Herbicide resistance technologies in soybean cultivars

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ABSTRACT

The objective of this work was to carry out a technical analysis of the biotechnologies that confer resistance to herbicides in soybeans. Two experiments were carried out (I and II) in the agricultural years 2016/17 and 2017/18, using a randomized block design with six and four replicates. In experiment I, two forms of management in weed control were evaluated for each technology studied (Roundup Ready® and Liberty Link®) and for conventional soybeans, as well as grain yield. In experiment II, the efficiency of using different herbicides to control voluntary soybeans (with and without technology) was evaluated. The pre-emergent herbicides in both managements proposed for the cultivars controlled the weeds from the emergence of the soybean crop to the application of the post-emergent herbicides in both crops. Likewise, all post-emergent herbicides showed weed control above 90% at 14 and 28 days after application. In the evaluation of the chemical control of Garra IPRO voluntary soybean, the herbicide 2,4-D stood out among the others for being more efficient in both agricultural years (above 90%). The herbicides glyphosate, 2,4-D and metsulfuron-methyl are the most effective in controlling voluntary soybean cultivars BRS 284 and CZ16B39LL.

Keywords: Biotechnology. Chemical management. Weeds.

INTRODUCTION

The raise in food production is essential to guarantee the needs of the growing world's population, which already surpass 7 billion inhabitants. The United Nations (UN) projects that the world's population will be 9.7 billion by 2050 and it is estimated that food production should increase by 70% to supply the population's food (FAO, 2018). Currently, the Brazilian agriculture is responsible for feeding 1.5 billion people and needs to be prepared to play its fundamental role in guaranteeing the human life on the planet (Novo Rural, 2018).

Thus, environmental impacts must be reduced and sustainability within productive systems must be pursued. In addition to natural resources, the farmers' knowledge and entrepreneurship combined with technical-scientific contributions from universities and organizations of studies and technical assistance are crucial to ensure the raise in food production. In this sense, in addition to knowing the technological innovations in the agricultural area, it is also important to understand how to manage these new technologies in an appropriate and responsible manner, such as genetically modified crops with resistance to herbicides, aiming at improving productivity rates and economic efficiency.

One of the main concerns of farmers and professionals working with soybeans is the damage caused by weeds, as they compete with the crop for light, nutrients and water, in addition to hindering harvesting processes, acting as hosts for pests and diseases, and exert pressure of an allelopathic nature (Pitelli, 1985). As a result, weeds impair soybean crops management and reduce production potential, directly reflecting the income of the rural producer and the country's economy. This fact encourages experiments on appropriate weed control strategies.

Among the methods currently indicated for the management of weeds in soybean crops, chemical control has been the alternative most used by producers (Salvadori *et al*., 2016). Thus, the advent of technological innovations in herbicide-resistant crops has emerged as an important tool, to facilitate the management of weeds, to ensure growth in productivity indexes in agriculture, with a relevant attribution for the progress of soybean cultivation in the country.

With the aid of advanced biotechnological techniques, Roundup Ready® (RR) soy from Monsanto was launched, the first genetically modified soybean in the country, with an event approved in 1998 (Bulletin CTNBio no. 54 of 1998) and commercialization started in 2005. The RR soybean is resistant to glyphosate, a broad-spectrum herbicide, one of the most used in cultivation systems in the world (KRUZE *et al*., 2000). Another important technology marketed in Brazil is Liberty Link® (LL), which was developed by the company Bayer and recently acquired by BASF. Soybean LL is resistant to ammonium Glufosinate, an herbicide widely used in agriculture on a global scale, due to both its high effectiveness and the broad spectrum of weed control (Brunharo *et al*., 2014).

In this context, the objective of this work was to carry out a technical analysis of the technologies for resistance to herbicides in the soybean crop, seeking to contribute to the better evaluation of these technologies used by the farmers.

MATERIAL AND METHODS

Two experiments were carried out simultaneously over 2016/17 agricultural year and repeated in the 2017/18 agricultural year. The experiments were conducted in the field, at the Technological Center (CETEC) of the company Três Tentos Agroindustrial S/A, located in the municipality of Santa Bárbara do Sul in the northwest region of the state of Rio Grande do Sul.

For the pre-planting desiccation in both agricultural years, the following products were applied: glyphosate at a dose of 1,080 g.e.a. ha^{-1}, saflufenacil at a dose of 49 g.i.a. ha^{-1} and adjuvant. However, in the first year (2016), a previous glyphosate desiccation was performed, at a dose of 1,080 g.e.a. ha^{-1}, followed by sequential application using the products described above.

