

Selectivity of pre-and post-emergence herbicides to very-early maturing soybean cultivars

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Abstract

The combination of pre- and post-emergence herbicides may affect their selectivity to soybean plants, especially to short-cycle cultivars. The objective of this work was to evaluate the selectivity of pre- and post-emergence herbicides to very-early maturing soybean cultivars. Two field experiments were conducted, one in Mandaguaiçu, Paraná (E1) and other in Rio Verde, Goiás (E2), Brazil, using a 4×7 factorial arrangement. The treatments consisted of four pre-emergence herbicide managements (S-metolachlor at 1440 g ha⁻¹, diclosulam at 25.2 g ha⁻¹, sulfentrazone at 300 g ha⁻¹, and no herbicide application); and seven post-emergence herbicide managements (lactofen at 120 g ha⁻¹, chlorimuron-ethyl at 12.5 g ha⁻¹, bentazon at 720 g ha⁻¹, lactofen at 120 g ha⁻¹ + chlorimuron-ethyl at 12.5 g ha⁻¹, glyphosate at 900 g a. e. ha⁻¹, two sequential glyphosate applications at 720 g a. e. ha⁻¹ each, and no herbicide application). The early-maturing soybean cultivars evaluated showed sensitivity to the herbicides used. The combined use of pre- and post-emergence herbicides increased the occurrence of injuries in the plants. Diclosulam and sulfentrazone were the least selective pre-emergence herbicides. All herbicide combinations used affected soybean grain yield in E1; lactofen, chlorimuron, and bentazon presented the least selectivity in E2.

Keywords: diclosulam, *Glycine max*, glyphosate, weed management

Introduction

The selection of resistant weeds to glyphosate in Brazil, especially *Conyza* spp. and *Digitaria insularis* (Heap, 2016), made the weed control more complex and farmers to use management systems with applications of pre- and post-emergence herbicides. Systems including combined applications of residual herbicides, such as sulfentrazone, diclosulam, and S-metolachlor, following applications of post-emergence herbicides, such as glyphosate, have been used to manage weeds that are difficult to control—resistant or tolerant to herbicides (Lopes-Ovejero et al., 2013).

The effect of herbicides can be

detrimental to soybean plants under certain conditions, causing injuries and decreasing their productivity (Santos et al., 2007; Alonso et al., 2010). The extent and intensity of these herbicide-induced injuries can vary depending on edaphoclimatic conditions, such as precipitation, soil carbon content, texture, and pH, and level of susceptibility of soybean cultivars to herbicides (Taylor-Lovell et al., 2001; Belfry et al., 2015). The use of very-early maturing soybean cultivars with sequential applications of pre- and post-emergence herbicides has raised concerns about their selectivity. Apparently, very-early maturing soybean cultivars are more susceptible to herbicides than cultivars with longer cycles

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(Zobiolo et al., 2010).

Sulfentrazone, diclosulam, and S-metolachlor are pre-emergence herbicides frequently applied to soybean crops. They are described as selective for soybean crops, however, sulfentrazone can affect the growth and yield of some cultivars (Taylor-Lovell et al., 2001; Belfry et al., 2016), especially when combined with post-emergence herbicides. Diclosulam is selective when applied to medium to clayey soils (Gazola et al., 2016), but it may reduce the soybean grain yield when applied to soils with surface compaction (Biffe, 2012). S-metolachlor occasionally causes some initial phytotoxicity, but does not affect soybean growth and yield, presenting good selectivity to this crop (Mahoney et al., 2014; Belfry et al., 2015).

The main post-emergence herbicides available for soybean crops are inhibitors of PROTOX, ALS, and EPSPs. Post-emergence inhibitors of PROTOX and ALS can cause leaf injuries such as chlorosis and necrosis, affecting the plant development and productivity (Alonso et al., 2010). Glyphosate (EPSPs inhibitor) is the most commonly used herbicide in genetically modified soybean cultivars (Roundup Ready®) and may have negative effects on nutrient uptake and plant growth (Bott et al., 2008; Zobiolo et al., 2010).

The objective of this work was to evaluate

the selectivity of pre- and post-emergence herbicides to very-early maturing soybean cultivars in weed management systems.

Material and Methods

Two field experiments were conducted in no-tillage system in the 2014/2015 crop season, using very-early maturing soybean cultivars recommended for the Southwest of Goiás (GO) and North of Paraná (PR), Brazil.

