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Article

Glyphosate-Resistant Sourgrass Management Programs Associating Mowing and Herbicides

Sistemas de Manejo Associando Roçada e Herbicidas para o Controle de Capim-Amargoso Resistente a Glyphosate

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ABSTRACT - Currently, sourgrass is one of the most important weeds in grain production areas in Brazil. The objective of this work was to evaluate the efficiency of associated systems composed by mowing and chemical control against clumped sourgrass. In the first experiment, different mowing heights (0, 5, 10, 15 and 20 cm), coupled with complementary applications of glyphosate + clethodim, were evaluated on sourgrass control. The second experiment was composed by programs starting with fallow mowing at different times, 50 (early), 35 (intermediate) and 20 (late) days before soybean sowing. After mowing, treatments were followed by herbicide applications according to the need until soybean harvest. The shorter the mowing height associated with herbicide application, the better the control of sourgrass. The weed management programs (anticipated, intermediate and late) were efficient on sourgrass control during fallow and along soybean cycle. Weed management programs starting with mowing provided better or similar control compared to systems that employed chemical control only, indicating that mowing can replace one of the herbicide applications.

Keywords: *Digitaria insularis*, mechanical control, soybean, fallow.

RESUMO - Atualmente, o capim-amargoso é uma das plantas daninhas mais importantes nas áreas de produção de grãos do Brasil. O objetivo deste trabalho foi avaliar a eficiência de associar a roçada ao controle químico de capim-amargoso entouceirado. Dois experimentos em campo foram realizados. No primeiro, buscou-se avaliar a influência da altura de roçada (0, 5, 10, 15 e 20 cm) sobre o controle de capim-amargoso com a complementação com aplicações de glyphosate + clethodim após a roçada. O segundo experimento foi constituído por tratamentos que iniciaram a operação de roçada durante a entressafra em diferentes períodos: 50 (antecipado), 35 (intermediário) e 20 (tardio) dias antes da semeadura da soja. Os tratamentos foram seguidos de aplicações de herbicidas conforme a necessidade até a colheita da soja. Quanto menor a altura de roçada associada à aplicação de herbicidas, melhor é o controle de capim-amargoso. Os sistemas de manejo (antecipado, intermediário e tardio) foram eficientes para o controle de capim-amargoso na entressafra e na cultura da soja. Sistemas de manejo que se iniciam com a roçada apresentam controle semelhante ou superior ao dos sistemas constituídos apenas por controle químico, podendo a roçada substituir uma aplicação de herbicidas.

Palavras-chave: *Digitaria insularis*, controle mecânico, soja, entressafra.

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INTRODUCTION

Sourgrass (*Digitaria insularis*) is a monocot rizomathous weed species with a C4-phostosynthesis type of metabolism (Kissman and Groth, 1997). Because it is a perennial species, capable of germinating, growing and developing during the whole year, the concern about this type of weed is not only restricted to the plants infesting the crops cycle, but comprises also those plants surviving along fallow periods (Gemelli et al., 2012). Around 45 days after its emergence, when first rhizomes are formed, the aerial part of sourgrass plants starts tillering and accumulating biomass exponentially, thereby impairing control by chemical means (Machado et al., 2006).

Problems of resistance to glyphosate for this species have already been found in citrus orchards (Carvalho et al., 2012), as well as for other mechanisms of action such as the ACCase inhibitors in areas of cotton production in Brazil (Heap, 2018). Due to the intense selection pressure imposed by the repeated use of Roundup Ready (RR®) crops, more than 57% of Brazilian sourgrass biotypes evaluated by Lopez Ovejero et al. (2017), in at least 12 states from Brazil, were considered as resistant to glyphosate.

Brazilian grain yield production from double cropping of soybean (in the summer) and corn "second season" (in fall/winter) exceeded, respectively, 114 and 68 million of metric tons in 2017 (IBGE, 2018), characterizing such succession as the most important among the different agricultural activities explored in the country. In production areas, such as those, there is usually a fallow period between corn harvest and next soybean sowing, when soil remains uncovered, promoting the emergence and development of weeds like sourgrass.

During the fallow period that precedes the summer crops, one of the most effective systems to control sourgrass consists in a program with two sequential applications of herbicides during burndown, usually followed by a third application after crop emergence. The first application usually occurs between 10 and 15 days prior to sowing, with systemic herbicides; the second application with a contact herbicide is performed at or very close to the sowing date (Melo et al., 2012; Zobiole et al., 2016). However, in situations where the crop is sown soon after this type of management with intense ground cover, negative impacts on initial development and decreases in crop yield have been observed (Oliveira Jr. et al., 2006; Constantin et al., 2007; Constantin et al., 2009). On the other hand, the permanence of sourgrass plants throughout fallow has raised concern due to its substantial biomass accumulation and to the resistance to herbicides currently employed in crop production systems.

