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Article

CHEMICAL CONTROL OF GLYPHOSATE-RESISTANT GOOSEGRASS

Controle Químico de Capim-Pé-de-Galinha Resistente ao Glyphosate

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ABSTRACT - The use of mixtures and rotation of herbicide modes of action are essential for herbicide resistance management. The purpose of this research was to evaluate different pre- and post-emergence herbicides to control goosegrass in soybean and corn. Four greenhouse experiments were conducted, one in pre-emergence and the three others in post-emergence. In pre-emergence, the number of emerged plants and the control percentage at 20, 35 and 50 days after application were evaluated. In post-emergence, the control percentage was evaluated at 14 and 28 days after application on plants with one tiller and four tillers. The use of residual herbicides to control glyphosate-resistant goosegrass is a very important tool for its effective management. The application stage is also crucial for post-emergence efficacy. Paraquat and [paraquat + diuron] are effective in controlling this species. The application of ACCase inhibiting herbicides alone seems to be more effective than their associations with glyphosate, especially in plants with four tillers. HPPD inhibiting herbicides have high synergism with atrazine and not with glyphosate.

Keywords: *Eleusine indica*, residual herbicides, ACCase inhibithors, contact herbicides, application stage.

RESUMO - A utilização de misturas e a rotação de mecanismos de ação de herbicidas são fundamentais para o manejo da resistência. O objetivo deste trabalho foi avaliar herbicidas aplicados em pré e pós-emergência recomendados para o controle de capim- pé-de-galinha resistente ao glyphosate em soja e milho. Para isso, foram conduzidos quatro experimentos em casa de vegetação, sendo um com aplicações em pré- e outros três em pós-emergência. Em pré-emergência, foram avaliados o número de plantas emergidas e a porcentagem de controle aos 20, 35 e 50 dias após a aplicação. Em pós-emergência, foi avaliada a porcentagem de controle aos 14 e 28 dias após a aplicação sobre plantas com um e quatro perfilhos. O uso de herbicidas residuais para controle de capim-pé-de-galinha resistente ao glyphosate constitui uma ferramenta de extrema importância para o seu manejo efetivo. O estádio de aplicação é determinante para se obter eficácia em pós-emergência. Paraquat e [paraquat+diuron] são eficazes no controle dessa espécie. Os herbicidas inibidores da ACCase isolados são mais eficazes que as suas associações com glyphosate, especialmente em plantas com quatro perfilhos. Os herbicidas inibidores da síntese de carotenoides apresentam elevado sinergismo com atrazine mas não com glyphosate.

Palavras-chave: *Eleusine indica*, herbicidas residuais, inibidores da ACCase, herbicidas de contato, estádio de aplicação.

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INTRODUCTION

Goosegrass (*Eleusine indica* (L.) Gaertn) is considered one of the most important weeds worldwide. Its intrinsic characteristics, such as photosynthetic C4, rapid growth and high seed production, which can germinate under a large range of soil conditions in terms of salinity, pH, compaction and temperature, make this species extremely competitive (Ismail et al., 2002; Chauhan and Johnson, 2008; Takano et al., 2016a). Goosegrass thrives mainly on roadsides and machinery tracks, due to the compaction of the soil in these places and the absence of other plants around it (Arrieta et al., 2009).

Goosegrass presents herbicide resistance history to several modes of action, such as microtubule synthesis inhibitors (Mudge et al., 1984), photosystem I inhibitors (Buker et al. 2002), photosystem II inhibitors (Brosnan et al., 2008), ACCase inhibitors (McCollough et al., 2016), EPSPS inhibitors (Lee and Ngim, 2000) and GS inhibitors (Jalaludin et al., 2010). In Brazil, the intense use of ACCase inhibitors for grass control across 20 years of soybean cultivation led to the selection of sethoxydim-, butroxydim-, fenoxaprop-, propaquizafop- and cyhalofop-resistant goosegrass (Vidal et al., 2006). Ten years after the introduction of RR® soybean, the selection pressure imposed by glyphosate applications also selected populations of goosegrass that are resistant to this herbicide (Takano et al., 2017).

