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Selectivity and efficacy of herbicides to control volunteer soybean in castor crop

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Abstract

Castor bean is an alternative to many grain production areas, mainly as crop for the second season after soybean. In this scenario, there is demand for research on management of plants, resulting from remaining seeds of soybean after harvest. The objective of this work was to evaluate the selectivity and efficacy of post-emergence herbicides for the control of volunteer soybean in the castor crop. Two greenhouse experiments were carried out in a completely randomized design with four replications. The first assay was focused on the selectivity of herbicides to the castor crop, and the second to the efficacy of herbicides for soybean control. Evaluation of herbicide selectivity for the castor cultivar BRS Energia was carried out at 4 to 6 true leave stages. The treatments corresponded to two doses of ethoxysulfuron, halosulfuron-methyl, iodosulfuron-methyl, ioxynil, metamitron, oxadiazon and a control without any application. To evaluate the control efficacy of soybean cultivar BRS 3280RR in 3 trefoil stage, the treatments were comprised of two doses of ethoxysulfuron, halosulfuron-methyl, metamitron and a control without application. The evaluations were: control, phytointoxication and plant height at 7, 14 and 21 DAA; stem diameter, leaf area, dry mass of aerial part and roots at 21 DAA. The results showed that herbicides ethoxysulfuron (60 and 80 g ha^{-1}), halosulfuron-methyl (75 and 112.5 g ha^{-1}) and metamitron (2,800 and 4,200 g ha^{-1}) were selective to castor. Ethoxysulfuron (60 and 80 g ha^{-1}) and halosulfuron-methyl (75 and 112.5 g ha^{-1}) were effective for the volunteer soybean control.

Keywords: *Glycine max*, *Ricinus communis*, management, tolerance, weed.
Abbreviations: ALS_acetolactate synthase; CEC_cation-exchange capacity; DAA_days after application; OM_organic matter; Protox_protoporphyrinogen oxidase.

Introduction

The oil extracted from castor seeds is used in the chemical industry for a number of products (Severino et al., 2015). However, world consumption has been limited by insufficient production, with an economic potential for the expansion of castor cultivation (Campbell et al., 2014).

In this context, the crop has aroused interests as an alternative of second crop to soybean in areas of grain production, such as Brazilian Savanna (Rocha et al., 2016). Consequently, concerns about the need to control plants resulting from remaining soybean seeds (called volunteers), have increased because they can compete for water, light and nutrients with crops sown in succession (Silva and Concenço, 2014; Sá et al., 2015). Despite this, research in weed management of castor crop has been neglected and are scarce (Severino et al., 2012; Costa et al., 2014) and the lack of information is substantially higher regarding the control of volunteer species such as soybean.

The only registered herbicide for the castor in Brazil is Saflufenacil, with a recommendation for application in directed application between the lines of the crop (Brasil, 2017). Brighenti (2015) found that Saflufenacil is not effective for the control of volunteer soybean. In this context, limitations may exist in finding herbicides to control dicotyldons, while simultaneously being selective to castor. Some herbicides are used for controlling castor in other crops (Vitorino et al., 2012). In general, castor is highly susceptible to the broadleaf herbicides.

The studies about this issue have indicated several compounds as non-selective to castor: acifluorfen, imazapic, imazethapyr, lactofen, 2,4-DB (Grichar et al., 2012), diuron, atrazine, atrazine + simazine, atrazine + metolachlor, diclosulan, 2,4-D, flumetsulan, imazaquin, imazapyr, sulfentrazone, isoxaflutole and pyrithiobac-sodium (Costa et al., 2014). The results have indicated only chlorimurom-ethyl as selective latifolicide to castor in post-emergence (Maciel et al., 2006; Sofiatti et al., 2012), but because it is selective and recommended for soybean crop, does not represent control this species (Brasil, 2017).

Assis et al. (2014) reported the control of soybean plants with ethoxysulfuron at 3 trefoil stage. Costa et al. (2015)

observed that herbicides with action mechanism of ALS inhibition, such as ethoxysulfuron and halosulfuron-methyl, contributed to the control of *Richardia scabra* in the castor crop, indicating the possibility of further studies involving these and other active ingredients for the control of dicotyledon species. Thus, the objective of this work was to evaluate the selectivity and efficacy of post-emergent herbicides for the control of volunteer soybean in the castor crop.