The first experiment (E1) was conducted in Mandaguaçu, PR (23°14'34.21"S; 52°00'21.21"W; and 442 m of altitude) in soil with clayey texture. The soil analysis (0.00 to 0.20 m layer) presented pH in CaCl₂ of 4.9, 17 g dm⁻³ of total carbon, 640 g kg⁻¹ of clay, 141 g kg⁻¹ of silt, 83 g kg⁻¹ of fine sand, and 136 g kg⁻¹ of coarse sand.

Experiment 2 (E2) was conducted in Rio Verde, GO (17°45'49.11"S; 51°01'54.52"W; and 840 m of altitude) in a soil with clay loam texture. The soil analysis (0.00 to 0.20 m layer) presented pH in CaCl₂ of 5.1, 19 g dm⁻³ of total carbon, 328 g kg⁻¹ of clay, 91 g kg⁻¹ of silt, 124 g kg⁻¹ of fine sand, and 457 g kg⁻¹ of coarse sand.

Precipitation and temperature during the experiments are shown in Figure 1.

Manual weeding was performed when necessary during the soybean crop cycle to maintain all plots always free from weeds to avoid their interference on the results.

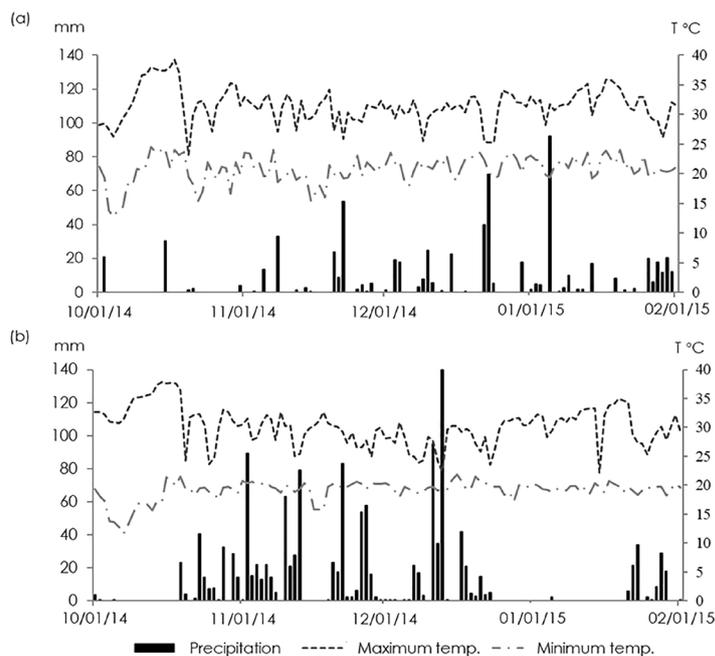


Figure 1. Precipitation and temperature data collected during the experiment period in Mandaguaçu, Paraná (a) and Rio Verde, Goiás (b), Brazil.

The experiments were conducted in randomized block designs, using a 4×7 factorial arrangements, with 8 replications. The treatments consisted of four pre-emergence herbicide managements (S-metolachlor at 1440 g ha⁻¹, diclosulam at 25.2 g ha⁻¹, sulfentrazone at 300 g ha⁻¹, and no herbicide application); and seven post-emergence herbicide managements (lactofen at 120 g ha⁻¹, chlorimuron-ethyl at 12.5 g ha⁻¹, bentazon at 720 g ha⁻¹, lactofen at 120 g ha⁻¹ + chlorimuron-ethyl at 12.5 g ha⁻¹, glyphosate at 900 g a. e. ha⁻¹, two sequential glyphosate applications at 720 g a. e. ha⁻¹ each, and no herbicide application), totaling 28 treatments.

The experimental plots were 4.00 m long and 4.00 m wide (16 m²) and the central 9 m² of the plots were considered for evaluation.

The soybean cultivars used were FPS

Iguaçu (E1) and NA 5909 RR (E2). These cultivars have indeterminate growth habit, beginning of reproductive phase at 30 to 45 days, and an expected cycle of 100 to 105 days (Fundação Pró Sementes, 2016; Sementes Goiás, 2016).