Weed resistance to glyphosate is the main herbicide resistance problem in the world (Powles, 2008). The selection of species that are resistant to this herbicide has occurred in response to the current management practices used in the field, such as the repeated use of herbicides with the same mode of action (Beckie and Reboud, 2009). Therefore, the effective management of herbicide resistance should consider all the available options of cultural, mechanical and chemical control, in order to minimize the selection pressure caused by one single tool (Norsworthy et al., 2012). The use of recommended doses of herbicides, mixture of different active ingredients, as well as the rotation of different modes of action, are fundamental for weed resistant management (Shaner, 2000; Johnson and Gibson, 2006; Norsworthy et al., 2012).

In addition to all of these factors, goosegrass is one of the most important weeds in the soybean and corn doble cropping system in Brazil, especially because the resistance to glyphosate in this species has been reported. The hypothesis of this work is that there are other herbicides with alternative modes of action that may be effective in the management of glyphosate-resistant goosegrass. Thus, the purpose of this work was to evaluate different herbicides to be used in these crops, in order to control glyphosate-resistant goosegrass.

MATERIAL AND METHODS

The experiments were conducted in greenhouse from 09/07/2016 to 11/26/2016. In total, four experiments were conducted in a completely randomized experimental design with four replications. In all experiments, glyphosate-resistant goosegrass seeds (*Eleusine indica*) were used, which were characterized in a preliminary study (resistance factor = 5). This population comes from a soybean field located in Campo Mourão - Paraná State, and the mechanism providing resistance is related to a mutation in the action site of the herbicide (Takano, 2017).

The experimental units consisted in 3 dm^3-capacity pots, which were filled with soil presenting values of: pH in water 6.30; 2.94 $cmol_c$ of $H^+ + Al^{+3}$ dm^{-3} of soil; 5.30 $cmol_c$ dm^{-3} of Ca^{+2}; 1.56 $cmol_c$ dm^{-3} of Mg^{+2}; 0.37 $cmol_c$ dm^{-3} of K^+; 4.40 mg dm^{-3} of P; 7.90 g dm^{-3} of C; 710 g kg^{-1} of sand; 20 g kg^{-1} of silt; and 270 g kg^{-1} of clay.

The first experiment was conducted aming to evaluate pre-emergence efficacy (Experiment 1). Sixteen herbicide treatments were evaluated comparing with one control treatment (Table 1). Initially, 100 goosegrass seeds were sown in each pot at a depth of approximately 0.5 cm. Then, an irrigation layer equivalent to 20 mm precipitation was applied. Subsequently, the application of the treatments was performed using a CO_2 constant pressure-based backpack sprayer, having a bar equipped with three XR 110.02 fan jet type nozzles, spaced 50 cm apart, under a pressure of 2.0 kgf cm^{-2}. These application conditions provided an application volume of 200 L ha^{-1}. At the application, the climatic conditions were: temp. = 25 °C; RH = 75%; and wind speed = 1.5 km h^{-1}.

Table 1 - Three evaluation times of control percentage (%) and number of emerged plants per pot (NP) of goosegrass after the application of herbicides in pre-emergence

Treatment*	Dose (g a.i. ha^{-1})	20 DAA		35 DAA		60 DAA	
		%	NP	%	NP	%	NP
Chlorimuron-ethyl	20	11.3 f	15.3 c	6.3 f	43.8 b	31.3 e	25.5 d
Diclosulam	25	22.5 e	23.8 b	41.3 d	43.8 b	30.0 e	44.0 b
Imazethapyr	106	18.8 e	50.0 a	40.0 d	52.5 a	51.3 d	35.8 c
Flumioxazin	60	81.3 b	5.8 d	72.5 b	19.0 d	61.3 c	18.0 d
Fomesafen	375	100.0 a	0.0 d	75.0 b	10.3 e	67.5 c	19.3 d
Sulfentrazone	600	100.0 a	0.0 d	97.0 a	2.3 e	94.5 a	3.5 e
Clomazone	800	100.0 a	0.0 d	92.3 a	8.8 e	77.5 b	18.3 d
Isoxaflutole	60	99.5 a	0.8 d	62.5 c	28.3 c	65.0 c	23.5 d
Pendimethalin	1250	100.0 a	0.0 d	100.0 a	0.0 e	100.0 a	0.0 e
S-metolachlor	1728	100.0 a	0.0 d	100.0 a	0.0 e	100.0 a	0.0 e
Trifluralin	1800	100.0 a	0.0 d	96.0 a	4.3 e	96.5 a	6.8 e
Amicarbazone	280	30.0 d	16.0 c	45.0 d	40.0 c	51.3 d	31.3 c
Atrazine	2000	21.3 e	15.8 c	26.3 e	32.8 c	25.0 e	27.5 c
Diuron	2000	80.0 b	15.3 c	79.3 b	15.5 d	77.8 b	15.3 d
Metribuzin	480	42.5 c	15.0 c	66.3 c	19.8 d	57.5 d	21.3 d
[Flumioxazin + imazethapyr]	[50 + 100]	93.8 a	1.3 d	78.0 b	22.8 d	79.5 b	21.8 d
Control treatment	-	0.0 g	47.0 a	0.0 f	55.0 a	0.0 f	57.5 a
F		327.6	28.2	124.7	23.2	131.9	47.6
VC		6.8	47.2	8.7	32.7	7.4	21.5