Mowing consists in cutting aerial parts of the plants very close to soil and it is a method widely used in perennial crops and in organic farming that can also be useful in annual cropping systems (Silva et al., 2011). Sourgrass plants are able to resprout, i.e. develop, from rhizomes located below soil surface. However, for successful resprouts emergence, part of the culms must remain in sourgrass plants (Raimondi, 2018). Hence, the hypothesis of this work is that the combination of mowing with chemical control can be an efficient method to provide control of sourgrass in soybean-producing systems and that the shorter the sourgrass plants are mowed, the more efficient is the inhibition of resprout growth. Additionally, there is a need to understand whether the application of systemic herbicides, immediately after mowing on the remaining culms and leaves, presents any positive effect on controlling such species.

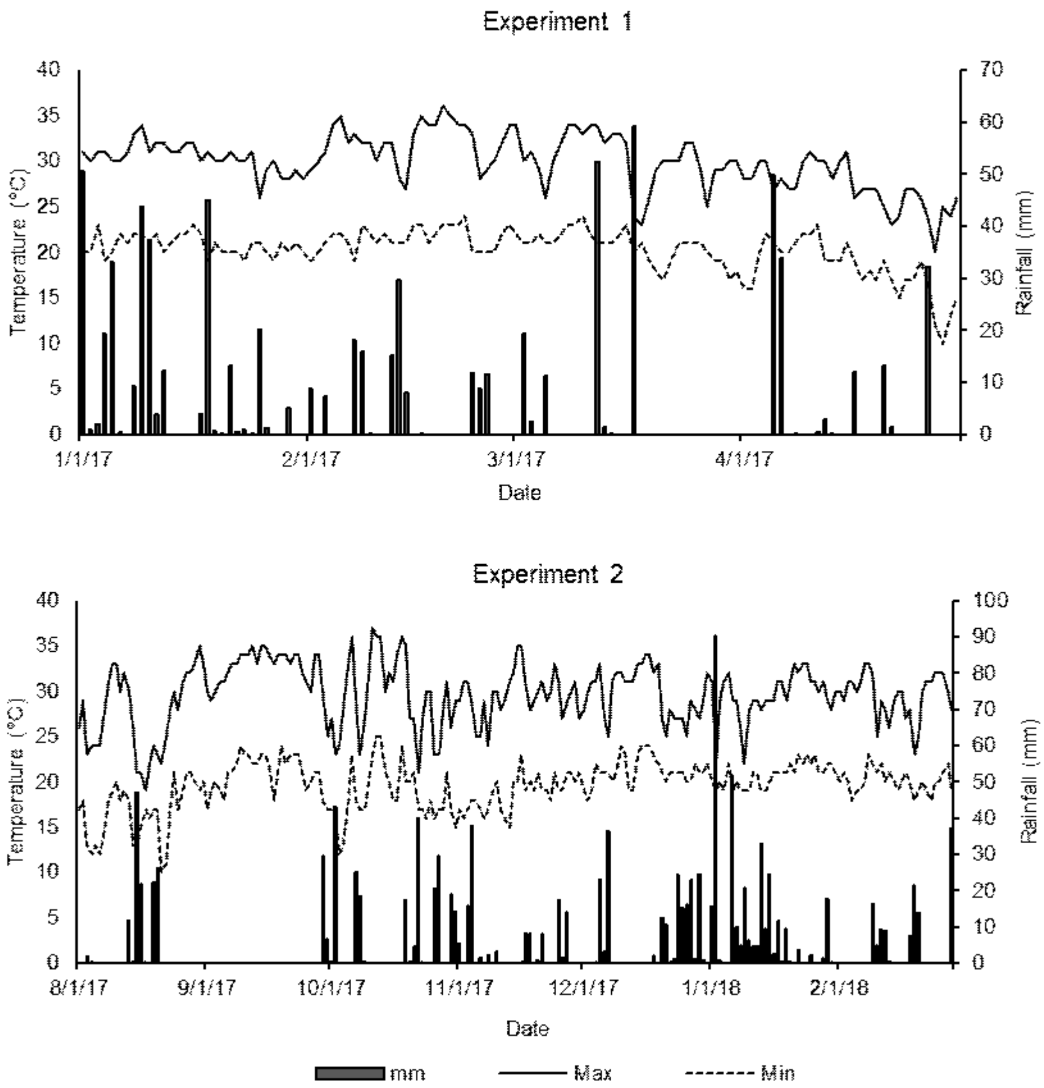
The objectives of the present study were (a) to investigate the effect of one application of glyphosate + clethodim immediately after sourgrass mowing; (b) to understand the effect of mowing height associated to herbicides on the control of clumped plants of sourgrass and (c) to evaluate options that integrate mowing and herbicide use in management programs comprising the fallow period and the successional soybean cropping.

MATERIAL AND METHODS

Experiment 1. Sourgrass mowing height associated to chemical control

The goal of the first experiment (Exp. 1) was to determine the effect of mowing height associated to chemical control for sourgrass management, as well as to evaluate the effectiveness of one herbicide application immediately after mowing.

