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CHEMICAL MANAGEMENT OF SOURGRASS WITH MIXTURE OF HERBICIDES IN AREAS UNDER NO-TILLAGE SYSTEM

Victor Luiz Peres de Souza[1*;] Vinícius Matoso Calistro[1]; Gustavo Loro[1]; Izidro dos Santos da Lima Júnior[1]; Elmo Pontes de Melo[1].

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ABSTRACT - The sourgrass [*Digitaria insularis* (L.) Fedde] is a native species of the Americas found in tropical and subtropical regions, the difficulty in controlling Digitaria insularis with the herbicide Glyphosate generates the need to use other herbicides for an adequate management of the species. Therefore, the objective of the present work was to evaluate whether mixtures of herbicides, such as glyphosate; 2,4-D and Cletodim interfere with the effectiveness of controlling bitter campuses. The experiment was carried out in Ponta Porã (Mato Grosso do Sul State), the experimental design was randomized blocks, where the *Digitaria insularis* specimens present in each plot had 3 to 5 tillers, with 30 to 40 cm in height, the treatments used were control without weeding, weeding control, 1,800 g ha^{-1} ai of glyphosate + 10 mL of mineral oil, 240 g ha^{-1} of ai of clethodim + 10 mL of mineral oil (MO), 670 g ha^{-1} of ai of 2,4-D + 10 mL of MO, 240 g ha^{-1} of ai of Cletodim + 1,800 g ha^{-1} of ai of glyphosate + 10 mL of MO, 240 g of ha^{-1} of ai of Cletodim + 670 g of ha^{-1} of ai of 2.4-D + 10 mL of MO, 240 g ha^{-1} of ai of Cletodim + 1,800 g ha^{-1} of ai of glyphosate + 670 g ha^{-1} of ai of 2.4-D + 10 mL of MO. A precision CO_2 sprayer was used, equipped with AIXR 110015 fan-type simple flat jet nozzles. The evaluations were carried out at 7, 14, 21 and 28 days after application. for the control of sourgrass, the treatments 6 (240 g ha^{-1} of ai of cletodim + 1,680 g ha^{-1} of ai of glyphosate + 10 mL of mineral oil) and treatment 8 (240 g ha^{-1} of ai of clethodim + 1,680 g ha^{-1} of glyphosate ae + 806 g ha^{-1} of 2,4-D ae + 10 mL of mineral oil), respectively, with better scores in visual control.
Keywords: *Digitaria insularis*, tolerance, ACCase inhibiting herbicides.

MANEJO QUÍMICO DE CAMPIM AMARGOSO COM MISTURA DE HERBICIDAS, EM ÁREA DE PLANTIO DIRETO

RESUMO - O capim amargoso é uma espécie nativa das Américas, encontrada em regiões tropicais e subtropicais. A dificuldade no controle com o herbicida glifosato gera a necessidade da utilização de outros herbicidas para um manejo adequado da espécie. Assim sendo, objetivou-se com o presente trabalho avaliar se misturas de herbicidas, como glifosato, 2,4-D e Cletodim, interferindo na eficácia de controle de campi amargoso. O experimento foi conduzido em Ponta Porã (MS) e o delineamento experimental utilizado foi blocos ao acaso, onde os exemplares de capim amargoso presentes em cada parcela apresentavam 3 a 5 perfilhos, com 30 a 40 cm de altura, os tratamentos utilizados foram testemunha sem capina, testemunha com capina, 1.800 g ha^{-1} de i.a de glifosato + 10 mL de óleo mineral (O.M.), 240 g ha^{-1} de i.a de cletodim + 10 mL de O.M., 670 g ha^{-1} de i.a de 2,4-D + 10 mL de O.M., 240 g ha^{-1} de i.a de cletodim + 1.800 g ha^{-1} de i.a de glifosato + 10 mL de O.M., 240 g ha^{-1} de i.a de cletodim + 670 g ha^{-1} de i.a de 2,4 D + 10 mL de O.M., 240 g ha^{-1} de i.a de cletodim + 1.800 g ha^{-1} de i.a de glifosato + 670 g ha^{-1} de i.a de 2,4 D + 10 mL de O.M. Utilizou-se um pulverizador de precisão a CO_2, munido de pontas jato plano simples do tipo leque AIXR 110015. As avaliações foram realizadas aos 7, 14, 21 e 28 dias após a aplicação. Para o controle do capim amargoso, destacaram-se o tratamento 6 (240 g ha^{-1} de i.a de cletodim + 1.680 g ha^{-1} de e.a de glifosato + 10 mL de O.M.) e o tratamento 8 (240 g ha^{-1} de i.a de cletodim + 1.680 g ha^{-1} de e.a de glifosato + 806 g ha^{-1} de e.a de 2,4-D + 10 mL de O.M., com melhores notas no controle visual.
Palavras-chave: *Digitaria insularis*, tolerância, inibidor de ACCase.