Results and Discussion

Selectivity of post-emergent herbicides to the castor crop

In all phases of evaluation, severe phytotoxification was verified in the castor with iodosulfuron-methyl, ioxynil and oxadiazon, with percentages between 72 and 88% (Table 1). Exception occurred for iodosulforun-methyl at 3.5 g ha^{-1} in the first evaluation (7 DAA), with 29% phytotoxification. No significant effect was observed to control soybean using ethoxysulfuron, halosulfuron-methyl and metamitron, because the phytotoxication rates were mild or moderate, with values between 4 and 20%.

A review of weed management in the castor crop (Costa et al., 2014) revealed that herbicides with mechanisms of enzyme Protox inhibition, such as oxadiazon in the present study, are not selective to this crop. However, for herbicides that inhibit photosystem II, some variation may occur, with occurrence of mild or even severe phytotoxification, as verified with metamitron and ioxynil, respectively. Similar situation can be verified for active ingredients with ALS inhibition action, as can be observed from the higher percentages of phytotoxification obtained with iodosulfuron-methyl and less with halosulfuron-methyl and ethoxysulfuron.

It was possible to verify growth reduction and plant height with application of ioxynil, oxadiazon and iodosulfuron-methyl (5 g ha^{-1}) at 14 and 21 DAA, whose values corresponded, on average, to 25% decrease compared to the control (Table 1). No significant effect was observed on height at all times after applicaton of iodosulfuron-methyl at the lowest dose (3.5 g ha^{-1}), ethoxysulfuron, halosulfuron-methyl and metamitron.

The iodosulfuron-methyl, ioxynil and oxadiazon herbicides interfered with the growth of stem diameter, leaf area and root and shoot mass accumulation in both evaluated doses of each active ingredient (Table 2). The mean reductions of stem diameter, leaf area and root and shoot mass accumulation were 32, 81, 79 and 74%, respectively, compared to control. Similar to that occurred by phytointoxication and plant height, ethoxysulfuron, halosulfuron-methyl and metamitron did not cause significant decrease in stem diameter, leaf area and dry mass of roots and shoot.

Costa et al. (2012) verified a mild phytotoxification (18%) by ethoxysulfuron, with a dose of 60 g ha^{-1}. However, they observed a reduction in the growth of the castor when the herbicide was applied at 150 g ha^{-1}. Silva et al. (2010) did not observe interferences on stem diameter, height and leaf area of the castor after post-emergence application of halosulfuron-methyl (13.5 to 112.5 g ha^{-1}). Silva et al. (2015) did not observe interferences on the same growth characteristics by application for desiccation with halosulfuron-methyl herbicide at 112.5 g ha^{-1}, applied just before sowing the castor.

In a work of selectivity and efficacy of herbicides, Costa et al. (2015) verified mild phytointoxication symptoms when chlorimuron-ethyl was applied between 4 to 6 true leaves of castor, followed by halosulfuron-methyl (112.5 g ha^{-1}) or ethoxysulfuron (60 or 120 g ha^{-1}). Besides, they did not find interference on the diameter of the stem and height of the plants at harvest time. In this study, the treatment with halosulfuron-methyl resulted in similar yield compared to control without herbicide application.

Thus, considering the previous studies and the information obtained, it is verified that halosulfuron-methyl is confirmed as selective herbicide for castor. In the present study, Ethoxysulfuron, especially at lower doses, also presented potential use for the crop, mainly because it caused slight symptoms of phytotoxification and did not interfere in any of the growth characteristics. In a similar way, it is important to highlight the tolerance of the castor to the metamitron. It might be a new possibility of latifolicide in post-emergence. It also appeared to be an alternative for new studies in pre-emergency applications, as it is also recommended for this modality of application (Brazil, 2017), for which there are no selective herbicides with predominant action on eudicots to castor.