Exp. 1 was performed in Mandaguaçú (PR), from January to April 2017. Individual plots measured 4 by 4 m in size (16 m²) and right at the beginning of the trial there were three to four sourgrass clumps per m² with an average height of 1.6 m. The biotype in this area had a previous documented history of glyphosate resistance for at least five years. Daily rainfall and average daily temperatures are presented in Figure 1.



Source: INMET – Climatologic Station of Maringá, 2018.

Figure 1 - Maximum and minimum temperatures (°C) and rainfall (mm) during the experiments conduction period.

Exp. 1 was planned as a factorial design (5 x 2) + 3. Levels of first factor were constituted by five mowing heights (0, 5, 10, 15 and 20 cm). The second factor was composed by the presence or absence of the herbicide application immediately after mowing (glyphosate + clethodim – 1,110 + 192 g ha^{-1}). The three additional treatments were composed by an absolute check (without any method of control), a mowing-only check and a standard herbicide program (two sequential applications of glyphosate+clethodim (at 1,110+192 g ha^{-1}) sprayed with the interval of 15 days followed by another application of glyphosate+clethodim (1,110+108 g ha^{-1}) 15 days after the second application) (Table 1). The experimental design was randomized complete block with four replications.

After mowing, resprouts of five aleatory clumps per plot had their height measured weekly. The moment of herbicide application was defined individually for each treatment based on when average growth of resprouts reached 15 cm. At 15 days after mowing (DAM), herbicide application

Table 1 - Description of treatments of Experiment 1. Mandaguaçu (PR), 2018

Treatment		Immediate herbicide application[1]	Application A gly+cle (1,110+192 g ha^{-1})	Application B gly+cle (1,110+108 g ha^{-1})
1	Mowing height at 0 cm	Yes	15 DAM	70 DAM
2	Mowing height at 5 cm	Yes	15 DAM	70 DAM
3	Mowing height at 10 cm	Yes	15 DAM	70 DAM
4	Mowing height at 15 cm	Yes	15 DAM	45 DAM
5	Mowing height at 20 cm	Yes	15 DAM	45 DAM
6	Mowing height at 0 cm	No	15 DAM	70 DAM
7	Mowing height at 5 cm	No	15 DAM	70 DAM
8	Mowing height at 10 cm	No	15 DAM	70 DAM
9	Mowing height at 15 cm	No	15 DAM	45 DAM
10	Mowing height at 20 cm	No	15 DAM	45 DAM
11	Absolute check[2]	-	-	-
12	Mowing check[3]	-	-	-
13	“Standard” herbicide program[4]			

[1]Application of glyphosate + clethodim (1,110 + 192 g ha^{-1}) immediately after mowing at 5 cm height; [2] Check without any method of control; [3] Check with mowing only; [4] Two sequential applications of gly+cle (1,110+192 g ha^{-1}) sprayed with the interval of 15 days followed by another application of gly+cle (1,110+108 g ha^{-1}) 15 days after the second application. All herbicide applications were performed with 0.5% v v^{-1} of mineral oil. Abbreviations: gly: glyphosate; cle: clethodim; DAM: days after mowing.

was performed for all treatments with mowing. Average 15 cm of regrowth was observed at 45 DAM for treatments with mowing heights at 15 and 20 cm, when a new application of the same herbicide treatment was performed. For treatments mowed at heights of 0, 5 and 10 cm, the average new regrowth of 15 cm was observed at 75 DAM, when these treatments also received a new application of the same herbicide treatment (Table 1).

The equipment used for all mowing operations was a Stihl FS 220 portable rotary mower with a three-pointed steel blade. All herbicide treatments were applied with a CO_2-pressurized backpack sprayer equipped with ST 0.15 flat-fan nozzle tips calibrated to deliver 150 L ha^{-1} at 30 psi. Treatments were applied at a speed of 1,0 m s^{-1}.

Sourgrass control was visually estimated weekly up to 90 DAM in five clumps per plot demarcated at the beginning of the trial with a visual scale of 0-100%, where 0 indicated no symptoms and 100% indicated plant death.

Data were analyzed by F test and a linear regression model was adjusted when the effect of mowing height was significative. Comparisons to additional treatments was performed by the decomposition of sum of squares of treatments into orthogonal contrasts. All statistical analysis was performed using the software Sisvar 2012 (UFLA, Lavras, MG, Brazil) and used a 5% probability ($p \leq 0.05$) level, along with Microsoft Excel, for F values correction.

Experiment 2. Weed control programs including mowing and chemical control

The goal of the second experiment (Exp. 2) was to determine the best weed control program for the fallow period prior to soybean sowing, associating mowing and chemical control.

Exp. 2 was also performed in Mandaguaçú (PR), from September 2017 to February 2018, in an experimental site cultivated with double cropping soybeans followed by corn. Meteorological data observed along the study are presented in Figure 1. Individual plots measured 5 by 4 m in size (20 m^2) and sourgrass density in the experimental site was from 6 to 9 clumps per m^2, with an average height of 1.5 m. The biotype in this area also had a previous documented history of glyphosate resistance for at least five years.