The use of fertilization practices, crop setting up and phytosanitary management were carried out according to the technical recommendations of the crop described in the South Region Soybean Research Meeting (SALVADORI, 2016). The non-tillage system was used, sowing soybeans in the previous crop, black oats (*Avena sativa*) in 2016 and wheat (*Triticum aestivum*) in 2017. In both agricultural years, sprinkling the herbicide mixture with the treatments were carried out with a backpack sprayer, pressurized with CO_2, equipped with a 2.5 m wide spray bar with six fan-type tips (TT 110015) providing a spray volume equivalent to 100 L ha^{-1}, under environmental conditions suitable for the application.

Soybean cultivars BRS 284 (Conventional) Brasmax Garra-63I64RSF IPRO (RR 2) and CZ16B39LL (LL) were used in both experiments.

Experiment I: Weed control using soybean cultivars with different herbicide-resistance Technologies.

In order to achieve the proposed objectives, it was used 12 treatments resulting from the combination of factors, Soybean Cultivars (Conventional, cultivar BRS 284; Roundup Ready2 Intacta, cultivate Brasmax Garra-63I64RSF IPRO® and Liberty Link®, cultivate CZ16B39LL) with different controls of weeds. Two manners of herbicide control were tested (Management 1 and Management 2) described in Table 1; a control with weeding or manual pulling, aiming to keep free of weeds interference (Clean control); and a witness without weed control (Infested control). The factorial design (3 x 4) followed the randomized block design with 6 replications. The area of each experimental plot was 16.5 m^2 (3 m wide X 5.5 m long), consisting of five rows of soybeans, spaced 0.5 m apart.

In the first agricultural year, millions (*Digitaria horizontalis*), caruru (*Amaranthus retroflexus*) and viola string (*Ipomoea grandifolia*) were sown aiming to homogenize the area with weeds. For the second agricultural year, weeds were not sown in the area, as it showed greater weed uniformity in the experimental area.

Table 1 shows for each cultivar, the pre- and post-emergent herbicides that were used in the treatments regarding Management 1 and Management 2, in which Management 1 was the recommendation of the company owner of the technology and management 2 was the usual alternative recommendation. Herbicide applications were carried out immediately after sowing (pre-emergent herbicides) and at 28 days after sowing the crop (post-emergent herbicides).

Table 1. Treatments used for weed control, with herbicide applications right after sowing (pre-emergent herbicides) and 28 days after planting (post-emergent herbicides).

Control	Pre-emergent herbicide	Dose (a.i.g. ha^{-1})	Post-emergent herbicide	Dose (a.i.g. ha^{-1}) **
		Conventional soubean, Cultivar BRS 284 (1)		
Management 1	Imazetapir Flumioxazin	100 50	Cletodim Clorimurom	84 10
Management 2	Diclosulam	29.4	Bentazona Cletodim	600 84
Clean control	-		-	-
Infested control	-		-	-
		Soybean Roundup Ready2 Intacta, Cultivar Brasmax Garra-63I64RSF IPRO (2)		
Management 1	Flumioxazin	60	Glyphosate	1.080 **
Management 2	Diclosulam	29.4	Glyphosate	1.080 **
Clean control	-		-	
Infested control	-		-	

Soybean Liberty Link, cultivar CZ16B39LL [(3)]				
Management 1	Imazetapyr Flumioxazin	100 50	Glufosinate	500
Management 2	Diclosulam	29.4	Glufosinate Cletodim	400 84
Clean control	-		-	-
Infested control	-		-	-

(1)) Conventional Soybean: with no genetic modification; (2) Soybean RR 2: resistant to the herbicide glyphosate; (3) Soybean Liberty Link: resistant to the herbicide glufosinate.

* Trade name of the herbicides used: Brasagran® (bentazone); Classic®(chlorimurom-ethyl); Liberty® (ammonium glufosinate); Pivot® (imazetapyr); Poquer® (cletodim); Roundup WG® (glyphosate); Spider® (diclosulam); Sumisoya® (flumioxazin). Adjuvants as recommended by the manufacturer.

Weed control, phytotoxicity in soybean culture, weed density, population and soybean grain yield were determined. Weed control and crop phytotoxicity were determined at 14 days after application of treatments (DAA) with pre-emergent herbicides and at 14 and 28 DAA with post-emergent herbicides. The two variables were evaluated visually using a percentage scale, in which, "0" represents the absence of weed control or symptoms of phytotoxicity to the crop and "100" represents the death of all weeds or cropped plants (Frans *et al*., 1986).

The survey of weeds and the population of soybean plants was carried out by counting the plants contained within a 0.5 m x 2.0 m rectangle, a useful area of 1 m^2. The soybean grain yield was estimated through mechanized harvesting of the three central lines, with the aid of a harvester from experimental plots. After harvesting, the grains were weighed to estimate the yield in Kg ha^{-1}, correcting the grain yield to a moisture content of 13%.