Applications of 400 g ha⁻¹ of paraquat were performed before the implementation of the experiments to kill the emerged weeds. Information about the soybean cultivars and cultural practices used are shown on Table 1. Pest and disease controls were performed when necessary to avoid interference of them on the results.

The herbicides were applied using a CO₂ pressurized sprayer with five single fan jet nozzles (XR-110.02) spaced 0.5 m apart, solution volume of 180 L ha⁻¹, and spray pressure of 2.0 kgf cm⁻² (Table 2).

Table 1. Dates of seeding, emergence, and harvest of soybean plants, and cultural practices used.

	Experiment 1	Experiment 2
Location	Mandaguaçu, PR	Rio Verde, GO
Cultivar	FPS IGUAÇU RR	NA 5909 RR
Seeding date	11/07/2014	10/30/2014
Emergence date	11/12/2014	11/04/2014
Harvest date	01/31/2015	01/21/2015
Space between rows (cm)	0.45	0.5
Seed density ha ⁻¹	400000	360000
N-P-K fertilizing (kg ha ⁻¹)	0 - 60 - 60	6 - 60 - 54

Table 2. Application of pre-emergence and post-emergence herbicides for soybean plants.

	Mandaguaçu, PR (E1)			Rio Verde, GO (E2)		
	Pre	Post	Seq	Pre	Post	Seq
Application day	11/10/14	12/03/14	12/18/14	10/31/14	11/29/14	12/12/14
Days after seeding	0	23	38	0	29	42
Air relative humidity	68	85	72	72	55	88
Air temperature (°C)	23	22	30.4	29	31	28.5
Wind speed (km h ⁻¹)	0.2	2	1.3	0.5	1.5	3.5
Soil moisture	wet	wet	wet	wet	wet	wet
Hours/depth (h/mm) *	42/1	24/5	72/40	04/5	06/32	06/140
Days after seeding	3	24	38	1	28	41

Pre = application of pre-emergence herbicide; Post = application of post-emergence herbicide; Seq = sequential application of post-emergence herbicides; * hour of the first precipitation event after the herbicide application, and precipitation depth.

Soybean leaf injuries caused by the herbicides used were evaluated visually, based on a 0% to 100% scale, wherein 0% is equivalent to no damage, and 100% is equivalent to the death of all plants (SBCPD, 1995). Plants in E1 were evaluated at 15 days after the pre-emergence application (DAA_{PRE}) and at 7, 22, and 37 days after the post-emergence applications (DAA_{POST}). Plants in E2 were evaluated at 15 DAA_{PRE} and at 1, 16, and 31 DAA_{POST}.

Plant height was evaluated before the soybean harvest using five random plants of the evaluation area of the plots. The plants in the central three meters of the four central rows of each plot (6 m²) were manually harvested and threshed. Grain moisture was determined using an electric moisture meter and corrected to 14% moisture to evaluate grain yield (kg ha⁻¹).

The data were analyzed using the Shapiro Wilk normality test. The 4×7 factorial arrangement

was subjected to analysis of variance, in which the pre-emergence herbicides were factor 1 and the post-emergence herbicides were the factor 2. Significant results were subjected to the Scott-Knott test ($p \leq 0.05$).

Results and Discussion

Toxicity of herbicides to soybean plants

Plants in Experiment 1 (E1) treated with pre-emergence application of diclosulam (25.2 g ha⁻¹) presented higher injuries (5.1%) at 15 DAA_{PRE} than those treated with the other pre-emergence herbicides. Plants in Experiment 2 (E2) presented similar results, with 7% of injuries, and shrinkage of younger trifoliate leaves (data not presented). Symptoms were similar in both experiments, regardless of the variations in soil and precipitation, and soybean cultivars.