Treatments were divided in three groups (“weed management programs”, WMP), according to the time interval during fallow between the first mowing and/or herbicide application and soybean sowing. The first group (treatments from 1 to 5) was referred as “Anticipated” (starting at 50 days before sowing – DBS); the second (treatments 6 and 7) as “Intermediate” (starting at 35 DBS), and the third (treatments from 8 to 12) as “Late” (starting at 20 DBS). Treatments 13 and 14 corresponded to nontreated check and weeded check, respectively. Similarly to Exp. 1, heights of sourgrass clumps were measured weekly, and the decision for a new herbicide application was always based in a new regrowth of 15 cm. Mowing and herbicide applications were performed as described in Exp. 1 and mowing height was fixed at 5 cm. Treatments are described in details in Table 2. The experimental design was randomized complete block with four replications.

Table 2 - Description of treatments of Experiment 2. Mandaguaçu (PR), 2018

Treat.	Weed Management Program (WMP)	Sep/11	Sep/26	Oct/11	Oct/16	Oct/31	Nov/25	Nov/30	Dec/05
		50 DBS	35 DBS	20 DBS	5 DBS	Sowing	25 DAS	30 DAS	35 DAS
1	Anticipated (starting at 50 DBS)	gly+cle	-	gly+cle	-	paraq	-	-	gly+cle
2		mowing/gly+cle	gly+cle	-	-	paraq	-	-	gly+cle
3		mowing/gly+cle	gly+cle	-	-	gly+cle	-	-	-
4		mowing	gly+cle	-	-	paraq	-	-	gly+cle
5		mowing	gly+cle	-	-	gly+cle	-	-	-
6	Intermediate (starting at 35 DBS)	-	mowing/gly+cle	gly+cle	-	-	-	-	gly+cle
7		-	mowing	gly+cle	-	-	-	-	gly+cle
8	Late (starting at 20 DBS)	-	-	gly+cle	paraq	-	gly+cle	-	-
9		-	-	mowing /gly+cle	gly+cle	-	-	-	-
10		-	-	mowing /gly+cle	paraq	-	-	gly+cle	-
11		-	-	mowing	gly+cle	-	-	-	-
12		-	-	mowing	paraq	-	-	gly+cle	-
13	Nontreated check	-	-	-	-	-	-	-	-
14	Weeded check	-	-	-	-	-	-	-	-

“/”: indicates immediate sequential application. Dose of glyphosate + clethodim prior to sowing: 1,110 + 192 g ha^{-1} + mineral oil (0.5% v v^{-1}). Dose of glyphosate + clethodim after sowing: 1,110 + 108 g ha^{-1} + mineral oil (0.5% v v^{-1}); paraquat applied at 400 g ha^{-1} + adjuvant (0.2% v v^{-1}). Abbreviations: Treat. = treatment; DBS = days before sowing; DAS = days after sowing; gly = glyphosate; cle = clethodim; paraq = paraquat.

Monsoy 6410 IPRO soybean was sowed (10/31/2017) at 222,000 seeds ha^{-1} in rows spaced 45 cm apart into a no-till seedbed and received 200 kg ha^{-1} of a 02-20-18 formulated NPK mixture. Each parcel was composed by seven soybean rows. Soybean protection against insects and diseases was based on the recommendations of Embrapa (2013). Weeds other than sourgrass were manually removed from the area throughout the experiment.

Sourgrass control was evaluated weekly as described in Exp. 1. At soybean harvest, remaining sourgrass clumps in each plot were counted. Concerning to soybean, crop stand (sample: plants present in 2 m of central line in each plot) and plant height (sample: 10 plants per plot, at harvest) were recorded. Soybean was harvested with a Wintersteiger plot combined with a 1.7 m wide draper type platform, on February 14, 2018, by harvesting 4 m of three central lines in each plot. After cleaning, plot yield moisture was determined on grain samples. Yields are reported in kg ha^{-1} on a 13 percent moisture basis.