Experiment II: Voluntary soybean control using post-emergent herbicides

This experiment was Split into three trials, one for each cultivar used (Conventional, cultivar BRS 284; Roundup Ready2 Intacta, cultivar Brasmax Garra-63I64RSF IPRO; and Liberty Link, cultivar CZ16B39LL) and the treatments used in the control of voluntary soybean described in the Table 2. The experimental design was a randomized block with 4 replications, the area of each experimental plot was 18 m^2 (3 m wide X 6 m long). The herbicides were applied when the soybean plants were in V4 stage of development (third trifoliolate leaf) according to the Fehr and Cavines scale (1977).

Table 2. Treatments applied in post-emergence (V4) in voluntary soybean in the three experimental tests.

Herbicide*	**Dose (a.i.g. ha^{-1}) ** **
Control	-
Glyphosate	720 **
2,4-D	670**
MCPA	360**
Metsulfuron	2.4
Paraquat	300

Diquat	200
Glufosinate	400
Saflufenacil	49

Trade name of the herbicides used: Roundup WG® (glyphosate); DMA® (2,4-D); Agritone® (MCPA); Ally® (metsulfuron-methyl); Helmoxone® (paraquat); Reglone® (Diquat); Finale® (ammonium glufosinate) and Heat® (saflufenacil). Adjuvants as recommended by the manufacturer.

The efficiency of controlling voluntary soybean was visually assessed using a percentage scale (FRANS et al., 1986). The population survey of voluntary plants was carried out at 42 DAA by counting the plants in an area of $1m^2$, with subsequent manual collection of the plants to determine dry matter (DM). The collected samples were submitted to drying in an oven with forced air circulation at a temperature of 60 ºC, until reaching constant mass. Afterwards, the samples were weighed to estimate dry matter, the results expressed in g m^{-2}.

The results of the variables evaluated in the experiment were subjected to analysis of variance and for significant differences by the F test, at 5% error probability. The treatment means were compared by the test of Tukey at 5% error probability.

RESULTS AND DISCUSSION

Weed control using soybean cultivars with different herbicide-resistance technologies

Table 3 shows the results obtained in the evaluation of weed control in the experiments regarded to the 2016/17 and 2017/18 harvests. According to the efficiency scale of Frans et al. (1986) (Appendix A), treatments with an average control greater than 80% (80-89%, satisfactory to good control; 90-99%, very good to excellent control; 100%, total control, considered efficient). Imazetapyr (100 a.i.g. ha^{-1}) and flumioxazin (50 a.i.g. ha^{-1}) were used as pre-emergent herbicides in Management 1 for the cultivars BRS 284 and CZ16B39 LL and for the cultivar Garra IPRO, flumioxazin (60 a.i.g. ha^{-1}); for Management 2, diclosulam (29.4 a.i.g. ha^{-1}) was used for the three cultivars under study. It was observed that the application of these proposed pre-emergent herbicides for each cultivar in Managements 1 and 2 showed satisfactory to very good control (80-90%) from the emergence of soybean cultivation to the application of post-emergent herbicides in both crops.

Such control is important for the establishment of a weed-free crop, as they compete with soybean for light, nutrients and water and reduce their productive potential (Pitelli, 1985). In addition, the efficient control of pre-emergent herbicides makes it possible to postpone and/or reduce the number of herbicide applications in post-emergence of soybean crops, as its residual effect provides the control of different weed emergence flows that are in the soil seed bank (Oliveira *et al*., 2011), which directly reflects in the income of the farmer.

Cletodim (84 a.i.g. ha^{-1}) and chlorimuron (10 a.i.g. ha^{-1}) were used as post-emergent herbicides for BRS 284 in Management 1 and for Management 2, bentazone (600 a.i.g. ha^{-1}) and cletodim (84 a.i.g. ha^{-1}); glyphosate (1080 a.i.g. ha^{-1}) was used for the Garra IPRO cultivar in both managements. For cultivar CZ16B39 LL in Management 1, glufosinate (500 g.i.a.ha^{-1}) was used and in Management 2, clethodim (84 g.i.a.ha^{-1}) was used in addition to glufosinate (400 g.i.a.ha-1).Similar to pre-emergent herbicides, the post-emergent herbicides used in Managements 1 and 2 of each cultivar, presented excellent weed control at 14 and 28 DAA, with means greater than 90%. In addition, the post-emergent herbecides used in both managements did not differ significantly between them and neither in relation to the Control clean treatment. However, when compared to the Control infested treatment, there was a significant difference in relation to weed control

Table 3. Weed control (%) in experiments regarding 2016/17 and 2017/18 crops**.**

