,8 x	17.50	a	143.65	b	3237.56	a

Means followed by the same letter in the column do not differ by Scott-Knott test ($p \leq 0.05$).

Regarding the final stand (EF), number of pods per plant (NVP), and number of grains per pod (NGV), there were no differences between treatments, with an overall average of 186.54 thousand plants ha^{-1}, 57.54 pods, and 2.21 grains per pod. This fact shows that the herbicides used and the ongoing weed infestation did not cause soybean plants' death or losses on yield components. However, the 1000-grain weight (MMG) was negatively affected by several treatments: isolated diclosulam 1.3x (-7%); two sequential doses of S-metolachlor (Met 1x / Met 0,8x) (-5%); S-metolachlor + diclosulam (regardless the dosage used); Met 1x + Dic 1,3x / Met 0,8x; Met 1x + Flu 1x; Sulf 1x; Met 1,5x + Sulf 1x; e Met 1x + Sulf 1x / Met 0,8 x. However, the losses of MMG can be considered low, with values varying between 3 and 7%, compared with the weeded witness.

From the 19 herbicide treatments tested, eight of them (Met 1,5x; Dic 1,3x; Met 1x / Met 0,8x; Met 1,5x + Dic 1,3x; Met 1x + Dic 1x / Met 0,8x; Met 1x + Dic 1,3x / Met 0,8x; Met 1x + Flu 1x e Met 1,5x + Flu 1x) negatively impacted grain yield, with losses varying between 7 and 17% (Table 5). Concerning the final yield (RF) of these treatments with weed infestation and the phytotoxicity (FT) (Table 5), the treatments of S-metolachlor 1.5x and S-metolachlor 1.5x + flumioxazin 1x were mainly affected by the high density of dicotyledonous weeds, which is expected for treatments with isolated S-metolachlor. Only the highest dose of isolated S-metolachlor influenced FY negatively, which can be associated with physiological alterations induced by the herbicide, which affected the plant metabolically. However, no visible morphological alterations were verified (Barros et al. 2014).

The treatments with isolated diclosulam (Dic 1.3x), in sequential use during V2 of S-metolachlor (Met 1x / Met 0,8x), associations of S-metolachlor with diclosulam (Met 1,5x + Dic 1,3x) or flumioxazin (Met 1x + Flu 1x e Met 1,5x + Flu 1x), and S-metolachlor + diclosulam followed by other sequential applications of S-metolachlor (Met 1x + Dic 1x / Met 0,8x e Met 1x + Dic 1,3x / Met 0,8x) presented a higher negative effect on the crop, negatively impacting grain yield. It is noteworthy that the treatment with diclosulam applied in isolation (Dic 1.3x) caused phytotoxicity to the crop, and it did not satisfactorily control broadleaf weeds. It is also important to highlight that the treatments with S-metolachlor in pre-emergency (1.0 x 1.5x) did not successfully control dicotyledonous species, and its application in any stage (isolated or sequential) also generated more expressive toxicity to soybeans.

The inefficiency in weed control may have caused grain yield losses (Met 1,5x e Met 1,5x + Flu 1x), phytotoxicity of herbicides (Met 1,5x + Dic 1,3x; Met 1x + Flu 1x; Met 1x + Dic 1x / Met 1x e Met 1x + Dic 1,3x / Met 1x), or low levels of weed control together with crop phytotoxicity (Dic 1.3x and Met 1x/Met 1.5x) that favored weeds over soybeans.

The use of diclosulam during soybean pre-emergence in the recommended doses does not reduce soybean yield. However, higher doses can provide high phytotoxic action affecting the yield (Osipe et al. 2013; Gazola et al. 2016; Braz et al. 2017; Krenchinski et al. 2019). The application of S-metolachlor and flumioxazin in pre-emergency provide total control of monocotyledonous plants, as bitter grass; diclosulam also presents high efficiency in the volunteer corn control (Coradin et al. 2019). A study conducted by Nunes et al. (2018) verified that, despite the phytotoxic effect provided by S-metolachlor to soybean plants, it controlled a broad spectrum of small seed weeds in pre-emergency, and its residual period does not affect crop yield. Then, it reduces weeds in the area, diminishing the need for pre-emergent herbicide and the probability of occurring resistance.