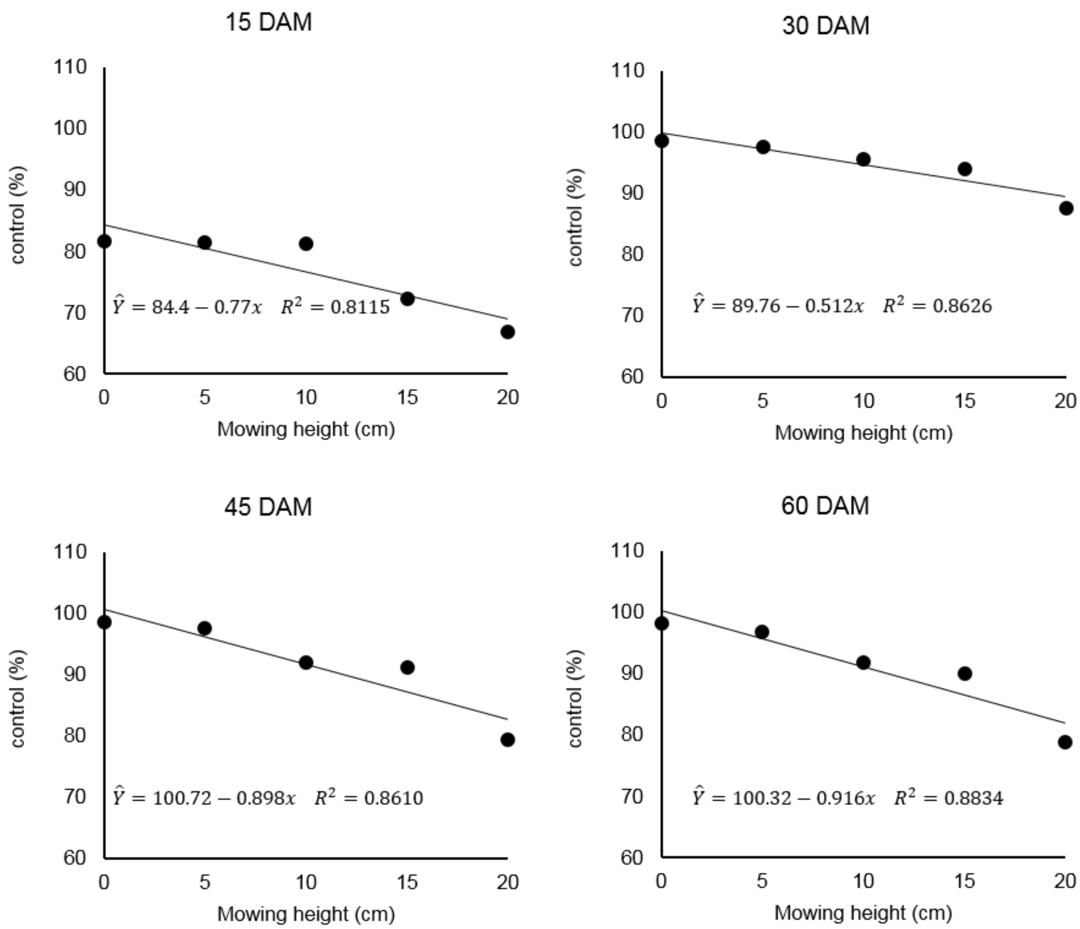
Data from each evaluation were submitted to F test and compared by Scott-Knott grouping test, both at 5% probability by using SISVAR 2012.

RESULTS AND DISCUSSION

Exp. 1. Sourgrass mowing height associated to chemical control

There was no interaction between main factors for all evaluations. The isolated effect of presence or absence of the herbicide application immediately after mowing was significative only at 7 DAM (data not shown). At this date, treatments with herbicide application provided improved (+4.1%) control. The relatively small difference was observed in only one evaluation date, providing evidences that mowing did not provided an important contribution to sourgrass control.

The isolated effect of mowing presented a linear effect on sourgrass control, i.e., the shorter the mowing height, the better the control up to 60 DAM. Every 10 cm the mowing height is reduced in relation to the ground caused an improvement of the control of sourgrass by 7.7, 5.1, 8.9 and 9.1% at 15, 30, 45 and 60 DAM, respectively (Figure 2). In subsequent evaluations, no relationship between mowing height and control was found, once treatments received another herbicide application as sourgrass clumps resprouts reached 15 cm. At the end of the experiment, all treatments with mowing, regardless of the height where it was executed, provided excellent levels of control (≥98.8%).



DAM = days after mowing.

Figure 2 - Control of clumped plants of sorgrass as affected by mowing height associated to chemical control. Mandaguaçu (PR), 2018.

For mowing heights of 0, 5 and 10 cm, the regrowth of sourgrass was slower after the first herbicide application. For those heights, the interval between applications was 49 days, while the interval between two applications in upper mowing heights (15 and 20 cm) was 30 days (Table 3). The taller the clumps are mowed, the more carbohydrate and nitrogen reserves remain available to accelerate the capacity to regrow (Foloni et al., 2008). Additionally, the elimination of an increased number of buds by mowing at shorter heights also contributes for the impaired resprouts regrowth.

As well as for other tropical grass species, the taller the mowing, the more foliar area remains in plants and, therefore, more light interception and biomass production is expected after mowing (Dim et al., 2015; Macedo et al., 2017). Hence, the lowest levels of control when mowing is associated to chemical control are found when plants are mowed at 40 cm (Raimondi, 2018).