Treatments	**Cultivars**			**Mean**
	BRS 284	Garra IPRO	CZ16B39 LL	
	2016/17 crop			
	14 DAA* in pre-emergence			
Management 1	87	86	86	86b
Management 2	86	89	90	89b
Clean control	98	97	95	96a
Infested Control	81	77	80	79c
Mean	88A	87A	88A	
CV (%)	3.8			
	14 DAA in Post-emergence			
Management 1	98Aa	98Aa	99Aa	-
Management 2	99Aa	99Aa	99Aa	-
Clean control	99Aa	93Aa	99Aa	-
Infested Control	64Ab	3Cb	39Bb	-
Mean	-	-	-	
CV (%)	12,1			
	28 DAA in Post-emergence			
Management 1	99	98	98	98a
Management 2	98	98	98	98a
Clean control	97	96	97	97a
Infested Control	6	0	5	4b
Mean	75[a]	73A	75A	
CV(%)	4,4			
	2017/18 crop			
	14 DAA in pre-emergence			
Management 1	81	85	81	82b
Management 2	86	80	86	84b
Clean control	99	98	98	98a
Infested Control	79	73	76	76c

Mean	86[a]	84A	85A	
CV (%)		6,7		
		14 DAA in Post-emergence		
Management 1	92	94	92	93a
Management 2	92	95	95	94a
Clean control	97	97	98	97a
Infested Control	22	0	0	7b
Mean	76[a]	71A	71A	
CV (%)		13,6		
		28 DAA in Post-emergence		
Management 1	88	95	97	93a
Management 2	94	96	96	96a
Clean control	97	93	96	96a
Infested Control	14	0	17	10b
Mean	73[a]	71A	77A	
CV (%)		16,9		

*DAA = days after application.

Means followed by the same letter, upper case letter in the line and lower-case letter in the column are not different from each other by the test of Tukey at 5% probability.

The cultivar factor did not present significant differences in weed control among themselves. It was only observed that the cultivar Garra IPRO in the 2016/17 crop had its establishment impaired by unidentified external factors, and some plots had a low plant stand, which reflected in the largest weed infestation found for Infested Control in the post-emergence evaluation at 14 DAA.

The results generally showed that both proposed managements could have been adopted for the soybean cultivars studied, either the genetically modified or not, the choice being conditioned to other variables, such as productivity and the cost of the chemical product.

Table 4 shows the results obtained for the weed population evaluated the day before the application of the herbicides in post-emergence of soybean crops. A significant difference was observed in the initial weed population, and the plots that received application of pre-emergent herbicides were less infested in both crops, when compared to the infested Control. This result is contrary to what was reported in the evaluation of the% of weed control (Table 3).

Table 4. Weed population (plants m^{-2}) at 21 after application of pre-emergent herbicides regarding 2016/17 and 2017/18 crops.

Treatments	Cultivars			Mean
	BRS 284	Garra IPRO	CZ16B39 LL	
		2016/17 crop		
Management 1	5.7Abc	14.0Ab	8.0Abc	-
Management 2	10.0Aab	9.7Ab	10.0Ab	-

Control clean	0.0Ac	0.0Ac	0.0Ac	-
Control infested	17.7Ca	40.3Aa	29.0Ba	-
Mean	-	-	-	
CV (%)		51.3		
		2017/18 crop		
Management 1	40.6	30.4	29.5	36.5b
Management 1	28.3	31.4	25.8	28.5b
Control clean	0.0	0.5	0.0	0.2b
Control infested	45.5	56.0	50.8	50.8a
Mean	28.6A	29.6A	26.5ª	
CV (%)		41.9		

Means followed by the same letter, uppercase on the line and lowercase on the column, do not differ by Tukey's test at 5% probability.

It can be seen in the first crop that the weed population is smaller when compared to the subsequent crop; however, it is composed of more competitive weed communities with the soybean crop – *milhã* (*Digitaria horizontalis*), *Giant caruru* (*Amaranthus retroflexus*) and rope of viola (*Ipomoea grandifolia*), which were uniformly selected and sown in the experimental area. In the second agricultural year, no sowing of selected species was carried out. In addition, the main weed was at the initial phase, wheat (*Triticum aestivum*), a predecessor crop of soybeans in the experimental area, which presented a large number of plants of this species.

The phytotoxicity outcome of the herbicides in the soybean crop used in the different managements in the two agricultural years are described in Table 5. Although there are some statistical differences between cultivars and treatments, the phytotoxicity values found did not surpass 10.3% for the soybean crop, presenting at most injuries classified by Frans et al. (1986) as slight discoloration or atrophy (Appendix A). Considering that only values above 40% can cause risk of phytotoxicity (FRANS et al., 1986), the results demonstrate the safety of using herbicides in pre- or post-emergence and their respective doses proposed in this work.