INTRODUCTION

Sourgrass [*Digitaria insularis* (L.) Fedde] is a perennial herbaceous species classified as a clump-forming plant, which can reach up to 100 cm height. The species is considered harmful to agriculture due to its levels of interference and competition for natural resources; in addition, it causes allelopathy and serves as host for phytonematodes (ARIEIRA, 2017). Its propagation is usually during the summer, through propagules (seeds) that can be easily dispersed and have high germination power; this plant can be found in pasture, roadside, and crop areas (AGOSTINETTO et al., 2015).

The existence of sourgrass biotypes that are resistant to glyphosate was reported in 2005 (CARVALHO et al., 2005); in Brazil, the first sourgrass plants resistant to glyphosate were reported in 2008, in the state of Paraná, and

[1]Federal Institute of Education, Science and Technology of Mato Grosso do Sul, Ponta Porã *Campus*, Ponta Porã, MS, Brazil. Email: victorlupe@gmail.com. *Corresponding author.

the first case of resistance to acetyl-CoA carboxylase inhibiting (ACCase) herbicides was reported in 2016 (HEAP, 2020). The infestation of sourgrass biotypes resistant to glyphosate increased in crop areas with no-tillage system in the Cerrado biome (LUCIO et al., 2019). Thus, high infestations of sourgrass increased the costs for control and management in soybean crops (ALBRECHT et al., 2018).

The control of sourgrass has becoming even more difficult due to the small number of chemical products available for its management (CARPEJANI; OLIVEIRA, 2013; GAZOLA et al., 2016; ZOBIOLE et al., 2016). According to Marochi et al. (2018), only changing the herbicide would not solve the problem, but the adoption of new crop systems, such as crop rotation, mixture of herbicides with different modes of action, and use of cover crops would avoid the selection of even more resistant biotypes.

Glyphosate interrupts the shikimate pathway, inhibiting specifically the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPs) (STEINRÜCKEN; AMRHEIN, 1980). However, the intense use of glyphosate results in high selection pressure within weed populations susceptible to the herbicide and, thus, resulting in selection of resistant biotypes (CHRISTOFFOLETI et al., 2009), which is a phenomenon found in practically all regions of the world where the product is intensively used (HEAP, 2020). The survival of sourgrass in the field after the herbicide application can indicate resistance to glyphosate (GAZOLA et al., 2016; ZOBIOLE et al., 2016; LUCIO et al., 2019). Thirty-two weed species resistant to glyphosate have been reported in 17 countries, including the United States, Australia, Brazil, Spain, and Argentina, where the highest numbers of cases were found (HEAP, 2015; 2020). In addition, the effect of sourgrass has a potential to decrease maize and soybean productions by 32% to 44% (GEMELLI et al., 2013)

The choice of a weed management is carried out considering the species present in the area, the infestation level, edaphoclimatic conditions, and the crop to be grown in the area (PROCÓPIO et al., 2006). After applying glyphosate, most growers continue using this product or a mixture of different herbicides for the management of other weeds in the same area (ZOBIOLE et al., 2016), thus increasing the crop production costs (ALBRECHT et al., 2018). Not all plants that survive to glyphosate applications are resistant, as there is a direct dependence on weather conditions, soil moisture, and plant size, as it is often applied to control plants with flowers, fruits, and seeds (ZOBIOLE et al., 2016; RAIMONDI et al., 2020).

One of the main control methods adopted for the control of adult sourgrass plants resistant to glyphosate is the use of ACCase inhibiting herbicides, mainly clethodim and haloxyfop-P-methyl, which are often applied at rates higher than that recommended by manufacturers and using sequential applications (ZOBIOLE et al., 2016). Multiple resistance is the ability of plants to survive after application of herbicides with two or more action mechanisms (CHRISTOFFOLETI; LÓPEZ OVEJERO, 2008). Takano et al. (2020) reported that resistance to ACCase inhibiting herbicides can be caused by a mutation in the site of action Trp2027Cys, which prevents the connection of several herbicides, such as aryloxyphenoxypropionate, haloxyfop-methyl, and fenoxaprop-p-ethyl.