* Averages followed by the same letter do not differ by Scott Knott's test at 5% probability. DAA - days after application.

At 20, 35 and 50 days after application (DAA), we evaluated the percentage of control and the number of emerged plants per pot. For the percentage of control, it was adopted a scale in which 0% corresponds to absence of injuries and 100% to death of plants (SBCPD, 1995). Data were submitted to analysis of variance (ANOVA), and means were compared by Scott-Knott grouping test at 5% probability.

The other experiments (Experiments 2, 3 and 4) the post-emergence control of this species was evaluated. Initially, goosegrass seeds were sown in 25 mL-cell trays. When seedlings presented one leaf, two seedlings per pot were transplanted. During the experiments, the plants were irrigated daily, keeping the soil close to its field capacity.

The treatments consisted in herbicides that are recommended for post-emergence application in different situations: Experiment 2 - herbicides aiming pre-planting desiccation of soybean or corn (Table 2); Experiment 3 - ACCase inhibitor herbicides sprayed alone or associated with glyphosate, aiming applications after soybean emergence (Table 3); and Experiment 4 - herbicides recommended in corn, with or without glyphosate (Table 4).

In all post-emergence experiments, two application stages (E1 - one tiller and E2 - four tillers) were evaluated. The application equipment and its configurations were the same as the ones described in Experiment 1. The weather conditions during post-emergence applications were: temp. = 23 ^{o}C; RH = 78%; and wind speed = 1.2 km h^{-1}. At 14 and 28 DAA, control percentage was evaluated using the 0-100% scale (SBCPD, 1995). Data were submitted to ANOVA, and the means were compared by Scott-Knott test at 5% probability.

RESULTS AND DISCUSSION

Pre-emergence – Experiment 1

In the first evaluation 20 days after application (20 DAA), fomesafen, sulfentrazone, clomazone, isoxaflutole, pendimethalin, S-metolachlor, trifluralin and [flumioxazin + imazethapyr] provided more than 93% control (Table 1). In this evaluation, diuron and flumioxazin presented a residual control of 80 and 81.3%, respectively. The high residual control of these herbicides was observed through the low number or absence of emerged plants in these treatments and through the weak development of the surviving plants. Although the control provided by chlorimuron, diclosulam, amicarbazone, atrazine, diuron and metribuzin was low at 20 DAA, a smaller number of emerged plants was observed in these treatments, when compared to the control treatment.

At 35 DAA, herbicides that still maintained high levels of residual control (>90%) and low number of emerged plants (<10 plants) were sulfentrazone, clomazone, pendimethalin, S-metolachlor and trifluralin. The herbicides flumioxazin, fomesafen, diuron and [flumioxazin + imazethapyr] provided a 70-80% range control, and isoxaflutole and metribuzin, 60-66%. The other herbicides provided less than 45% control and low suppression of the emergence of goosegrass plants.

In the evaluation at 60 DAA, herbicides that still had high levels of residual control were sulfentrazone, pendimethalin, S-metolachlor and trifluralin. For these treatments, control was above 94%, and the number of emerged plants was less than seven. At the second level of efficacy, clomazone, diuron and [flumioxazin + imazethapyr] had 77-80% control. At the third level of efficacy, the herbicides flumioxazin, fomesafen and isoxaflutole provided control between 60 and 68%. The other herbicides showed low efficacy in controlling goosegrass. The results of this experiment support several studies in literature. McCullough et al. (2013) observed that the application of 420 g ha^{-1} of sulfentrazone in pre-emergence controlled goosegrass for over 90%. Molin et al. (2013) and Takano et al. (2016b) found that pendimethalin (1,120 g ha^{-1}) and S-metolachlor (1,120 g ha^{-1}) applied in pre-emergence provided 100% control of this species at 14 DAA.