Table 5. Crop phytotoxicity (%) in experiments related to the 2016/2017 and 2017/2018 crops.

Treatments	**Cultivars**			**Mean**
	BRS 284	Garra IPRO	CZ16B39 LL	
		***2016/17*crop**		
		14 DAA* in Pre-emergence		
Management 1	1.8	0.7	0.8	1.1a
Management 2	0.8	0.5	0.5	0.6ab
Control clean	0.3	0.7	0.2	0.4b
Control infested	0.2	0.0	0.0	0.1b
Mean	0.8A	0.5A	0.4ª	

CV (%)		118,2		
		14 DAA in Post-emergence		
Management 1	10.3Aa	4.3Ba	2.0Ba	-
Management 2	2.0Ab	3.8Aab	2.8Aa	-
Control clean	1.2Ab	1.0Abc	0.5Aa	-
Control infested	0.7Ab	0.5Ac	0.2Aa	-
Mean	-	-	-	
CV (%)		86,7		
		28 DAA in Post-emergence		
Management 1	1.8	0.7	0.3	0.9a
Management 2	0,5	0	0.7	0.4ab
Control clean	0	0	0	0b
Control infested	0	0	0.7	0.2ab
Mean	0.6A	0.2A	0.4[a]	
CV (%)		211,5		
		***2017/18* crop**		
		14 DAA in Pre-emergence		
Management 1	6.7	6.7	4.7	6.0a
Management 2	5.3	6.2	3.8	5.1a
Control clean	5.7	4.3	5.0	5.0a
Control infested	6.5	6.3	5.5	6.1a
Treatments	**Cultivars**			**Mean**
	BRS 284	Garra IPRO	CZ16B39 LL	
Mean	6.0A	5.9A	4.7[a]	
CV (%)		37,7		
		14 DAA in Post-emergence		
Management 1	2.2	1.2	2.2	1.8a
Management 2	3.8	0.3		1.9a
			1.5	
Control clean	0	0	1.5	0.5a
Control infested	1.8	0.8	3.0	1.9a
Mean	2.0A	0.6B	2.0A	
CV (%)		107.4		
		28 DAA in Post- emergence		
Management 1	2.8	2.7	2.3	2.6ab
Management 2	3.7	1.3	1.0	2.0ab
Control clean	0.7	1.0	2.0	1.2b
Control infested	5.7	2.3	5.0	4.3a
Mean	3.2A	1.8A	2.6[a]	

CV (%)	119.6

*DAA = days after application.

Means followed by the same letter, uppercase on the line and lowercase on the column, do not differ by Tukey's test at 5% probability.

The results obtained for the soybean grain yield and the crop plant population in the 2016/17 and 2017/18 crops are shown in Table 6. In the first experimental year, no significant differences were observed in the soybean grain yields between the Managements 1 and 2 proposed within the same cultivar, which proved to be as efficient as the clean Control and better ($p <0.05$) than the infested Control. Similarly, the presence of herbicide-resistance technology did not have a significant influence on grain yield in that agricultural year, indicating that the use of genetically modified cultivars does not result in an increase in productivity.

However, in the second year of experiment, the average yield of all treatments was significantly higher for the cultivar that presents resistance to the herbicide glyphosate (Garra IPRO). It is likely that one of the factors that contributed to this higher productivity in the 2017/2018 crop is due to the fact that the predominant weed species in the second agricultural year (*Triticum aestivum*) is more susceptible to the herbicide glyphosate applied in post-emergence of the soybean crop used in Managements 1 and 2 of the cultivar Garra IPRO, when compared to the other herbicides used in the management of other cultivars.

By analyzing productivity between agricultural years for the Control infested treatment, the lower value observed for the 2016/17 crop can be justified by the weed species in that agricultural year being more competitive than wheat, a predominant species in the second year. In this sense, the presence of more competitive weed plant communities showed greater interference in the development of soybean culture, which responded with lower values of grain yield for the Control infested in the 2016/17 crop.

Regarding the plant population of the soybean crop, it is noted that for the two agricultural years there was no difference between treatments and cultivars, except for Garra IPRO, which showed lower values in the 2016/17 crop for Management 2 and Control infested. This may be related to the fact that its establishment has been compromised by some unidentified external factors, as mentioned above, which was reflected in the smaller plant stand in some experimental plots.

Table 6. Grain yield (Kg ha^{-1}) and plant population (m2) in the experiments related to the 2016/2017 and 2017/2018 crops.