Volunteer soybean control with post-emergence herbicides

In all control evaluations, it was possible to observe effects of the herbicides on soybean plants (Table 3). At 7 DAA, the herbicide actions and respective doses were similar, with percentages varying between 67 and 76%. At 14 and 21 DAA, there was an intensification of the control caused by ethoxysulfuron and halosulfuron-methyl, with percentages varying between 99 and 100%, which corresponded respectively to excellent control and plant death. However, for metamitron the values remained lower, between 67 and 74%, corresponding to bad or weak control levels.

York et al. (2005) found effective control of volunteer soybeans in cotton with trifloxysulfurom-sodium. This herbicide, as well as ethoxysulfuron and halosulfuron-methyl, belongs to the chemical group of sulfonylureas, whose mechanism of action is the inhibition of the ALS enzyme (Oliveira Jr, 2011), however, it is not considered selective to castor (Ferreira et al., 2009).

Assis et al. (2014) verified the death of soybean plants with the 36 g ha^{-1} of ethoxysulfuron in mixture with 0.5% (v v^{-1}) mineral oil applied in V3. However, the results were below 80% when the adjuvant was not used. Considering these results, smaller doses than those used in the present study may also control volunteer soybeans. However, they may require the addition of mineral oil to the application solution and, consequently, increase the risk of phytointoxication to castor.

Other post-emergent herbicides have been reported to be effective in controlling volunteer soybeans such as diquat, paraquat, paraquat + diuron, 2,4-D, atrazine (Dan et al., 2009 and 2011; Lima et al., 2011 and Silva and Concenço, 2014), ametryn and glufosinate-ammonium (Brighenti, 2015). However, for the castor there are studies indicating only viability of 2,4-D associated with glyphosate in the desiccation prior to sowing and paraquat + diquat in a

Table 1. Effect of treatments on phytointoxication and height of castor plants.

Treatments	Doses (g ha^{-1})	Phytointoxication (%) 7 DAA	14 DAA	21 DAA
Ethoxysulfuron	60.0	5.3 d	4.5 b	5.8 b
Ethoxysulfuron	80.0	11.0 d	10.8 b	17.0 b
Halosulfuron-methyl	75.0	6.0 d	4.0 b	10.5 b
Halosulfuron-methyl	112.5	5.0 d	4.3 b	5.3 b
Iodosulfuron-methyl	3.5	29.3 cd	72.3 a	73.8 a
Iodosulfuron-methyl	5.0	53.8 bc	80.0 a	80.8 a
Ioxynil	355.0	78.8 ab	81.5 a	69.0 a
Ioxynil	710.0	87.3 a	88.0 a	81.3 a
Metamitron	2800.0	15.5 d	20.3 b	19.5 b
Metamitron	4200.0	4.8 d	6.3 b	9.5 b
Oxadiazon	750.0	71.8 ab	82.0 a	75.0 a
Oxadiazon	1000.0	80.0 ab	85.8 a	78.8 a
Control	0.0	0.0 d	0.0 b	0.0 b
F	-	32.6*	53.9*	28.6*
CV (%)	-	34.9	25.6	32.5
Treatments	**Doses (g ha^{-1})**	**Height (cm) 7 DAA**	**14 DAA**	**21 DAA**
Ethoxysulfuron	60.0	29.1	43.5 a	47.3 ab
Ethoxysulfuron	80.0	30.2	42.0 a	45.0 abc
Halosulfuron-methyl	75.0	30.1	44.1 a	47.5 ab
Halosulfuron-methyl	112.5	31.7	43.9 a	46.8 ab
Iodosulfuron-methyl	3.5	23.9	25.3 b	26.8 cd
Iodosulfuron-methyl	5.0	24.4	25.4 b	25.3 d
Ioxynil	355.0	29.3	33.1 ab	36.8 abcd
Ioxynil	710.0	24.9	25.1 b	24.8 d
Metamitron	2800.0	27.4	38.1 ab	41.8 abcd
Metamitron	4200.0	31.0	45.0 a	49.0 a
Oxadiazon	750.0	22.8	25.1 b	29.3 bcd
Oxadiazon	1000.0	23.4	22.9 b	26.3 cd
Control	0.0	30.3	48.1 a	52.8 a
F	-	2.3^{NS}	9.1*	7.7*
CV (%)	-	15.6	17.9	19.8

Means followed by the same letter in the column does not differ significantly from each other by Tukey test ($p \leq 0.05$). * Significant at 5% of probability; ^{NS} not significant.