Comparing treatments composed by mowing + chemical control with those with use of herbicides only, the final control of sourgrass was significatively higher when sourgrass clumps

Table 3 - Control of clumped sourgrass after mowing at different heights associated to herbicide application. Mandaguaçu (PR), 2018

Treat.	% control									
Mowing height (cm)	Jan/28 15 DAM	Jan/28 A	Feb/12 30 DAM	Feb/27 45 DAM	Feb/27 B	Mar/14 60 DAM	Mar/24 70 DAM	Mar/24 B	Mar/29 75 DAM	Apr/13 90 DAM
0	81.6(+)	*	98.5(+)	98.6(+)		98.2	94.5(+)	*	97.6(+)	100.0(+)
5	81.4(+)	*	97.6(+)	97.6(+)		96.8	86.3	*	93.9(+)	100.0(+)
10	81.3(+)	*	95.6(+)	92.0(+)		91.8	87.4	*	89.0(+)	98.8(+)
15	72.3(+)	*	94.0(+)	91.1(+)	*	90.0	94.8(+)		99.5(+)	99.0(+)
20	66.9(+)	*	87.5(+)	79.4	*	78.8(-)	89.9		99.3(+)	99.0(+)
Chemical control(1)	46.0		79.0	79.0		94.0	82.0		83.0	96.0

(+) superior to the treatment with chemical control only (5% probablility) by the decomposition of sum of squares of treatments into orthogonal contrasts. (1) Treatment with chemical control only: glyphosate + clethodim (1,110 + 192 g ha^{-1}) + mineral oil (0.5% v v^{-1})/ glyphosate + clethodim (1,110 + 192 g ha^{-1}) + mineral oil (0.5% v v^{-1})/glyphosate + clethodim (1,110 + 108 g ha^{-1}) + mineral oil (0.5% v v^{-1}), * indicate that treatments were sprayed at that date. Abbreviations: DAM = days after mowing. A = application A (glyphosate + clethodim at 1,110 + 192 g ha^{-1} + mineral oil 0.5% v v^{-1}); B = application B (glyphosate + clethodim at 1,110 + 108 g ha^{-1} + mineral oil 0.5% v v^{-1}).

were mowed (Table 3), providing evidences that mowing can replace one of the herbicide applications in management systems developed for sourgrass control.

Experiment 2. Weed control programs including mowing and chemical control

Exp. 2 confirmed that one herbicide application right after mowing does not provide any benefit in the final control imposed to sourgrass. For both anticipated and intermediate WMPs, sourgrass control at six days before sowing (DBS) was similar to those treatments with or without herbicide application immediately after mowing (Table 4).

Close to the sowing date (6 DBS), the group of treatments with the best results was that in which WMP was initiated at 35 DBS (intermediate WMP). The group of treatments with anticipated

Table 4 - Control (%) of clumped sourgrass with different management programs associating mowing and chemical control throughout fallow and soybean cropping cycle. Mandaguaçu (PR), 2018

Treat.	Sep/11 50 DBS	Sep/26 35 DBS	Oct/11 20 DBS	Oct/25 6 DBS	Oct/26 5 DBS	Oct/31 Sowing	Nov/10 10 DAS	Nov/25 25 DAS	Nov/30 30 DAS	Dec/04 34 DAS	Dec/05 35 DAS	Jan/15 76 DAS	Jan/15 Clump density (nº m^{-2})
1	gly+cle	-	gly+cle	90.0 b	-	paraq	91.7 b	-	-	73.0 c	gly+cle	87.7 c	0.03 c
2	mowing/gly+cle	gly+cle	-	94.7 b	-	paraq	97.2 a	-	-	79.5 b	gly+cle	96.5 a	0.04 c
3	mowing/gly+cle	gly+cle	-	92.5 b	-	gly+cle	99.7 a	-	-	98.0 a	-	99.0 a	0.14 c
4	mowing	gly+cle	-	89.7 b	-	paraq	94.0 b	-	-	77.5 b	gly+cle	94.5 a	0.06 c
5	mowing	gly+cle	-	91.0 b	-	gly+cle	98.0 a	-	-	94.5 a	-	97.2 a	0.18 c
6	-	mowing /gly+cle	gly+cle	98.5 a	-	-	98.7 a	-	-	85.7 b	gly+cle	97.7 a	0.03 c
7	-	mowing	gly+cle	97.5 a	-	-	99.0 a	-	-	84.7 b	gly+cle	96.2 a	0.00 c
8	-	-	gly+cle	73.0 e	paraq	-	76.2 c	gly+cle	-	70.7 c	-	91.5 b	0.64 b
9	-	-	mowing/gly+cle	85.5 c	gly+cle	-	99.7 a	-	-	97.7 a	-	97.7 a	0.14 c
10	-	-	mowing/gly+cle	83.7 c	paraq	-	91.7 b	-	gly+cle	80.0 b	-	95.7 a	0.08 c
11	-	-	mowing	79.0 d	gly+cle	-	99.5 a	-	-	95.0 a	-	95.5 a	0.24 c
12	-	-	mowing	80.0 d	paraq	-	93.0 b	-	gly+cle	84.7 b	-	96.2 a	0.01 c
13	Nontreated check	-	-	0.0 f	-	-	0.0 d	-	-	0.0 d	-	0.0 d	6.19 a
14	Weeded check	-	-	100.0 a	-	-	100.0 a	-	-	100.0 a	-	100.0 a	0.00 c
F				210.3			395.3			101.7		957.9	230.16