Plants in E1 treated with sulfentrazone (300 g ha⁻¹) had 3.4% of injuries, reduced size, and leaf chlorosis. Plants in E2 treated with sulfentrazone had 29% of injuries (data not shown). Sulfentrazone is an inhibitor of the protoporphyrinogen oxidase enzyme (PROTOX) and has low mobility in the soil; it concentrates mainly in the soil surface layer and, when there is a contact between plants and treated soil surface, they may present tanning and necrosis, and delayed development, even in species that are tolerant to herbicides (Oliveira Jr., 2011). Soils with high moisture and pH and low clay content generate more intense toxic

effects of sulfentrazone on plants since the availability of this herbicide in the soil solution is concentrated on the soil surface (Blanco et al., 2010). The highest percentage of injuries of plants in E2 caused by sulfentrazone was probably due to the lower soil clay content (324 g kg⁻¹) of this experimental area, and the occurrence of precipitation on the day of application (28 mm), and on the following five days after the pre-emergence herbicide application (141 mm). Contrastingly, the soil of the E1 is clayey (640 g kg⁻¹ of clay), and no precipitations occurred until ten days after application of the pre-emergence herbicides, thus, reducing herbicide activity and concentration in the soil solution. Osipe et al. (2014) evaluated the selectivity of diclosulam and sulfentrazone to soybean using the same rates used in the present study and observed leaf injuries and reduction in the stand of plants. S-metolachlor (1440 g ha⁻¹) was the most selective herbicide in E1 and E2 in the same evaluation (15 DAA_{PRE}) (data not shown). Similar results for S-metolachlor selectivity was found in other studies, with no injuries in soybean plants, even when using higher rates (up to 3,200 g ha⁻¹) in pre-emergence applications (Mahoney et al., 2014; Belfry et al., 2015).

Regarding the post-emergence herbicides, no injuries were found in plants in E2 at 1, 16, and 31 DAA_{POST}. The interaction between pre-emergence and post-emergence herbicides was significant for plants in E1 (Table 3).

Table 3. Percentage of injuries in soybean plants (FPS Iguauçu RR cultivar) caused by pre-emergence and post-emergence herbicides, at 7 days after the post-emergence applications. Mandaguaçu, Paraná, Brazil, 2014/2015 crop season.

Post-emergence herbicide	Pre-emergence herbicide			
	S-metolachlor	Diclosulam	Sulfentrazone	NHA
Lactofen	6.9 Bb	14.4 Ab	8.1 Bb	6.3 Bb
Chlorimuron ¹	2.5 Bc	10.6 Ac	4.0 Bc	2.5 Bc
Bentazon ¹	0.0 Ac	0.6 Ad	0.0 Ad	0.0 Ac
Lactofen + Chlorimuron ²	20.0 Ba	23.8 Aa	21.3 Ba	18.8 Ba
Glyphosate	0.0 Ac	0.6 Ad	1.3 Ad	0.0 Ac
Glyphosate - Glyphosate ³	8.1 Ab	9.4 Ac	8.8 Ab	6.9 Ab
NHA	0.0 Ac	0.0 Ad	0.0 Ad	0.0 Ac
CV (%)	30.28			

Means followed by the same uppercase letter in the rows or lowercase letter in the columns do not differ by the Scott-Knott test ($p \leq 0.05$). S-metolachlor (1440 g ha⁻¹); diclosulam (25.2 g ha⁻¹); sulfentrazone (300 g ha⁻¹); lactofen (120 g ha⁻¹); chlorimuron-ethyl (12.5 g ha⁻¹); bentazon (720 g ha⁻¹); lactofen (120 g ha⁻¹) + chlorimuron-ethyl (12.5 g ha⁻¹); glyphosate (900 g a. e. ha⁻¹); NHA = No herbicide application; ¹ = addition of mineral oil (Assist 0.5% v/v); ² applied together in a mixed solution; ³ two sequential applications of glyphosate (720 g a. e. ha⁻¹ each); CV = coefficient of variation.

Regarding the post-emergence herbicides, Lactofen (120 g ha⁻¹) + chlorimuron (12.5 g ha⁻¹), and lactofen (120 g ha⁻¹) caused the greatest injuries to soybean plants at 7 DAA_{POST} in all

combinations with the pre-emergence herbicides (S-metolachlor, diclosulam, sulfentrazone), and with no application of pre-emergence herbicide. However, the greatest injuries were found in

plants treated with diclosulam (Table 3). The high percentage of injuries caused by lactofen may be due to its mechanism of action (inhibitor of PROTOX), which causes lipid peroxidation and, consequently, loss of chlorophyll and rupture of membranes, generating necrosis and chlorotic points in leaves (Oliveira Jr., 2011). Effects of lactofen on soybean plants are usually more expressive soon after its application, with occurrence of high percentages of injuries at 7 days after application, and reduced toxicity from the emission of new leaves (Galon et al., 2007), as observed at 22 and 37 DAA_{POST} (data not shown).