Control	Cultivars			Mean
	BRS 284	Garra IPRO	CZ16B39 LL	
		***2016/17* crop**		
		Grain yield		
Management 1	4795Aa	4451Aa	4910Aa	-
Management 2	4643Aa	4908Aa	4623Aa	-
Control clean	4460Aa	4448Aa	4721Aa	-
Control infested	1969Ab	1301Bb	2479Ab	-

Mean	-	-	-	
CV (%)		10		
		Plant population		
Management 1	23.7Aa	20.0Ba	20.0Bb	-
Management 2	24.3Aa	18.3Ba	23.3Aa	-
Control clean	23.3Aa	21.0Aa	22.0Aab	-
Control infested	24.0Aa	19.0Ba	23.7Aa	-
Mean	-	-	-	
CV (%)		9,7		
		***2017/18* crop**		
		Grain yield		
Management 1	4457	4764	4553	4592a
Management 2	4146	4673	4365	4395b
Control clean	4158	4524	4328	4336b
Control infested	4119	4165	4091	4125c
Mean	4220B	4532A	4334B	
CV (%)		3,9		
		Plant population		
Management 1	22.3	21.3	21.0	21.5a
Management 2	20.0	21.7	20.7	20.8a
Control clean	20.7	20.7	21.0	20.8a
Control infested	22.0	21.7	20.0	21.2a
Mean	21.2A	21.3A	20.7[a]	
CV (%)		10.1		

Means followed by the same letter, uppercase on the line and lowercase on the column, do not differ by Tukey's test at 5% probability.

Voluntary soybean control using post-emergent herbicides

One of the main problems mentioned in areas cultivated with genetically modified soy is the difficulty of controlling voluntary plants of this species, also known as guaxa or tiguera soybean, which emerge naturally after the mechanized harvest operation (LIMA et al., 2011). The results found for the chemical control of voluntary soybean BRS 284, Garra IPRO and CZ16B39 LL are shown in Table 7. Although several herbicides have shown satisfactory to excellent control efficiency (80 - 99%), in at least one crop in the last evaluation (42 DAA), there were differences in behavior for some products between agricultural years. For all the evaluated soybean cultivars evaluated, there was potentiation or attenuation in the efficiency of some herbicides between the 2016/17 and 2017/18 crops, which may be related to variations in experimental conditions between the years, such as light, rainfall, temperature, among other uncontrollable climate issues.

When Analyzing Table 7, it can be observed that the herbicides diquat and saflufenacil did not present satisfactory control of the BRS 284 soybean, which decreased visibly during the days after application, allowing the restoration of the voluntary plants. The glyphosate, 2,4-D and metsulfuron-methyl herbicides, on the other hand, show significant control efficiency above 97% for the conventional soybean plant in both agricultural years, demonstrating that these herbicides can control this soybean cultivar extremely well when applied in post-emergence regardless of the experimental variables that may have occurred.

In the evaluation of the chemical control of the Garra IPRO voluntary soybean, the herbicide 2,4-D stood out for being efficient in both agricultural years (above 90%). All other herbicides tested in post-emergence showed unsatisfactory control in one of the harvests. One of the main difficulties in controlling these soybean plants is the fact that the main herbicide used in post-harvest applications is glyphosate, which does not control RR soybean plants due to the resistance acquired by transgenics. Such resistance was confirmed in the two harvests of this experiment, showing zero control (0%) with the use of the herbicide glyphosate in the same way as the Control treatment. In addition, the RR Garra soybean used in this experiment has a tolerance to sulfonylureas, justifying, in part, the lower efficiency found for the metsulfuron-methyl herbicide.

Liberty Link (LL)-technology soybean is resistant to the herbicide glufosinate ammonium, as it was observed in this experiment. In addition to this asset, saflufenacil should also not be recommended for the control of this variety because it did show a satisfactory control in both agricultural years. The herbicides glyphosate, 2,4-D and metsulfuron-methyl showed similar control behavior to the conventional soybean cultivar, showing efficiency that varied from satisfactory to excellent (80-99) in the control of LL-transgenic soybean. Although glyphosate showed satisfactory control in the second year of the experiment, its efficiency was attenuated, showing greater difficulty in the initial control of the voluntary plants, which gradually increased. This behavior does not corroborate with that seen in the previous harvest, nor with that found for conventional soybeans, in which an excellent control had been observed since the first evaluation at 7 DAA. On the other hand, the active metsulforon-methyl stands out among the herbicides for presenting a very good to excellent efficiency in the two years of experiment for the voluntary soybean CZ16B39 LL.