In the case of soybeans and corn, since the application of the herbicide in pre-emergence is carried out at the time of sowing, residual control up to 20 DAA may be enough to keep the crop clean between sowing and post-emergence. Even if the residual control of some herbicides is lower after 35 or 60 DAA, the suppression imposed by these products allows the post-emergence application to be carried out in a more favorable situation (less infestation and plants at initial growth stages). Another important point is that the use of residual herbicides will be determinant for the management of glyphosate-resistant goosegrass populations. In this work, at least five action mechanisms that are different and alternative to glyphosate were effective in pre-emergence.

Considering all these aspects, among the herbicides evaluated in this experiment, sulfentrazone, pendimethalin, S-metolachlor and trifluralin were the most effective. However, flumioxazin, fomesafen, clomazone, isoxaflutole, diuron and [flumioxazin + imazethapyr] may also be used to control glyphosate-resistant goosegrass in pre-emergence.

Post-emergence – Experiment 2

For plants with one tiller, paraquat and [paraquat + diuron] provided percentage of control above 95%, and were grouped at control levels above the other treatments in the evaluation at 14 DAA (Table 2). Treatments with 600 g ha^{-1} doses of ammonium-glufosinate alone or associated with glyphosate had higher control levels than those at lower doses. However, no ammonium-glufosinate treatment was effective in controlling goosegrass. At 28 DAA, the same trend of the previous evaluation was observed, but the treatment with a lower dose of paraquat provided lower control levels than the higher dose of this herbicide and than treatments with [paraquat + diuron], presenting shoot sprouts in plants from this treatment.

For plants with four tillers, the lowest dose of paraquat, as well as all the ammonium-glufosinate treatments, were not very effective in controlling goosegrass at 14 DAA. The highest dose of paraquat and treatments with [paraquat + diuron] presented control levels above 85%. In the evaluation at 28 DAA, the treatment with [600 + 300] g ha^{-1} of [paraquat + diuron] provided greater control than the others. At a second efficacy level, the highest dose of paraquat and the lowest dose of [paraquat + diuron] also provided control between 81 and 87%. None of the ammonium-glufosinate treatments were efficient controlling goosegrass.

Table 2 - Two evaluation dates of control percentage of goosegrass at two stages (E1 - 1 tillers and E2 - 4 tillers) after the application of herbicides for pre-planting desiccation

Treatment*	Dose (g a.i. or a.e. ha^{-1})	Control percentage (%)			
		E1		E2	
		14 DAA	28 DAA	14 DAA	28 DAA
Paraquat	240	98.5 a	87.5 b	27.5 c	1.3 e
Paraquat	400	100.0 a	100.0 a	88.8 a	81.3 b
[Paraquat + diuron]	[400 + 200]	100.0 a	100.0 a	93.8 a	87.5 b
[Paraquat + diuron]	[600 + 300]	100.0 a	100.0 a	99.5 a	99.8 a
Glufosinate	400	42.5 d	22.3 d	35.0 c	27.5 d
Glufosinate	600	66.3 b	40.0 c	64.5 b	40.0 c
Glyphosate + glufosinate	(960 + 400)	58.8 c	22.5 d	40.0 c	22.5 d
Glyphosate + glufosinate	(960 + 600)	66.3 b	47.5 c	68.8 b	41.3 c
Control	-	0.0 e	0.0 e	0.0 d	0.0 e
F		361.4	161.1	134.3	80.4
VC		5.1	11.9	9.39	14.8

* Averages followed by the same letter do not differ by Scott Knott's test at 5% probability. DAA - days after application.

The low efficacy of ammonium glufosinate on goosegrass, especially for plants at advanced development stages, is also reported in other studies (Culpepper and York, 1999; Culpepper et al., 2000). In these works, the maximum control provided by ammonium-glufosinate (490 g ha^{-1}) is 60% over plants with 4-8 leaves. Molin et al. (2013) also found that the application of paraquat (840 g ha^{-1}) provided 100% control over small plants (5-8 cm).

Both doses of the herbicides paraquat and [paraquat + diuron] were effective in controlling goosegrass plants with one tiller. Paraquat (600 g ha^{-1}) and both doses of [paraquat + diuron] controlled plants with up to four tillers for more than 80%. These herbicides have recommendation for being applied in pre-planting desiccation, both on soybean and corn crops (Rodrigues and Almeida, 2005); they are good alternatives to start planting the crop on a weed free field.