The interaction arising from the combination of pesticides can influence plant response, characterized as synergistic, antagonistic, and null (Polito et al. 2021). When the association of herbicides results in higher control of weed species than the sum of isolated effects of herbicides, then synergism is characterized. However, synergism also can occur in cultivated species, causing an increase in phytotoxicity (Viecelli et al. 2017). In the associations with S-metolachlor, only with Dic 1x, Flu 1x / Met 0.8x, and sulfentrazone (1x), there was no decrease in grain yield (Table 6).

Table 6. Summary of the effects of S-metolachlor (Met) alone and when associated with other chemical treatments on soybean grain yield of cultivar BMX Elite. Pato Branco, 2020.

Association	/ Met 0,8x	Dic 1x	Dic 1,3x	Dic 1x / Met 0.8x	Dic 1,3x / 0.8x	Flu 1x	Flu 1x / Met 0,8x	Sul 1x	Sul 1x / Met 0,8x
Met 1x	-[1/]	x[2/]	-	-	-	-	x	x	x
Met 1,5x	*[3/]	+	-	*	*	-	*	-	*

[1/] Negative effect of the association compared to Met 1x isolated; [2/] No significant difference observed compared to Met 1x isolated; [3/] Association not tested in the experiment; The (-) and (x) effects were determined according to the Scott-Knott cluster test (Table 4) for p≤0.05.

The other associations were harmful to the crop because they increased the phytotoxic effect of Met 1x isolated. The alteration of herbicide doses association may also affect its synergistic response in plants (Zhang et al. 1995; Dalazen et al. 2015), as observed with S-metolachlor 1.5x + Sul 1x that produced a negative effect, differently from the corresponding treatment with Met 1x.

The negative effect of flumioxazin associated with both doses of S-metolachlor on grain yield is highlighted. However, the use of flumioxazin + S-metolachlor followed by a sequential application of Met 0.8x did not result in the effect described above. This may be due to the higher control of weed species in the sequential application, which was enough to overcome the phytotoxic impact and maintain the yield. Association of herbicides with flumioxazin are known as enhancers of monocotyledonous weed control compared with the isolated applications (Andrade et al. 2020).

The association effect of Dic (1.0x or 1.3x) to S-metolachlor was different from the one observed with Flu (1x). For Dic (1.0x or 1.3x), there was a derogatory effect on grain yield when the sequential application of Met (0.8x) increased. This grain yield decrease may be explained by the increased toxicity to soybean plants, resulting from the sequential application of Met (0.8x) (Table 7).

Table 7. Summary of the effects of (Dic), flumioxazin (Flu) and sulfentrazone (Sul) isolated and when associated with S-metolachlor (Met) for soybean grain yield of the cultivar BMX Elite. Pato Branco, 2020.

Association	Met 1x	Met 1,5x	Met 1x / Met 0,8x
Dic 1x	x	x	-
Dic 1,3x	x	x	-
Flu 1x	-[1/]	-	x
Sul 1x	x[2/]	x	x

[1/] Negative effect of the association compared to Flu or Dic isolated; [2/] No significant difference observed compared to Sul 1x isolated; The (-) and (x) effects were determined according to the Scott-Knott cluster test (Table 4) for p≤0.05.

The use of herbicide mixtures can have beneficial effects, aiding the management of plants hard to control. This fact allows the reduction of application costs, applicator exposure, soil compaction, and increases weed control at the beginning of a crop (Vidal et al. 2016). However, it depends on the dose and products used, application strategies, biological characteristics of weeds, and the soybean cultivar.

In conclusion, the use of pre-emergent herbicides was an efficient and viable option for weed control in soybean crops; pre-emergent residual herbicides in an association or sequential manner generally increased the control levels of natural weed infestations; still, they presented a higher toxicity risk to soybeans than their isolated application; residual herbicides must be applied in the recommended doses, and sequential applications of s-metolachlor must be avoided to prevent yield losses.

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