The treatment with two sequential application of glyphosate caused mild chlorosis to the leaves. When glyphosate is applied to genetically modified soybean plants (Roundup Ready®), it may cause immobilization of bivalent

and trivalent cations, decreasing the Fe and Mn contents in leaf tissues, generating chlorosis (Zobiolo et al., 2010). Despite the injuries caused to the plants, a single application of glyphosate or bentazon presented higher selectivity compared to the other post-emergence herbicides, not differing from the treatment with no herbicide application.

Plant height

The interaction between the factors (pre- and post-emergence herbicides) was significant (Table 4) for plant height at preharvest. The combination of S-metolachlor with chlorimuron resulted in higher plant heights than the other combinations of pre-emergence herbicides with post-emergence application of chlorimuron.

The combination of diclosulam with

Table 4. Soybean plant heights before harvest as a function of applications of pre-emergence and post-emergence herbicides. Mandaguaçu, Paraná (E1) and Rio Verde, Goiás (E2), Brazil, 2014/2015 crop season.

Post-emergence herbicide	E1 (FPS Iguazu RR)			
	Pre-emergence herbicide			
	S-metolachlor	Diclosulam	Sulfentrazone	NHA
Lactofen	98 Aa	97 Aa	96 Aa	84 Bb
Chlorimuron ¹	98 Aa	90 Ba	88 Ba	91 Ba
Bentazon ¹	99 Aa	85 Bb	92 Aa	93 Aa
Lactofen + Chlorimuron ²	92 Ab	92 Aa	91 Aa	84 Ab
Glyphosate	92 Ab	92 Aa	78 Bb	96 Aa
Glyphosate – Glyphosate ³	95 Aa	77 Bc	91 Aa	95 Aa
NHA	85 Bb	93 Aa	95 Aa	97 Aa
CV (%)	7.63			
Post-emergence herbicide	E2 (NA 5909 RR)			
	Pre-emergence herbicide			
	S-metolachlor	Diclosulam	Sulfentrazone	NHA
Lactofen	52 Aa	46 Ba	45 Ba	52 Aa
Chlorimuron ¹	50 Ba	46 Ca	45 Ca	55 Aa
Bentazon ¹	51 Ba	51 Ba	48 Ba	55 Aa
Lactofen + Chlorimuron ²	49 Aa	49 Aa	44 Ba	50 Aa
Glyphosate	52 Ba	49 Ba	44 Ca	55 Aa
Glyphosate - Glyphosate ³	51 Aa	52 Aa	48 Aa	55 Aa
NHA	55 Aa	48 Ba	48 Ba	55 Aa
CV (%)	9.17			

Means followed by the same uppercase letter in the rows or lowercase letter in the columns do not differ by the Scott-Knott test (ps0.05). S-metolachlor (1440 g ha⁻¹); diclosulam (25.2 g ha⁻¹); sulfentrazone (300 g ha⁻¹); lactofen (120 g ha⁻¹); chlorimuron-ethyl (12.5 g ha⁻¹); bentazon (720 g ha⁻¹); lactofen (120 g ha⁻¹) + chlorimuron-ethyl (12.5 g ha⁻¹); glyphosate (900 g a. e. ha⁻¹); NHA = No herbicide application; ¹ = addition of mineral oil (Assist 0.5% v/v); ² applied together in a mixed solution; ³ two sequential applications of glyphosate (720 g a. e. ha⁻¹ each); CV = coefficient of variation.

bentazon or with two sequential glyphosate applications in E1 resulted in lower plant heights than the other combinations of diclosulam with post-emergence herbicides. The application of sulfentrazone combined with glyphosate resulted in plants with heights 18 cm lower than those in the treatment with no pre-emergence herbicide application. Osipe et al. (2014) evaluated

the selectivity of this herbicide to soybean plants (V-MAX RR cultivar) and found that pre-emergence application of diclosulam followed by post-emergence application of glyphosate affected the plant height; this effect was not observed for sulfentrazone, with no differences between the treatment with sulfentrazone and post-emergence application of glyphosate and

the treatment with no herbicide application, which differs from the results found in the present study.