Means followed by the same letters do not differ from each other by Scott-Knott test (5% probability). "/": indicates immediate sequential application. Dose of glyphosate + clethodim prior to sowing: 1,110 + 192 g ha^{-1} + mineral oil (0.5% v v^{-1}). Dose of glyphosate + clethodim after sowing: 1,110 + 108 g ha^{-1} + mineral oil (0.5% v v^{-1}); paraquat applied at 400 g ha^{-1} + adjuvant (0.2% v v^{-1}). Abbreviations: Treat. = treatment; DBS = days before sowing; DAS = days after sowing; gly = glyphosate; cle = clethodim; paraq = paraquat. For all tratments, herbicide reapplication was performed when resprouts reached 15 cm height.

WMP (50 DBS) also provided good control levels (≥89.1%), but the time interval between the beginning of WMP and soybean sowing was long enough for sourgrass to resprout twice. The lowest levels of control (between 73 and 85.5%) were found in late WMP treatments starting at 5 DBS (Table 4).

At 10 days after sowing (DAS), which is concomitant to the soybean emergence, treatments that had previously received glyphosate + clethodim provided better control if compared with those treated with paraquat when resprouts reached 15 cm after mowing. This has been observed for both treatments in anticipated WMP, as well as for those in late WMP. Treatments from the intermediate WMP remained providing outstanding control levels (≥98.7%) in this evaluation. The treatment with the exclusive use of chemical control, composed by the application of the herbicides glyphosate + clethodim at 20 DBS followed by paraquat, demonstrated the lowest control at 10 DAS (Table 4).

Due to the limited control, late WMP treatments comprised by sequential applications of paraquat allowed the fast regrowth of sourgrass clumps, requiring new post-emergence herbicide applications at very early stages of soybeans (Table 4).

At 34 DAS, close to the soybean canopy closure, all treatments applied with systemic herbicides (glyphosate + clethodim) before sowing (20 DBS, 5 DBS or at sowing date) provided excellent levels of control. In contrast, despite the WMP, treatments receiving paraquat before soybean sowing presented the lowest levels of sourgrass control (Table 4). Correia et al. (2015) also found efficient control of sourgrass by applying ACCase inhibitors after sourgrass mowing at heights of 30-40 cm.

At harvest (76 DAS), all treatments including mowing at the beginning of WMPs provided excellent levels of control and were superior if compared to the treatments composed only by herbicide application. An increased density of sourgrass clumps was found for the treatments composed by late WMP with herbicides, if compared to the remaining treatments (Table 4).

Lack of efficient control of sourgrass caused losses of 52.1% in crop stand and impaired crop growth by 40.5%, resulting in grain yield losses of 76.4%. All treatments employing weed control methods were appropriate to prevent negative effects on those variables (Table 5). Despite no negative effects were found for crop stand, height and yield, treatments providing lower levels of

Table 5 - Soybean stand, plant height and soybean yield as a function of treatments associating mowing and herbicides to provide control of clumped plants of sourgrass, Mandaguaçu (PR), 2018

Treat.	Sep/11	Sep/26	Oct/11	Oct/16	Oct/31	Nov/25	Nov/30	Dec/05	At soybean harvest		Feb/14
	50 DBS	35 DBS	20 DBS	5 DBS	Sowing	25 DAS	30 DAS	35 DAS	Stand (plants m^{-1})	Height (cm)	Yield (kg ha^{-1})
1	gly+cle	-	gly+cle	-	paraq	-	-	gly+cle	11.4 a	81.7 a	3345.2 a
2	mowing/gly+cle	-	-	-	paraq	-	-	gly+cle	11.6 a	77.9 a	3669.9 a
3	mowing/gly+cle	-	-	-	gly+cle	-	-	-	11.3 a	78.8 a	3294.7 a
4	mowing	-	-	-	paraq	-	-	gly+cle	11.6 a	76.0 a	3367.0 a
5	mowing	-	-	-	gly+cle	-	-	-	11.8 a	81.3 a	3347.4 a
6	-	mowing/gly+cle	gly+cle	-	-	-	-	gly+cle	12.4 a	80.4 a	3444.2 a
7	-	mowing	gly+cle	-	-	-	-	gly+cle	11.8 a	82.9 a	3521.5 a
8	-	-	gly+cle	paraq	-	gly+cle	-	-	11.1 a	75.6 a	3196.7 a
9	-	-	mowing/gly+cle	gly+cle	-	-	-	-	11.9 a	84.2 a	3532.8 a
10	-	-	mowing/gly+cle	paraq	-	-	gly+cle	-	11.8 a	77.9 a	3486.6 a
11	-	-	mowing	gly+cle	-	-	-	-	12.3 a	79.7 a	3473.2 a
12	-	-	mowing	paraq	-	-	gly+cle	-	12.2 a	77.3 a	3788.0 a
13	Nontreated check	-	-	-	-	-	-	-	5.8 b	49.1 b	827.0 b
14	Weeded check	-	-	-	-	-	-	-	12.0 a	82.6 a	3509.4 a
F									5.72	6.16	16.1