Table 2. Effect of treatments on stem diameter (SD), leaf area (LA), dry mass of roots (DMR) and aerial part (DMAP) of castor plants.

Treatments	Doses (g ha^{-1})	SD (mm)	LA (cm^2)	DMR (g)	DMAP (g)
Ethoxysulfuron	60.0	4.2 abcd	1998.2 a	3.2 ab	14.5 a
Ethoxysulfuron	80.0	4.3 abcd	1730.6 a	3.1 ab	16.0 a
Halosulfuron-methyl	75.0	4.6 abc	2128.5 a	4.0 a	15.2 a
Halosulfuron-methyl	112.5	4.8 ab	1961.4 a	3.6 a	16.2 a
Iodosulfuron-methyl	3.5	3.7 bcd	457.6 b	1.0 bc	6.2 bc
Iodosulfuron-methyl	5.0	3.5 cd	149.4 b	0.7 c	4.0 c
Ioxynil	355.0	3.7 bcd	686.3 b	0.9 bc	4.5 c
Ioxynil	710.0	3.2 d	378.1 b	0.6 c	3.6 c
Metamitron	2800.0	4.2 abcd	1778.1 a	2.6 abc	12.0 ab
Metamitron	4200.0	4.7 ab	2040.8 a	3.2 ab	16.0 a
Oxadiazon	750.0	3.4 d	628.5 b	0.9 bc	4.9 bc
Oxadiazon	1000.0	3.3 d	486.6 b	0.6 c	4.6 c
Control	0.0	5.1 a	2439.0 a	3.7 a	17.6 a
F	-	7.6*	16.7*	8.5*	15.4*
CV (%)	-	11.5	31.3	43.3	28.1

Means followed by the same letter in the column does not differ significantly from each other by Tukey test ($p \leq 0.05$). * Significant at 5% of probability; ^{NS} not significant.

Table 3. Effect of treatments on control and height of soybean plants.

Treatments	Doses (g ha^{-1})	Control (%) 7 DAA	14 DAA	21 DAA
Ethoxysulfuron	60.0	75.3 a	99.0 a	100.0 a
Ethoxysulfuron	80.0	75.8 a	98.8 a	99.3 a
Halosulfuron-methyl	75.0	78.3 a	99.0 a	99.5 a
Halosulfuron-methyl	112.5	83.8 a	99.3 a	99.5 a
Metamitron	2800.0	69.5 a	66.5 b	67.3 b
Metamitron	4200.0	67.5 a	72.8 b	73.5 b
Control	0.0	0.0 b	0.0 c	0.0 c
F	-	59.8*	57.2*	58.2*
CV (%)	-	11.6	12.6	12.5
Treatments	Doses (g ha^{-1})	Height (cm) 7 DAA	14 DAA	21 DAA
Ethoxysulfuron	60.0	17.3 c	14.8 c	11.5 b
Ethoxysulfuron	80.0	18.6 bc	15.0 c	12.9 b
Halosulfuron-methyl	75.0	18.8 bc	14.8 c	3.0 b
Halosulfuron-methyl	112.5	19.0 bc	15.3 c	10.4 b
Metamitron	2800.0	21.5 ab	25.8 ab	26.4 a
Metamitron	4200.0	19.3 bc	23.6 b	27.6 a
Control	0.0	22.5 a	29.1 a	33.9 a
F	-	6.9*	68.9*	22.6*
CV (%)	-	7.0	7.6	26.5

Means followed by the same letter in the column does not differ significantly from each other by Tukey test ($p \leq 0.05$). * Significant at 5% of probability; ^{NS} not significant.

Table 4. Effect of treatments on stem diameter (SD), leaf area (LA), dry mass of roots (DMR) and aerial part (DMAP) of soybean plants.