Post-emergence – Experiment 3

In plants with one tiller, clethodim, haloxyfop, quizalofop-tefuril, quizalofop-methyl and fluazifop at both doses provided 100% control of goosegrass at 14 DAA (Table 3). On the other hand, even though they were grouped among treatments with the best control, these herbicides associated with glyphosate did not present 100% control. Fenoxaprop (200 g ha^{-1}) and glyphosate + fluazifop (960 + 500 g ha^{-1}) were also included in the same group, providing control above 95%. The herbicides fenoxaprop (110 g ha^{-1}), sethoxyfim at both doses, glyphosate + fluazifop (960 + 250 ha^{-1}) and glyphosate + sethoxydim (960 + 368 ha^{-1}) showed satisfactory control. In this evaluation, glyphosate + fenoxaprop at both doses and glyphosate + sethoxydim (960 + 184 g ha^{-1}) were ineffective in controlling goosegrass plants with one tiller.

At 28 DAA, the herbicides clethodim, haloxyfop, quizalofop-tefuryl, quizalofop-methyl and fluazifop, applied alone or in combination with glyphosate, had provided control above 96%. On the other hand, fenoxaprop and sethoxydim only controlled goosegrass plants when they applied alone. The mixture of both doses of fenoxaprop with glyphosate, as well as the lowest dose of sethoxyfim, provided control similar to or lower than the control level of these herbicides when applied alone. As expected, since they are resistant plants, glyphosate alone presented a low control level, especially over higher plants.

No treatment provided satisfactory control for applications at the stage with four tillers, at 14 DAA. However, in the evaluation at 28 DAA, the herbicides clethodim (192 g ha^{-1}) and haloxyfop (120 g ha^{-1}) were the ones providing the highest control levels (> 97%). Treatments with clethodim (108 g ha^{-1}), haloxyfop (60 g ha^{-1}), quizalofop-tefuril (both doses), quizalofop-methyl (100 g ha^{-1}), glyphosate + haloxyfop (960 + 120 g ha^{-1}), glyphosate + quizalofop-tefuril (960 + 120 g ha^{-1}) and glyphosate + fluazifop (both doses) provided control between 80 and 90%, and were framed at the

Table 3 **-** Control percentage of goosegrass at two stages (E1 - 1 tiller and E2 - 4 tillers) after the application of different ACCase inhibiting herbicides alone or in association with glyphosate

Treatment*	Dose (g a.i. or a.e. ha^{-1})	Control percentage (%)			
		E1		E2	
		14 DAA	28 DAA	14 DAA	28 DAA
Clethodim	108	100.0 a	100.0 a	61.3 b	81.3 b
Clethodim	192	100.0 a	100.0 a	70.0 a	97.5 a
Haloxyfop	60	100.0 a	100.0 a	57.5 b	82.5 b
Haloxyfop	120	100.0 a	100.0 a	78.3 a	99.0 a
Quizalofop-tefuril	72	100.0 a	100.0 a	62.5 b	87.0 b
Quizalofop-tefuril	120	100.0 a	100.0 a	58.8 b	83.8 b
Quizalofop-methyl	75	100.0 a	100.0 a	55.0 b	75.3 c
Quizalofop-methyl	100	100.0 a	100.0 a	60.0 b	86.3 b
Fluazifop	250	100.0 a	100.0 a	55.0 b	71.3 c
Fluazifop	500	100.0 a	100.0 a	62.5 b	75.0 c
Fenoxaprop	110	86.8 b	100.0 a	52.5 b	63.8 d
Fenoxaprop	220	98.3 a	100.0 a	52.5 b	67.0 c
Sethoxydim	184	83.8 b	100.0 a	55.0 b	56.3 d
Sethoxydim	368	83.8 b	100.0 a	67.5 a	71.3 c
Glyphosate + clethodim	(960 + 108)	96.3 a	100.0 a	68.8 a	73.3 c
Glyphosate + clethodim	(960 + 192)	98.8 a	100.0 a	70.0 a	70.8 c
Glyphosate + haloxyfop	(960 + 60)	99.8 a	100.0 a	62.5 b	73.3 c
Glyphosate + haloxyfop	(960 + 120)	100.0 a	100.0 a	67.5 a	80.8 b
Glyphosate + quizalofop-tefuril	(960 + 72)	95.0 a	100.0 a	63.8 b	73.8 c
Glyphosate + quizalofop-tefuril	(960 + 120)	98.8 a	100.0 a	65.0 a	86.3 b
Glyphosate + quizalofop-methyl	(960 + 75)	99.3 a	100.0 a	63.8 b	63.8 d
Glyphosate + quizalofop-methyl	(960 + 100)	100.0 a	100.0 a	68.8 a	86.3 b
Glyphosate + fluazifop	(960 + 250)	93.3 b	97.0 a	70.0 a	87.8 b
Glyphosate + fluazifop	(960 + 500)	97.0 a	100.0 a	73.8 a	88.8 b
Glyphosate + fenoxaprop	(960 + 110)	61.3 d	37.5 d	62.5 b	72.5 c
Glyphosate + fenoxaprop	(960 + 220)	66.3 d	40.0 d	61.3 b	72.5 c
Glyphosate + sethoxydim	(960 + 184)	70.0 c	62.5 c	60.0 b	61.3 d
Glyphosate + sethoxydim	(960 + 368)	83.3 b	100.0 a	67.5 a	70.0 c
Glyphosate	960	62.5 d	60.0 c	36.3 c	43.8 e
Glyphosate	1920	70.0 c	70.0 b	63.8 b	55.0 d
Control	-	0.0 e	0.0 e	0.0 d	0.0 f
F		79.5	117.6	10.1	17.9
VC		5.2	5.1	14.3	12.5