For the accumulation of dry matter mass (DM) of the aerial part of conventional soybean plants (Table 8), it was found that glyphosate, 2,4-D and metsulfuron provided a greater percentage of reduction compared to the control in the two agricultural years. Such results corroborate the evaluation of chemical control of these herbicides for this voluntary soybean (Table 7). The values of DM found for voluntary soybean plants with resistance to glyphosate (Table 8) showed that the active 2,4-D provided a greater percentage of reduction in relation to the control in the two agricultural years, results that are in agreement with the chemical control evaluated in relation to this herbicide for the cultivar (Table 7). A reduction in DM was also observed in the treatments that used the herbicides MCPA and glufosinate, although these herbicides tested in post-emergence did not present satisfactory control in at least one of the evaluated crops.

In relation to the accumulation of DM mass in the aerial part of the voluntary soybean plants with resistance to ammonium glufosinate (Table 8), the results were in line with the evaluations carried out on conventional soybean in the first agriculture year, where glyphosate, 2,4-D and metsulfuron provided a greater percentage of reduction compared to the control.

Such results corroborate the evaluation of chemical control of these herbicides for the control of voluntary soybean with resistance to glufosinate (Table 7). For the second agricultural year, these herbicides maintained the reduction in DM mass, but the other herbicides also obtained better results, with the exception of ammonium glufosinate, due to the fact that the cultivar is resistant to this herbicide and saflufenacil. This result evidences those obtained with the chemical control evaluations for this test in the second year.

Table 7. Efficiency of herbicides in the control of voluntary soybeans on different days after the application of chemical treatment

Control efficiency (%)																		
2016/17 crop																		
	BRS 284 soybean						Garra IPRO soybean						CZ16B39 LL					
DAA*	7	14	21	28	35	42	7	14	21	28	35	42	7	14	21	28	35	42
Control**	0f	0d	0e	0e	0e	0e	0f	0e	0e	0e	0g	0e	0e	0f	0f	0e	0f	0e
Glyphosate	93a	98a	99a	99a	97a	98a	0f	0e	0e	0e	0g	0e	97a	98a	98a	98a	96a	96a
2,4-D	63e	92a	92a	91ab	93a	93a	62cd	87a	88a	91a	92a	90a	57d	79b	79b	82bc	83bc	84b
MCPA	60e	76b	76b	79bc	79b	80b	61d	70b	69c	68bc	73dc	74bc	56d	73c	71c	73c	78c	77c
Metsulfuron	60e	72b	91a	97a	95a	97a	50e	62c	72c	84ab	69de	67c	59d	72c	78b	86b	90ab	90ab
Paraquat	88ab	76b	75b	76c	77b	76b	91a	84a	79b	76abc	83ab	80b	78b	59d	60d	42d	56d	42d
Diquat	82bc	68b	65c	66c	60c	60c	84b	70b	71c	60cd	63e	58d	77b	57de	56d	32d	45e	38d
Glufosinate	76c	76b	76b	74c	73b	73b	81b	80a	79b	75bc	78bc	77b	0e	0f	0f	0e	0f	0e

Saflufenacil	69d	49c	48d	46d	40d	46d	67c	54d	49d	46d	48f	51d	67c	54e	47e	42d	48de	41d
CV (%)	3.9	5.8	5.8	8.6	7.1	5.6	3.5	5.5	3.7	11.8	6.4	6.3	4.1	3.3	4.1	8.3	7.3	5.3
2017/18 crop																		
	BRS 284 soybean						Garra IPRO soybean						CZ16B39 LL					
DAA*	7	14	21	28	35	42	7	14	21	28	35	42	7	14	21	28	35	42
Control**	4c	0f	0d	0c	0c	0c	0e	0e	0e	0d	0d	0d	0d	0d	0d	0d	0d	0d
Glyphosate	97a	97a	98a	98a	98a	98a	0e	0e	0e	0d	0d	0d	69b	72b	77b	80b	80b	80b
2,4-D	74b	97a	98a	99a	99a	99a	71c	96a	98a	99a	98a	98a	69b	98a	99a	99a	99a	99a
MCPA	72b	91abc	95a	96a	95a	96a	69c	91ab	94ab	96a	96a	95a	66b	96a	99a	99a	99a	99a
Metsulfuron	75b	86cd	91a	97a	97a	98a	60d	75d	78d	85bc	80b	80b	59bc	64bc	74b	91a	98a	98a
Paraquat	89a	89bc	91a	91a	91a	91a	87a	87bc	86bc	86b	80b	77b	89a	97a	98a	98a	99a	99a
Diquat	75b	75e	60c	59b	57b	57b	76bc	78d	77d	78c	66c	63c	85a	97a	98a	99a	99a	99a
Glufosinate	91a	95ab	96a	97a	96a	97a	86a	94ab	95a	97a	95a	96a	0d	0d	0d	0d	0d	0d
Saflufenacil	80b	79ed	74b	72b	64b	64b	82ab	81cd	81cd	80bc	74b	71bc	51c	56c	57c	55c	60c	60c
CV (%)	4.7	4.2	6.6	9.0	6.9	7.0	5.0	4.8	4.8	4.9	3.6	6.2	9.9	5.7	8.1	6.5	5.8	7.5

*DAA – days after application. **Control: no herbicide application.