In this context, the objective of this work was to evaluate the efficacy of mixtures of herbicides to clethodim (clethodim 240 g a.i. L^{-1}, EC, Nortox) and the effect on the efficacy of control of sourgrass, which is a weed species resistant to glyphosate.

MATERIAL AND METHODS

The experiment was conducted in the experimental area of the Federal Institute of Education, Science, and Technology of Mato Grosso do Sul, Ponta Porã campus, Brazil (22°33'07"S; 55°39'02"W). The climate of the region is Aw, with a rainy season in the summer and a dry season in the winter, according to Köppen-Geiger classification (PEEL et al., 2007). The mean annual temperature varies from 20 to 22°C, with means varying from 15 to 19°C and from 23 to 26°C, respectively, in the coldest and hottest months. The mean annual rainfall depths vary from 1,400 to 1,700 mm; November, December, and January are the rainiest months. The rainfall distribution has similar dynamics to the temperature; June, July, and August are the coldest months and present the lowest rainfall indexes.

A commercial area with succession of soybean and maize crops and presence of sourgrass (*Digitaria insularis*) was selected for the experiment, which was conducted from September to October 2020. The area presented biotypes resistant to glyphosate; an application of 1,120 g a.e. ha^{-1} of glyphosate (720WG, Nortox) was carried out before beginning the experiment to verify the resistance of the plants. The soil of the experimental area was classified as a Typic Hapludox (Latossolo Vermelho Distrofico) (EMBRAPA, 2018) of medium texture, whose physical and chemical compositions are described in Table 1.

A randomized block experimental design was used, with 8 treatments (Table 2) and 4 replications, including control treatments with and without manual weeding. The experiment contained 32 plots of 3 m length and 5 m width (15 m^2) each.

The herbicides were applied using a CO_2-pressurized backpack sprayer, with a working pressure of 420 kPa, for an application volume of 200 L ha^{-1}. The sprayer had a 3 m boom with 6 application nozzles with flat spray tips (AIXR 110015; Teejet®, Wheaton, USA) and a 100-µm mesh sieve. The herbicides used were: clethodim, glyphosate, and 2,4-D; the leftovers of the products were discarded in an adequate place for decontamination and water treatment. The application of herbicides and the weeding were carried out on September 5, when the sourgrass plants presented 3 to 5 tillers and 30 to 40 cm height. After the application of herbicides, the percentages of control at 7, 14, 21, and 28 days after application (DAA) were visually evaluated.

TABLE 1 - Physical and chemical compositions of the Typic Hapludox (Latossolo Vermelho Distrofico) collected in the experimental area.

Variable	Unit	Value
pH (water)		6.22
Organic matter	g dm^{-3}	9.24
P (Mehlich)	mg dm^{-3}	3.91
K^+ (potassium)	$cmol_c$ dm^{-3}	0.09
Ca^{2+} (calcium)	$cmol_c$ dm^{-3}	2.98
Mg^{2+} (magnesium)	$cmol_c$ dm^{-3}	1.23
Al^{3+} (aluminum)	$cmol_c$ dm^{-3}	0.30
H+Al (hydrogen + aluminum)	$cmol_c$ dm^{-3}	4.39
Sum of bases	$cmol_c$ dm^{-3}	4.30
Cation exchange capacity (pH = 7.0)	$cmol_c$ dm^{-3}	8.69
Base saturation	%	49.50
Aluminum saturation	%	5.90

TABLE 2 - Description of the treatments used, and commercial product rate, chemical group, primary mode of action, commercial brand, and formulation of herbicides used for sourgrass control.