* Averages followed by the same letter do not differ by Scott Knott's test at 5% probability. DAA - days after application.

second level of efficacy. The other treatments were not effective in controlling goosegrass plants with four tillers.

According to the results of this experiment, studies in literature show that applications of clethodim, haloxyfop and fluazifop on goosegrass plants with up to two tillers present control above 90% (Barroso et al., 2010; Molin et al., 2013; Ulguim et al., 2013). On the other hand, sethoxyfim (230 g ha^{-1}) and [clethodim + fenoxaprop] [50 + 50 g ha^{-1}] provided final control below 80% when applied on plants with two to four tillers (Barroso et al., 2010).

In general, most ACCase inhibiting herbicides applied alone provided greater or similar control to that obtained by the association of these herbicides to glyphosate. In the case of small plants (one tiller - E1), except for fenoxaprop and sethoxydim, even though control was slower, the association of these graminicides to glyphosate was effective. On the other hand, as for bigger plants (four tillers), the final control over goosegrass plants was limited in most cases, especially in associations to glyphosate. Even if ACCAse inhibiting herbicides were effective over the goosegrass population used in this experiment, it is worth remembering that other populations that are resistant to this action mechanism have already been documented in Brazil (Vidal et al., 2006). Therefore, these herbicides should be used rationally in order to preserve their efficacy on goosegrass and avoid selection of multiple resistance.

Among the herbicides evaluated in this experiment, glyphosate alone had a maximum of 70% control over small plants and 55% control over big plants. All graminicides alone or associated with glyphosate showed efficacy above 80% on goosegrass plants with one tiller, with the exception of glyphosate + fenoxaprop (960 + 110 and 960 + 220 ha^{-1}) and glyphosate + sethoxydim (960 + 384 g ha^{-1}). For plantas with four tillers, the only efficient options were clethodim (108 and 192 g ha^{-1}), haloxyfop (60 and 120 g ha^{-1}), quizalofop-tefuril (70 and 120 g ha^{-1}), quizalofop-methyl (75 and 100 g ha^{-1}), glyphosate + haloxyfop (960 + 120 g ha^{-1}), glyphosate + quizalofop-tefuril (960 + 120 g ha^{-1}), glyphosate + quizalofop-methyl (960 + 100 g ha^{-1}) and glyphosate + fluazifop (960 + 250 and 960 + 500 g ha^{-1}). All these herbicides are registered for post-emergence application on conventional soybean or RR® soybean (Rodrigues and Almeida, 2005), and may be recommended to control glyphosate-resistant goosegrass within the crop.