Treatments	Doses (g ha^{-1})	SD (mm)	LA (cm^2)	DMR (g)	DMAP (g)
Ethoxysulfuron	60.0	1.9 bc	0.0 c	25.3 b	174.0 c
Ethoxysulfuron	80.0	1.7 bc	0.0 c	26.3 b	199.5 c
Halosulfuron-methyl	75.0	1.1 c	0.0 c	31.8 b	182. 5 c
Halosulfuron-methyl	112.5	1.1 c	0.0 c	41.3 b	175.0 c
Metamitron	2800.0	2.8 ab	261.3 b	87.0 ab	437.0 b
Metamitron	4200.0	2.7 ab	167.5 bc	44.0 b	296.5 bc
Control	0.0	3.2 a	671.8 a	109.5 a	848.5 a
F	-	9.9*	30.9*	5.9*	25.2*
CV (%)	-	26.0	57.1	51.7	29.9

Means followed by the same letter in the column does not differ significantly from each other by Tukey test ($p \leq 0.05$). * Significant at 5% of probability; ^{NS} not significant.

Direct application between the crop lines (Maciel et al., 2008; Costa et al., 2014).

For height of soybean plants, treatments with ethoxysulfuron and halosulfuron-methyl promoted the reductions in all epochs of evaluation (Table 3). The mean percentages of growth reduction corresponded to 18, 49 and 72% at 7, 14 and 21 DAA, respectively, compared to the control. Only the highest dose of metamitron, (4,200 g ha^{-1}) at 14 DAA resulted in interference with soybean plant height with a lower effect than other herbicides.

Similar to the effect on height, ethoxysulfuron and halosulfuron-methyl herbicides caused the greatest growth reductions for other evaluated characteristics (Table 4). The mean percentages of decrease in relation to the control corresponded to: 55% for stem diameter, 100% for leaf area, 71% for root and 72% for aerial part dry mass. The metamitron at the dose of 4,200 g ha^{-1}, did not make any difference on leaf area, root and aerial part dry mass, compared to the effect of ethoxysulfuron and halosulfuron-methyl.

Therefore, the herbicides ethoxysulfuron (75 and 112.5 g ha^{-1}) and halosulfuron-methyl (60 and 80 g ha^{-1}) were shown to be the most effective control options for volunteer soybean at V3 stage. It is also worth to mention that if these herbicides are used in the castor crop, they may be options for the control of glyphosate-resistant soybean, whose cultivation is predominant in Brazil (Rizzardi and Silva, 2014; ISAAA, 2016).

Materials and Methods

Plant materials, experimental design and conduction

Two experiments were conducted under greenhouse conditions, located at coordinates 7° 13’ 20’’ S, and 35° 54’ 14’’ W. The first assay was focused on the selectivity of herbicides to the castor crop, and the second to evaluate efficacy of herbicides for soybean control, conducted from September to November 2015 and May 2016 to July 2016, respectively.

In order to compose the substrate in both trials, we used a soil from the arable layer (0 to 20 cm) of fallow agricultural area (7º 17’ 29’’ S e 39º 15’ 59’’ W), classified as Fluvisol (Embrapa, 2013), sandy-clay-sand, whose chemical characteristics were: pH in water = 6.7; Ca^{+2} = 149.7 mmol$_c$ dm^{-3}; Mg^{+2} = 69.1 mmol$_c$ dm^{-3}; Na^{+} = 1.2 mmol$_c$ dm^{-3}; K^{+} = 6.2

$mmol_c\ dm^{-3}$; S = 226.2 $mmol_c\ dm^{-3}$; H + Al = 49.5 $mmol_c\ dm^{-3}$; CEC = 275.7 $mmol_c\ dm^{-3}$; V = 82.0%; Al^{+3} = 0.03 $mmol_c\ dm^{-3}$; P = 9.4 mg dm^{-3} and OM = 23.5 g kg^{-1}. Subsequently, the soil was sieved in a 2 mm mesh, dried in the shade, fertilized with 3 kg m^{-3} of monoammonium phosphate. In the first experiment, the substrate was composed only of the fertilized soil, and in the second in a mixture of three equal parts in volume, composed of soil fertilized, sand and organic fertilizer composed of decomposed vegetable residue, commercialized for seedlings production. In both experiments, the substrates were used to fill 5 L plastic vessels, constituting the experimental plots.