The pre-emergence application of diclosulam or sulfentrazone with two sequential post-emergence applications of glyphosate or with single application of glyphosate resulted in lower plant heights when compared to the treatment with no post-emergence herbicide application. Similar results were found in other studies, with glyphosate affecting the soybean plant height (Zobiolo et al., 2010; Casonatto et al., 2014; Osipe et al., 2014). However, when no pre-emergence herbicide was applied or a pre-emergence application of S-metolachlor was applied, the post-emergence application of glyphosate and the treatment with no post-emergence herbicide application had similar results. Similarly, Mendonça Filho et al. (2010) and Basso et al. (2011) evaluated post-emergence application of glyphosate rates up to 1440 g a. e. ha⁻¹ in soybean crops and found no effects of this herbicide on plant height and grain yield.

Plants in E1 with no pre-emergence herbicide application and with single or combined application of lactofen and chlorimuron presented lower heights than plants treated with post-emergence herbicides. These herbicides caused the highest percentages of injuries in the plants and, consequently, affected the final height of plants at preharvest.

No differences in plant height between the post-emergence herbicides applied were found in E2. The plant height varied between 44 and 55 cm, which are smaller than the average heights (65 to 85 cm) described for the NA 5909 RR soybean cultivar (Sementes Goiás, 2016). The water stress occurred during the reproductive period of the soybean (R3 to R5) in E2 (Rio Verde, GO) probably affected the crop development, since water stress in this critical period may affect the plant's growth, reproductive capacity, and cycle (Farias et al., 2007). Despite this water stress, some combinations of pre- and post-emergence herbicides resulted in less selectivity. Pre-emergence applications of diclosulam, and sulfentrazone, and post-emergence application of lactofen, and chlorimuron resulted in lower plant heights than the pre-emergence applications

with S-metolachlor, and with no pre-emergence herbicide application (Table 4). This result denotes the higher selectivity of S-metolachlor. However, plants in treatments with pre-emergence application of S-metolachlor, diclosulam, and sulfentrazone, and post-emergence application of chlorimuron, bentazon, and glyphosate had lower heights than those of the treatment with no pre-emergence herbicide application. The treatment with post-emergence application of glyphosate (900 g ha⁻¹) combined with pre-emergence application of sulfentrazone resulted in the lowest plant heights, followed by the treatments with S-metolachlor, and diclosulam, all presenting lower plant heights than the treatment with no pre-emergence herbicide application. Therefore, the combination of pre- and post-emergence herbicides affect the soybean plant height.

Grain yield

The climatic conditions in E1 (Mandaguaçu, PR) favored the development of soybean plants, with precipitation of approximately 606 mm during the crop cycle, with well distributed rainfalls and no drought periods longer than five days (Figure 1); whereas the E2 (Rio Verde, GO) had no favorable precipitations during the crop cycle, causing water stress during the reproductive period of the soybean plants, reducing the crop cycle in 15 days (Table 2), since the NA 5909 RR cultivar has crop cycles ranging from 100 to 105 days (Sementes Goiás, 2016).

The interaction between pre- and post-emergence herbicides was significant for soybean grain yield in both experiments (Table 5). All combinations of herbicides in E1 resulted in lower grain yield than the treatment with no herbicide application, denoting the negative effects of these combinations on very-early maturing soybean cultivars.

According to Mahoney et al., (2014), the S-metolachlor and sulfentrazone herbicides cause injuries to plants of long-maturing soybean cultivars (118 to 151 days), but with no decrease in grain yield. Apparently, the tolerance of soybean cultivars to sulfentrazone herbicide varies. More tolerant cultivars show no injuries

due to the rapid metabolization of this herbicide, which is stimulated by the oxidative stress caused at the reaction center of the protoporphyrinogen oxidase enzyme (Taylor-Lovell et al., 2001).

Table 5. Soybean grain yield as a function of application of pre-emergence and post-emergence herbicides. Mandaguáçu, Paraná (E1) and Rio Verde, Goiás (E2), Brazil, 2014/2015 crop season.