Post-emergence – Experiment 4

For goosegrass plants with one tiller, treatments grouped in the highest control group at 14 DAA were: atrazine + mesotrione, atrazine + mesotrione, atrazine + tembotrione, atrazine + tembotrione, atrazine + mesotrione + nicosulfuron e atrazine + tembotrione + nicosulfuron (Table 4). These treatments provided 100% control in this evaluation, whereas the others presented control levels below 80%. At the second level of efficacy, there are the herbicides mesotrione (192 g ha^{-1}), nicosulfuron (both doses), glyphosate + atrazina (960 + 1,500 g ha^{-1}), glyphosate + mesotrione (960 + 192 g ha^{-1}) and glyphosate + nicosulfuron (both doses).

At 28 DAA, in addition to the treatments containing combinations of atrazine and mesotrione, tembotrione and nicosulfuron, the application of nicosulfuron alone or associated with atrazine also controlled goosegrass plants for more than 85%. Atrazine, mesotrione and tembotrione alone or in combination with glyphosate were not effective. However, the control obtained by applying the mixture of these herbicides with glyphosate was greater than its isolated application.

For plants with four tillers, no treatment provided control over 80% in the evaluation at 14 DAA. The highest control percentages were observed in treatments with atrazine + mesotrione (1,500 + 192 g ha^{-1}), atrazine + tembotrione (1,500 + 105 g ha^{-1}), atrazine + mesotrione + nicosulfuron (1,500 + 120 + 150 g ha^{-1}), atrazine + tembotrione + nicosulfuron (1,500 + 180 + 150 g ha^{-1}) and glyphosate + nicosulfuron (960 + 60 g ha^{-1}).

At 28 DAA, the treatment glyphosate + nicosulfuron (960 + 60 g ha^{-1}) controlled 80.8% of goosegrass plants. The mixtures of atrazine + tembotrione (1,500 + 105 g ha^{-1}) and glyphosate + nicosulfuron (960 + 50 g ha^{-1}) were grouped at the same level of this treatment and provided 71.3% and 73.8% control, respectively. The control percentage presented by nicosulfuron, atrazine + mesotrione, atrazine + mesotrione + nicosulfuron and atrazine + tembotrione + nicosulfuron was approximately 65%, and these herbicides were classified at the second level of efficacy. The remaining treatments showed final control below 60%.

In agreement with these results, Takano et al. (2016b) also verified goosegrass control above 80% after the application of atrazine + mesotrione (2,000 + 100 g ha^{-1}), atrazine+tembotrione (2,000 + 75 g ha^{-1}) and atrazine + nicosulfuron (2,000 + 50 g ha^{-1}). These authors also observed that the application of these herbicides alone is not effective on this species.

Among the herbicides evaluated in this experiment, nicosulfuron (50 and 60 g ha^{-1}), glyphosate + nicosulfuron (960 + 50 and 960 + 60 g ha^{-1}), as well as all the associations of atrazine and mesotrione, tembotrione and nicosulfuron were effective in controlling plants with one tiller. On the other hand, over plants with four tillers, the only treatment providing satisfactory control (>80%) was glyphosate + nicosulfuron (960 + 60 g ha^{-1}). Even though these herbicides are recommended for corn (Rodrigues and Almeida, 2005), controlling goosegrass plants at advanced stages becomes very limited in this crop, especially in conventional crops (non-RR®).

Table 4 **-** Control percentage of goosegrass at two stages (E1 - 1 tiller and E2 - 4 tillers) after the application of different herbicides in post-emergence that are used in corn