Means followed by the same letters do not differ from each other by Scott-Knott test (5% probability). “/”: indicates sequential application; Dose of glyphosate + clethodim prior to crop sowing: 1,110 + 192 g ha^{-1} + mineral oil (0.5% v v^{-1}); Dose of glyphosate + clethodim afeter crop sowing and emergence: 1,110 + 108 g ha^{-1} + mineral oil (0.5% v v^{-1}); paraquat applied at 400 g ha^{-1} + adjuvant (0.2% v v^{-1}). Abbreviations: Treat. = treatment; DBS = days before sowing; DAS = days after sowing; gly = glyphosate; cle = clethodim; paraq = paraquat. For all tratments, herbicide reapplication was performed when resprouts reached 15 cm height.

control at early stages of crop development (10 and 34 DAS) tend to impose crop interference due to the regrowth of sourgrass clumps.

In general, when paraquat is applied prior to sowing, sourgrass regrowth is faster, leading to decreasing levels of control. At the same time, the use of paraquat represents an alternative mode of action to substitute clethodim within sourgrass control programs, which is important to decrease selection pressure for resistant biotypes (Johnson and Gibson, 2006).

All WMPs (anticipated, intermediate or late) provided appropriated final results, and did not cause any soybean yield reduction. Thus, the choice of treatments can be made based on the lowest costs, on the availability of supplies, on the ideal conditions of application and on the increased diversity of weed control methods towards the implementation of more diverse integrated programs of weed control.

The most efficient WMP with the fewest operations was that with mowing at 20 DBS, followed by glyphosate + clethodim at 5 DBS, with no need of a further soybean post-emergence application (T11 – Table 4). Crop sowing right after sequential applications of herbicides served as a cultivation control method. After emergence, crop canopy may have prevented light to reach the inter-rows, and therefore, inhibited regrowth of sourgrass. However, in situations where other emergence fluxes or other weeds are present, there might be the necessity of keeping post-emergence soybean control methods.

Practical implications in sourgrass integrated management

The hypothesis of improved control by herbicide application immediately after mowing is related to the eventual herbicide absorption and translocation through culms and remaining leaves. This type of practice is usual for weed control in pastures by cut-stump herbicide applications (Mendes et al., 2016). However, the most common weeds in pastures are dicotyledonous species, either herbaceous plants or woody shrubs. Morphologically, grasses like sourgrass do not have a differentiated vascular system as dicotyledonous species, which can somehow limit herbicide translocation to other parts of the plants and, therefore, explain the lack of control gain with this type of mechanical operation found in the present work.

Applications of ACCase inhibitor herbicides in sourgrass plants of up to five tillers have provided efficient control (Licorini et al., 2015). However, at least two sequential applications are required to provide control of pre-flowering plants (Melo et al., 2012; Zobiole et al., 2016). Aiming at the reduction of the use of herbicides and, thereby, decrease the selection pressure for resistant biotypes, mowing poses as a very important tool, once it can efficiently replace one herbicide application and bring diversity into the weed control systems.

Mowing is usually considered a low performance operational task. However, this method can provide benefits for the control of adult plants of sourgrass and other weeds compared to programs based on chemical measures only. Elimination of aerial parts prevents seeds to be formed and dispersed and contributes to the depletion of reserves in vegetative structures, decreases the risk of selection of herbicide-resistant biotypes, improves the operational performance of seeders and prevents crop etiolation by the straw shading. Mowed plants will develop new leaves with thinner cuticles, what enable increased leaf absorption of herbicides applied afterwards (Correia et al., 2015).

In production areas like the Brazilian Cerrado, the fallow periods have very limited to no rain and low relative air humidity, unsuitable conditions for herbicide application. In such areas, sourgrass control has recurrently been performed by plowing and harrowing. Soil disturbance may have negative effects on soil quality, on organic matter contents, on erosion and on compaction below plow layer (Lisboa et al., 2012), and may also represent even more limited operational task performances if compared to mowing. Therefore, mowing fits as an alternative practice of mechanical control with more conservationist features than soil revolving practices, which can also be even performed in periods of the year when climatic conditions limit or prevent the application of herbicides.

Because sourgrass is a perennial species, it cannot be controlled only by mowing, and chemical control is required. That observation does not exclude the need of considering other methods of control in annual crops production areas, such as soil cover crops like *Urochloa brizantha, Mucuna pruriens* and *Cajanus cajan* (Petter et al., 2015).

There is no benefit for sourgrass control when glyphosate + cletodim are applied soon after mowing. The shorter is the mowing height associated to chemical control, the better the control of clumped sourgrass. During fallow periods when sourgrass develop and infestation is mainly composed by clumped plants, mowing associated to chemical control pose as an efficient alternative for weed control programs starting from 50 to 20 days prior to soybean sowing.

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