T	Description	Commercial product rate	Chemical group	Primary mode of action	Commercial brand	Formulation
1	Control with no weeding	-	-	-	-	-
2	Control with weeding	-	-	-	-	-
3	1,800 g e.a. ha^{-1} of glyphosate + 10 mL of MO	Glyphosate (720 g Kg^{-1} a.e.)	Substituted glycine	Inhibition of the EPSPs enzyme	Glyphosate Nortox	Water dispersible granules
4	240 g a.i. ha^{-1} of clethodim + 10 mL of MO	clethodim (240 g a.i. L^{-1})	Cyclohexanedione oxime	Inhibition of the ACCase enzyme	Clethodim Nortox	Emulsifiable Concentrate
5	670 g a.e. ha^{-1} of 2,4-D + 10 mL of MO	2,4-D (670 g a.e. L^{-1})	Phenoxyacids	Growth reduction	2,4-D Nortox	Soluble Concentrate
6	240 g a.i. ha^{-1} of clethodim + 1,800 g e.a. ha^{-1} of glyphosate + 10 mL of MO	clethodim (240 g a.i. L^{-1}) + glyphosate (720 g a.e. Kg^{-1})	Cyclohexanedione oxime + Substituted glycine	Inhibition of ACCase and EPSPs enzymes	Clethodim Nortox + Glyphosate Nortox	Emulsifiable Concentrate + Water dispersible granules
7	240 g a.i. ha^{-1} of clethodim + 670 g a.e. ha^{-1} of 2.4 D + 10 mL of MO	clethodim (240 g a.i. L^{-1}) + 2,4-D (670 g a.e. L^{-1})	Cyclohexanedione oxime + Phenoxyacids	Inhibition of the ACCase enzyme and growth reduction	Clethodim Nortox + 2,4-D Nortox	Emulsifiable Concentrate + Soluble Concentrate
8	240 g a.i. ha^{-1} of clethodim + 1,800 g e.a. ha^{-1} of glyphosate + 670 g a.e. ha^{-1} of 2.4 D + 10 mL of MO	clethodim (240 g a.i. L^{-1}) + glyphosate (720 g Kg^{-1} a.e.) + 2,4-D (670 g a.e. L^{-1})	Cyclohexanedione oxime + Substituted glycine + Phenoxyacids	Inhibition of ACCase, and EPSPs enzymes and growth reduction	Clethodim Nortox + Glyphosate Nortox + 2,4-D Nortox	Emulsifiable Concentrate + Water dispersible granules + Soluble Concentrate

T = treatment, a.i. = active ingredient, a.e. = acid equivalent, MO = mineral oil. Source: Souza et al (2021).

The weed control percentage was evaluated visually using a scale of grades, in which 0 represents the total absence of symptoms and 100 represents the death of the plant (ROLIM, 1989), as described in Table 3. The data obtained were subjected to analysis of variance by the F test and the means were compared by the Tukey's test at 5% probability of error, using the Sisvar® program (FERREIRA, 2011).

TABLE 3 - Scale of grades used to visually evaluate the weed control percentages.

Percentage of control	Evaluation	Grade
99.1 – 100.0	Excellent	9
96.6 – 99.0	Very Good	8
92.6 – 96.5	Good	7
85.1 – 92.5	Fair	6
75.1 – 85.0	Doubtful	5
60.1 – 75.0	Insufficient	4
40.1 – 60.0	Bad	3
15.1 – 40.0	Very bad	2
0.00 – 15.0	With no effect	1

Source: Rolim (1989).

RESULTS AND DISCUSSION

The grades of percentage of control attributed to the treatments are presented in Table 4, which shows significance for all treatments. The evaluation of the experiment at 7 DAA showed that the treatment 2 (with manual weeding) presented a mean grade of 9.0, and was considered the best control. The treatments 6 (clethodim + glyphosate) and 8 (clethodim + glyphosate + 2,4-D) presented means between 2.25 and 3.00; the visual analysis showed that the effect of these treatments on the weeds resulted in a low control. The treatments 4 (clethodim) and 7 (clethodim + 2,4-D) presented the same mean grade, 1.75. The treatments 1 (with no weeding), 3 (glyphosate), and 5 (2,4-D) presented mean grades of 1.00; these treatments had no effect on weed control, since translocation is required for systemic herbicides to reach the sites of action. Herbicides can be translocated by the symplast, the apoplast, or both (MONQUERO, 2014).

TABLE 4 - Grades attributed in the visual evaluation of weed control percentage.