Post-emergence herbicide	Pre-emergence herbicide			
	E1 (FPS Iguazu RR soybean cultivar)			
	S-metolachlor	Diclosulam	Sulfentrazone	NHA
Lactofen	3093.0 Bb	2905.2 Bc	2859.6 Bc	3558.0 Ac
Chlorimuron ¹	2986.8 Bc	2686.2 Bd	2781.0 Bc	3466.2 Ac
Bentazon ¹	3184.8 Bb	3129.6 Bb	2946.0 Bc	3670.2 Ac
Lactofen + Chlorimuron ²	2814.0 Bc	2643.0 Bd	2667.0 Bc	3108.0 Ad
Glyphosate	3326.4 Bb	3197.4 Bb	3172.2 Bb	3795.0 Ab
Glyphosate – Glyphosate ³	3153.0 Bb	3006.0 Bc	3282.0 Bb	3571.2 Ac
NHA	3773.4 Ba	3489.6 Ba	3575.4 Ba	4150.2 Aa
CV (%)	8.32			
Post-emergence herbicide	E2 (NA 5909 RR soybean cultivar)			
	Pre-emergence herbicide			
	S-metolachlor	Diclosulam	Sulfentrazone	NHA
Lactofen	3196.2 Aa	2790.0 Ba	2569.8 Ba	3397.8 Aa
Chlorimuron ¹	3019.2 Aa	2408.4 Ba	2442.0 Ba	3488.4 Aa
Bentazon ¹	2623.2 Ba	2766.6 Ba	2729.4 Ba	3358.2 Aa
Lactofen + Chlorimuron ²	3112.2 Aa	2830.8 Aa	2464.8 Aa	3045.6 Aa
Glyphosate	3203.4 Aa	2965.8 Aa	2746.8 Aa	3522.6 Aa
Glyphosate - Glyphosate ³	2883.0 Aa	2676.0 Aa	2334.6 Aa	3111.6 Aa
NHA	3436.2 Aa	3089.4 Aa	2994.6 Aa	3655.8 Aa
CV (%)	19.75			

Means followed by the same uppercase letter in the rows or lowercase letter in the columns do not differ by the Scott-Knott test ($p \leq 0.05$). S-metolachlor (1440 g ha⁻¹); diclosulam (25.2 g ha⁻¹); sulfentrazone (300 g ha⁻¹); lactofen (120 g ha⁻¹); chlorimuron-ethyl (12.5 g ha⁻¹); bentazon (720 g ha⁻¹); lactofen (120 g ha⁻¹) + chlorimuron-ethyl (12.5 g ha⁻¹); glyphosate (900 g a. e. ha⁻¹); NHA = No herbicide application; ¹ = addition of mineral oil (Assist 0.5% v/v); ² applied together in a mixed solution; ³ two sequential applications of glyphosate (720 g a. e. ha⁻¹ each); CV = coefficient of variation.

All applications of pre-emergence herbicides in E1 combined with post-emergence applications of lactofen + chlorimuron or chlorimuron caused great grain yield loss. The use of these post-emergence herbicides combined with pre-emergence treatments (S-metolachlor, diclosulam, sulfentrazone, and no herbicide application) presented grain yield losses of 25% (lactofen + chlorimuron) and 21% (chlorimuron), compared to the treatment with no post-emergence herbicide application. The post-emergence applications of lactofen (144 g ha⁻¹) or lactofen (96 g ha⁻¹) + chlorimuron (17,5 g ha⁻¹) cause leaf injuries and reduce the plant development, and post-emergence application of chlorimuron or lactofen with glyphosate cause leaf injuries of 50% and 65%, respectively, with decreases in plant height, and grain yield; however, the toxic effects of these herbicides are reduced when they are applied alone (Alonso et al., 2010). These results agree with those found in the present study, in which the application of lactofen + chlorimuron resulted in low herbicide selectivity, affecting the evaluated

characteristics, including grain yield.

The pre-emergence application of S-metolachlor combined with any of the post-emergence herbicides resulted in lower grain yield than the treatment with pre-emergence application of S-metolachlor with no post-emergence herbicide application. However, applications of lactofen + chlorimuron or chlorimuron were the least selective, presenting plants with grain yields 15.5% lower than those with pre-emergence application of S-metolachlor with no post-emergence herbicide.

All combinations of post-emergence herbicides applied after pre-emergence application of diclosulam or sulfentrazone resulted in grain yield loss when compared to the treatments with only pre-emergence application (diclosulam with no post-emergence herbicide, and sulfentrazone with no post-emergence herbicide). The combination of pre-emergence application of diclosulam with post-emergence application of bentazon (720 g ha⁻¹) or glyphosate (900 g a. e. ha⁻¹) resulted in the lowest grain yield losses, 10% and 8%, respectively. The combinations

of pre-emergence application of sulfentrazone with post-emergence application of glyphosate (one, or two sequential applications) were the most selective, but they decreased grain yields by 8%, and 11%, respectively.