The tests were installed in a completely randomized design with four replicates. The cultivars BRS Energia (castor) and BRS 8280RR (soybean) were sown in the first and second experiments, at 3 cm depth and twelve seeds per pot, and the thinning was carried out seven days after the emergence of the seedlings, from which one plant was maintained per container. To maintain humidity, daily irrigation was carried out using a system composed of micro sprinklers with preprogrammed operation.

Treatments

In the first experiment, to evaluate the efficacy of selectivity of post-emergent herbicides to castor, the treatments were constituted by: ethoxysulfuron (60 g ha^{-1}); ethoxysulfuron (80 g ha^{-1}); halosulfuron-methyl (75 g ha^{-1}); halosulfuron-methyl (112.5 g ha^{-1}); iodosulfuron-methyl (3.5 g ha^{-1}); iodosulfuron-methyl (5 g ha^{-1}); ioxynil (355 g ha^{-1}); ioxynil (710 g ha^{-1}); metamitron (2,800 g ha^{-1}); metamitron (4,200 g ha^{-1}); oxadiazon (750 g ha^{-1}); oxadiazon (1,000 g ha^{-1}) and one control without application. In the second assay, treatments to evaluate soybean control were selected based on the results obtained in the first experiment: ethoxysulfuron (60 g ha^{-1}); ethoxysulfuron (80 g ha^{-1}); halosulfuron-methyl (75 g ha^{-1}); halosulfuron-methyl (112.5 g ha^{-1}); metamitron (2,800 g ha^{-1}); metamitron (4,200 g ha^{-1}) and one control without application.

Herbicide applications

The applications were carried out as post-emergence, in the stages of 4 and 6 true leaves of the castor and the third open soybean trefoil (V3). A backpack sprayer with CO_2 constant pressure was used. It was equipped with a boom containing four XR 11002 flat fan nozzles, spaced 0.5 m apart and positioned at 0.5 m height of the target, constituting consumption of 200 L ha^{-1}. In the application solutions, noni poly (ethyleneoxy) ethanol compound (200 g L^{-1} commercial product) was added with concentration of 0.5% (v v^{-1}) for halosulfuron-methyl and 0.3% for metamitron and iodosulfuron-methyl, according to general recommendations for their use (Brasil, 2017). The wind speed, temperature and relative humidity data were recorded at the beginning and at the end of the applications by a digital thermo-hygrometer, whose averages corresponded respectively to: 1 m s^{-1}, 27 ^oC and 63% in the first experiment and at 0.4 m s^{-1}, 25.1 °C and 70.2% in the second experiment.

Traits measured

At 7, 14 and 21 days after application (DAA), the height of the plants of both species was evaluated. The height was measured from the soil surface until the insertion of the apical bud. The phytointoxication of castor and soybean was measured by means of visual scales of percentage notes (SBCPD, 1995), where 0% meant no damage and 100% the death of the plants. At 21 DAA, stem diameter, leaf area, dry shoot biomass and root system were evaluated in both plants and trials. The diameter of the castor and soybean stems was measured close to the soil surface using a digital caliper. The leaf area was obtained by estimation from the leaf dimensions of castor and leaflets of soybean plants, according to Severino et al. (2004) and Richter et al. (2014), respectively. The dry shoot biomass and roots of the plants were obtained by drying the plant material in a forced air ventilation oven at 65°C and for a period of 72 hours until reaching a constant mass and then weighing it in a semi-analytical balance.

Statistical analysis

The data were subjected to analysis of variance and the means were compared by the Tukey test at 0.05 probability.

Conclusion

The herbicides ethoxysulfuron (60 and 80 g ha^{-1}), halosulfuron-methyl (75 and 112.5 g ha^{-1}) and metamitron (2,800 and 4,200 g ha^{-1}) applied at the 4 to 6 leaf stage were selective to castor (BRS Energia). Ethoxysulfuron (60 and 80 g ha^{-1}) and halosulfuron-methyl (75 and 112.5 g ha^{-1}) applied in the V3 stage were effective to the control the volunteer soybean (BRS 8280RR).

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