T	Description	7 DAA	14 DAA	21 DAA	28 DAA
1	Control with no weeding	1.00d*	1.00d	1.00d	1.00d
2	Control with weeding	9.00a	9.00a	9.00a	9.00a
3	1,800 g a.e. ha^{-1} of glyphosate + 10 mL of MO	1.00d	1.00d	2.00d	2.50d
4	240 g a.i. ha^{-1} of clethodim + 10 mL of MO	1.75c	3.75bc	6.25c	6.25c
5	670 g a.e. ha^{-1} of 2,4-D + 10 mL of mineral oil	1.00d	1.75cd	2.50d	2.75d
6	240 g a.i. ha^{-1} of clethodim + 1,800 g a.e. ha^{-1} of glyphosate + 10 mL of MO	2.25bc	3.25bc	8.00ab	7.00bc
7	240 g a.i. ha^{-1} of clethodim + 670 g a.e. ha^{-1} of 2,4-D + 10 mL of MO	1.75c	2.50cd	7.00bc	7.50ab
8	240 g a.i. ha^{-1} of clethodim + 1,800 g a.e. ha $^{-1}$ of glyphosate + 670 g a.e. ha $^{-1}$ of 2,4-D + 10 mL of MO	3.00b	4.75B	8.25ab	8.25ab

*Means followed by the same letter in the columns are not different from each other by the Tukey's test at 5% probability of error. T = treatments; a.i. = active ingredient; a.e. = acid equivalent; T = treatment; MO = mineral oil; DAA = days after application.

According to Rodrigues and Almeida (2018), the recommended glyphosate rate for sourgrass control varies from 720 to 1,080 g a.e. ha^{-1}; however, a higher rate was used in the present experiment because the plants already presented formed rhizomes and they were resistance to glyphosate, which was confirmed by the previously application of the herbicide in the area. The two mechanisms of action that present capacity to translocate to the rhizomes are the inhibition of EPSPs, ACCase, auxins, and ALS. Cases of resistance to the first and second had already been described in the literature, showing that they can have a strong action on the meristematic region, but not completely destroying the weed shoots (GEMELLI et al., 2012).

In the evaluation at 14 DAA, the treatment 2 presented a mean grade of 9, while treatments 4, 6, and 8 presented mean grades between 3.25 and 4.75, treatments 5 and 7 presented means between 1.75 and 2.5, and treatments 1 and 3 presented mean grade of 1, based on the visual scale of grades for injuries in weed plants recommended by the Brazilian Weed Science Society (SBCPD, 1995), in which 0 represents absence of control and 10 represents the death of the plant.

In the evaluation at 21 DAA, the treatments 2, 6, and 8 presented the best means (8 to 9); treatment 7 presented a mean grade of 7, with a better control efficacy; treatment 4 presented an increase in the mean to 6.25; and treatments 1, 3, and 5 presented a very low variation, between 1 and 2.5. The combination of herbicides is recommended to increase the quantity of species to be controlled (VIEIRA JÚNIOR et al., 2015) and can assist in the prevention of resistance (OWEN; ZELAYA, 2005) or tolerance (VIEIRA JÚNIOR et al., 2015) in weeds.

In the evaluation at 28 DAA, the means of the treatments 2, 7, and 8 presented variations between 7.5 and 9. The treatment 7 showed increases in the control until the end of the experiment. The treatment 6 presented a mean grade of 7, treatment 4 presented a mean grade of 6.25, and treatments 1, 3, and 5 presented a variation between 1 and 2.75, however, maintaining the grade zero for control, as the weeds in the plots presented resistance to glyphosate and the herbicide rate used had no effect.

ACCase inhibiting herbicides can act on sourgrass plants at later stages, causing necrosis in meristematic growth areas. However, part of the leaves remained chlorotic, erect, and able to interfere with the light that reach the crop (GEMELLI et al., 2012). In the present study, the sourgrass control was more effective with application of clethodim, which should be applied to young plants, avoiding the umbrella effect, i.e., when old leaves protect new sprouts, causing flaws in the deposition of raindrops (COSTA et al., 2011).

However, as new molecules have been created, further works are recommended for evaluating the use of them, or even for these same known molecules, combined and stabilized, to make possible the control and management of sourgrass to reduce costs, facilitate the management, and decrease losses in crops.

CONCLUSIONS

The sourgrass control efficacy was higher for the treatments 6 (240 g a.i. ha^{-1} of clethodim + 1,680 g a.e. ha^{-1} of glyphosate + 10 mL of mineral oil) and 8 (240 g a.i. ha^{-1} of clethodim + 1,680 g a.e. ha^{-1} of a.e. of glyphosate + 806 g a.i. ha^{-1} of 2,4-D + 10 mL of mineral oil), which presented the highest grades in the visual evaluations of weed control.

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