Plants treated with no pre-emergence herbicides, with post-emergence application of glyphosate (one, or two sequential applications) presented grain yield losses of 8.6%, and 14.0%, respectively. The application of pre-emergence herbicides (S-metolachlor, diclosulam, and sulfentrazone) combined with glyphosate (one, or two sequential applications) resulted in grain yield losses 15% and 12%, respectively, compared to the treatment with no pre-emergence herbicide application. Despite the adverse effects on soybean plants, glyphosate is still the most used herbicide for weed management for soybean crops because it presents a broad spectrum of control when compared to the other post emergence herbicides applied. The effects of glyphosate on genetically modified soybean plants (Roundup Ready®) may vary according to the cultivar, maturing group, application time, and rate used (Oliveira Jr. et al., 2008). The evaluated soybean cultivars (FPS Iguaçu RR, and NA 5909 RR) present similar cycle and growth habit, but presented differences in herbicide selectivity. These differences may be related to the tolerance of each cultivar to the herbicides used and to the different edaphoclimatic factors of the evaluated areas.

Santos et al. (2007), Bott et al. (2008), Zobiolo et al. (2010) and Casonatto et al. (2014) reported the toxic effects of glyphosate on genetically modified soybean plants (Roundup Ready®). Plants treated with glyphosate may present leaf chloroses, smaller amounts of root nodules, lower plant heights, and lower nutrient contents. The prevention of the negative effects of glyphosate on RR soybean cultivars has been considered in recent studies, with the use of products that minimize leaf injuries and preserve the plant productive potential (Constantin et al., 2016).

The post-emergence applications of lactofen or chlorimuron combined with pre-emergence applications of diclosulam, and sulfentrazone in E2 resulted in less selectivity when

compared to these herbicides combined with pre-emergence application of S-metolachlor or with no pre-emergence application.

The combination of post-emergence application of lactofen with pre-emergence application of diclosulam, or sulfentrazone decreased grain yield by 18%, and 24%, respectively, when compared to the combination of lactofen with no pre-emergence herbicide, and by 12.7% and 19.6% when this treatment was combined with pre-emergence application of S-metolachlor. The combination of post-emergence application of chlorimuron with pre-emergence application of diclosulam, or sulfentrazone resulted in even higher grain yield losses, 30% lower than that of the combination of chlorimuron with no pre-emergence herbicide.

The pre-emergence herbicides (S-metolachlor, diclosulam, and sulfentrazone) combined with post-emergence application of bentazon, reduced the grain yield in 22%, 18%, and 19%, respectively, when compared to the treatment with no pre-emergence herbicides. The combination of bentazon with the pre-emergence herbicides increased plant injuries. The selectivity of post-emergence application of bentazon + glyphosate is low, presenting leaf injuries and reduced grain yield (Alonso et al., 2010). However, soybean plants have tolerance to bentazon due to metabolization and detoxification processes, reducing the toxic effects of this product (Zhu et al., 2009). The selectivity of bentazon in E1 and E2 was limited, especially when pre-emergence herbicides were used, denoting that the toxicity effects of pre- and post-emergence herbicides can reduce soybean grain yield.

Conclusions

The very-early maturing soybean cultivars FPS Iguaçu, and NA 5909 RR presented sensitivity to the herbicides used.

The diclosulam and sulfentrazone herbicides caused higher percentage of injuries in soybean plants in both experiments than the other pre-emergence herbicides applied; and S-metolachlor presented the highest selectivity.

All pre- and post-emergence herbicides applied to plants in Experiment 1 showed limited

selectivity to the soybean crops, and decreased grain yield when compared to the treatments with no herbicide application. The post-emergence application of chlorimuron + lactofen was the least selective, and glyphosate (900 g a. e. ha⁻¹) was the most selective herbicide to soybean plants.

Combinations of the post-emergence herbicides lactofen, chlorimuron, or bentazon with pre-emergence herbicides in Experiment 2 resulted in low selectivity, and reduced grain yield. The other treatments were selective under the conditions of this experiment.

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