Treatment*	Dose (g a.i. or a.e. ha^{-1})	Control percentage (%)			
		E1		E2	
		14 DAA	28 DAA	14 DAA	28 DAA
Atrazine	1500	55.0 c	25.0 d	35.0 c	38.8 d
Mesotrione	120	57.5 c	17.5 d	32.5 c	32.5 d
Mesotrione	192	68.8 b	33.8 c	37.5 c	20.0 d
Tembotrione	75.6	53.8 c	17.5 d	32.5 c	32.5 d
Tembotrione	105	58.8 c	27.5 d	36.3 c	31.3 d
Nicosulfuron	50	65.0 b	87.5 a	47.5 b	65.0 b
Nicosulfuron	60	70.0 b	92.3 a	55.0 b	67.5 b
Atrazine + mesotrione	(1500 + 120)	100.0 a	100.0 a	56.3 b	67.5 b
Atrazine + mesotrione	(1500 + 192)	100.0 a	100.0 a	66.3 a	63.8 b
Atrazine + tembotrione	(1500 + 75.6)	100.0 a	100.0 a	57.5 b	52.5 c
Atrazine + tembotrione	(1500 + 105)	100.0 a	100.0 a	75.8 a	71.3 a
Atrazine + mesotrione + nicosulfuron	(1500 + 120 + 6)	100.0 a	100.0 a	70.0 a	62.5 b
Atrazine + tembotrione + nicosulfuron	(1500 + 180 + 6)	100.0 a	100.0 a	73.8 a	63.8 b
Glyphosate	960	52.5 c	45.0 c	47.5 b	50.0 c
Glyphosate + atrazina	(960 + 1500)	61.3 b	51.3 b	20.0 c	30.0 d
Glyphosate + mesotrione	(960 + 120)	55.0 c	40.0 c	35.0 c	47.5 c
Glyphosate + mesotrione	(960 + 192)	62.5 b	56.3 b	48.8 b	56.3 c
Glyphosate + tembotrione	(960 + 75.6)	51.3 c	40.0 c	35.0 c	32.5 d
Glyphosate + tembotrione	(960 + 105)	55.0 c	50.0 b	36.3 c	30.0 d
Glyphosate + nicosulfuron	(960 + 50)	63.8 b	92.5 a	60.0 b	73.8 a
Glyphosate + nicosulfuron	(960 + 60)	67.5 b	94.8 a	66.3 a	80.8 a
Control	-	0.0 d	0.0 e	0.0 d	0.0 e
F		80.9	50.3	15.1	27.4
VC		7.9	15.6	20.7	16.2

* Averages followed by the same letter do not differ by Scott Knott's test at 5% probability. DAA - days after application.

From all the above, in all post-emergence experiments, the number of effective treatment options to control goosegrass with four tillers was always lower than the one for plants with one tiller. As for this species, the time between emergence and the beginning of tillering is only nine days, which means a short time to perform the application at the appropriate stage (Takano et al., 2016a). There is an interesting hypothesis to explain the lower efficacy of herbicides on goosegrass in advanced stages. The cuticle of individuals with more than three tillers presents greater wax accumulation, which may limit the herbicide absorption by the plant. These waxes act as a compartment of herbicide accumulation, and therefore they partially prevent the entrance of the active ingredient into epidermal cells and, consequently, into the phloem (Chamel and Vitton, 1996; Malpassi, 2006). In this sense, for an effective control of goosegrass in advanced stages, complementary or sequential applications might be necessary (Wiecko, 2000).

Another important fact observed in this research is that, unlike for sourgrass, glyphosate mixtures with ACCase inhibiting herbicides apparently have an antagonistic effect on goosegrass control. The association of these herbicides is one of the main tools to control glyphosate-resistant sourgrass (Gemelli et al., 2012). Therefore, additional studies on the response of goosegrass to the application of these herbicides and their respective doses are being conducted.

In this work, several effective herbicide options were presented for pre- or post-emergence application on glyphosate-resistant goosegrass. The use of residual herbicides is determinant for the management of this species, since most of the herbicides applied in post-emergence control only small plants. The rotation of herbicide action mechanisms, as well as the mixtures of these products, generally have a retarding effect on the selection of resistant populations, especially for species that are self-pollinated, have target site resistance, and present limited dispersion of seeds (Beckie and Reboud, 2009). Those characteristics are suitable for goosegrass, which is a self-pollinated species whose seed dispersal is strictly by seeds and the glyphosate-resistance mechanism is a mutation in the EPSPS gene (Takano, 2017).

Therefore, alternative herbicides to glyphosate that are effective on goosegrass may be recommended in rotation and mixtures aiming to handle this glyphosate resistant species. In addition to the chemical management, other control methods should be considered to avoid the selection of short-term multiple resistance. The use of cover crops (Adler and Chase, 2007), soil tilling (McCollough et al., 2016) and rapid growth of the crop (Arrieta et al., 2009) are alternative management methods that also decrease the population size of weeds in the field.

The use of residual herbicides to control glyphosate-resistant goosegrass is an extremely important tool for its effective management. The application stage is decisive for achieving post-emergence efficacy (one tiller maximum). Paraquat and [paraquat + diuron] are effective for burndown applications. ACCase inhibiting herbicides alone seems to be more effective than their associations with glyphosate; however, further studies are under evaluation. HPPD inhibitors presented high synergism with atrazine but not with glyphosate.

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