Means followed by the same letter in the column are not different by the Tukey's test at 5% probability.

Table 8. Effect of different herbicides on plant population and dry matter (DM) of voluntary soybean.

	2016/17 crop								
	BRS 284 soybean			Garra IPRO soybean			CZ16B39 LL		
	Population (plants.m-2)	DM (g.m-2)	Rate (g. plants-1)	Population (plants.m-2)	DM (g.m-2)	Rate (g. plants-1)	Population (plants.m-2)	DM (g.m-2)	Rate (g. plants-1)
Control*	20.9a	604.5a	28.8a	20.0a	579.4a	28.9a	20.3ab	679.0a	33.7a
Glyphosate	18.5a	12.2c	0.7d	19.6a	558.9a	29.6a	25.4a	15.7d	0.6c
2,4-D	15.8a	32.2c	1.6cd	17.1ab	23.4d	1.3d	19.8ab	46.6d	2.9c
MCPA	16.7a	84.6c	5.7bcd	15.7ab	52.7cd	3.1d	20.5ab	100.5d	4.7c
Metsulfuron	16.7a	19.7c	1.2d	20.9a	68.7cd	3.3d	20.0ab	35.9d	1.8c
Paraquat	13.3a	85.5c	6.9bcd	14.4ab	50.9cd	3.7cd	18.0ab	299.9c	16.3b
Diquat	16.2a	138.1bc	8.3bcd	15.5ab	211.9bc	13.4bc	20.9ab	446.9bc	21.5b
Glufosinate	17.6a	167.8bc	10.1bc	11.7b	52.4cd	4.4cd	12.6b	498.3ab	40.2a
Saflufenacil	19.6a	277.3b	14.1b	17.1ab	285.3b	17.1b	22.3a	500.4ab	22.8b
CV (%)	33.5	46.6	41.3	18.0	33.3	35.0	18.3	26.3	23.7
	2017/18 crop								
	BRS 284 Soybean			Garra IPRO Soybean			CZ16B39 LL		
	Population (plants.m-2)	MS (g.m-2)	Rate (g. plants-1)	Population (plants.m-2)	DM (g.m-2)	Rate (g. plants-1)	Population (plants.m-2)	DM (g.m-2)	Rate (g. plants-1)
Control*	20.2a	333.0a	18.4a	18.0a	349.7b	20a	21.0a	319.0a	15.5a
Glyphosate	15.0a	3.5c	0.2c	24.7a	430.7a	20,6a	15.5a	83.5bc	5.7b
2,4-D	20.0a	5.9c	0.3c	16.5a	4.8d	0.2b	19.0a	58.5c	3.2b
MCPA	17.7a	26.9c	1.5bc	16.5a	5.9d	0.4b	14.5a	53.0c	4.3b
Metsulfuron	21.0a	13.9c	0.6bc	22.0a	59.4cd	2.9b	13.0a	81.0bc	6.7b
Paraquat	16.5a	23.4c	1.6bc	17.5a	55.0cd	3.0b	16.0a	53.0c	3.5b
Diquat	22.2a	162.9b	7.3b	19.5a	110.0c	5.8b	20.5a	49.5c	2.4b
Glufosinate	18.0a	4.1c	0.2c	13.0a	5.0d	0.4b	19.2a	301.5a	16.6a
Saflufenacil	23.7a	143.7b	6.4bc	25.5a	104.2c	4.1b	19.0a	130.0b	7.1b
CV (%)	37.8	55.0	69.8	34.6	20.8	46.1	33.4	23.6	32.8

**Control: no herbicide application. Means followed by the same letter in the Colum are not different by the Tukey's test at 5% probability.

CONCLUSIONS

The pre-emergent herbicides in both managements proposed for the cultivars controlled the weeds from the emergence of the soybean crop to the application of the post-emergent herbicides in both crops. Likewise, all post-emergent herbicides showed weed control above 90% at 14 and 28 days after application.

For all treatments, no significant phytotoxicity was observed in the soybean crop, therefore demonstrating the safety of using herbicides in pre- or post-emergence and their respective doses proposed in this study.

In the evaluation of the chemical control of the Garra IPRO voluntary soybean, the herbicide 2,4-D stood out among the others for being more efficient in both agricultural years (above 90%). The herbicides glyphosate, 2,4-D and metsulfuron-methyl are the most effective in controlling voluntary soybean cultivars BRS 284 and CZ16B39L.

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