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Crop Science/ Original Article

Alternatives for the chemical control of sourgrass at post-emergence

Abstract – The objective of this work was to evaluate the effectiveness of herbicides when applied alone and in combinations at sourgrass (*Digitaria insularis*) post-emergence, as well as to identify a substitute to paraquat in sequential application. Field and greenhouse experiments were conducted during the 2019/2020 and 2020/2021 crop seasons. The herbicides applied alone and in combinations were: atrazine, clethodim, clodinafop, diquat, glufosinate, haloxyfop, imazapic, imazapyr, mesotrione, nicosulfuron, paraquat, glyphosate, saflufenacil, tembotrione, and tepraloxydim. In the 2019/2020 crop season, in the experiment conducted in the field, the control of sourgrass was considered low due to the dry weather condition and to the full flowering of the plants. In the greenhouse, a satisfactory control above 80% was observed at 28 days after herbicide application for most treatments. In the 2020/2021 crop season, under field conditions, the application of glyphosate combined with haloxyfop, with a sequential application of glufosinate, resulted in the highest weed control. In the greenhouse, most treatments were effective and, of these, all contained glufosinate. The sequential application of glufosinate or in combinations favors a better control of sourgrass. However, diquat and glufosinate do not differ in efficacy in sequential application and are an option for the control of the weed.

Index terms: clethodim, glufosinate, haloxyfop, herbicide resistance, weed control.

Alternativas para o controle químico de capim-amargoso em pós-emergência

Resumo – O objetivo deste trabalho foi avaliar a eficácia de herbicidas quando aplicados isolados e em combinações na pós-emergência de capim-amargoso (*Digitaria insularis*), bem como identificar um substituto ao paraquat na aplicação sequencial. Experimentos em campo e em casa de vegetação foram conduzidos durante as safras de 2019/2020 e 2020/2021. Os herbicidas aplicados isolados e em combinações foram: atrazina, cletodim, clodinafope, diquate, glufosinato, haloxifope, imazapique, imazapir, mesotriona, nicossulfurom, paraquate, glifosato, saflufenacil, tembotriona e tepraloxidim. Na safra de 2019/2020, no experimento em campo, o controle de capim-amargoso foi considerado baixo devido às condições de clima seco e ao pleno florescimento das plantas. Na casa de vegetação, observou-se controle satisfatório acima de 80% aos 28 dias após a aplicação dos herbicidas para a maioria dos tratamentos. Na safra de 2020/2021, em condições de campo, a aplicação de glifosato combinado com haloxifope, com aplicação sequencial de glufosinato, resultou no maior controle da planta daninha. Na casa de vegetação, a maioria dos tratamentos foi eficaz e, destes, todos continham glufosinato. A aplicação sequencial de glufosinato ou em combinações favorece um melhor controle de capim-amargoso. No entanto, o diquate e o glufosinato não diferem em eficácia na aplicação sequencial e são opções de controle desta planta daninha.

Termos para indexação: cletodim, glufosinato, haloxifope, resistência a herbicidas, controle de plantas daninhas.

Introduction

Sourgrass [*Digitaria insularis* (L.) Mez ex Ekman] is a hard-to-control weed of the family Poaceae. It is native to tropical and subtropical regions of America (Veldman & Putz, 2011), being commonly found in the Southeastern, Midwestern, and Northeastern regions of Brazil (Albrecht et al., 2020b). The species is perennial and herbaceous, with slightly rough leaves and small seeds, which are easily dispersed by the wind and show a high reproduction capacity, germinating almost the whole year, with a high regrowth capacity due to its rhizomes that facilitate the formation of clumps (Machado et al., 2008).

These characteristics of sourgrass allow of its survival in environments that present challenging conditions to its growth and development (Albrecht et al., 2020b), hindering the growth of crops. In the case of soybean [*Glycine max* (L.) Merr.], the coexistence of eight plants of this weed species per square meter is enough to reduce crop yield by 80% (Gazziero et al., 2019; Braz et al., 2021). However, managing sourgrass is complex because of the reduced effectiveness of many herbicides, whose improper applications favor selection pressure and cause the emergence of resistant populations. Another particular reason is that this weed presents biotypes resistant to glyphosate (Gonçalves-Netto et al., 2021), to herbicide inhibiting 5-enolpyruvylshikimate-3-phosphate synthase, and to herbicides inhibiting acetyl-CoA carboxylase (ACCase), such as haloxyfop, fenoxaprop, and pinoxaden (Takano et al., 2020).

For a more effective control of sourgrass, the herbicide must be applied when the weed is still small, with a maximum of one to three tillers. Moreover, in order to manage resistant sourgrass, two strategies can be adopted: desiccation with post-emergence herbicides in the beginning of weed development to prevent seed production; and rotation of the modes of action or chemical groups of the herbicides. These strategies should be complemented with other agricultural practices, such as cleaning of the used machinery after harvesting, weeding, crop rotation, mowing, cover crops, and the application of pre-emergence herbicides. Oliveira Júnior et al. (2006) and Canedo et al. (2019) highlighted that desiccation should be done before crop planting and, when necessary, complemented with the application of other products. According to Oliveira Jr. et al. (2006), desiccation immediately prior to sowing involves the application of one or more herbicides, depending on the floristic composition of the area and weed density.

Among the herbicides used for the control of sourgrass resistant to glyphosate, ACCase inhibitor herbicides, such as clethodim and haloxyfop, stand out. These herbicides are generally effective in the early stages of weed development (Presoto et al., 2020). However, considering plant regrowth, a single application of herbicides, even at high rates, is not sufficient for an effective control of perennial weeds, requiring sequential applications (Zobiole et al., 2016; Mendes et al., 2020).

In Brazil, alternative products are required for the control of sourgrass (Albrecht et al., 2022), especially since the commercialization of paraquat, in combinations or sequentially, was prohibited since 2021 (Zobiole et al., 2016). It is hypothesized that the combination of herbicides with different modes of action will be effective in controlling sourgrass at post-emergence.

The objective of this work was to evaluate the effectiveness of herbicides when applied alone and in combinations at sourgrass post-emergence, as well as to identify a substitute to paraquat in sequential application.

Materials and Methods

Four different experiments were carried out in the state of Paraná, Brazil, using sourgrass biotypes resistant to glyphosate. The first and second experiments were conducted in the field, in 3.0x5.0 m plots, using a randomized complete block design, with four replicates. The meteorological conditions for the field experiments are shown in Figure 1. The third and fourth experiments were performed in a greenhouse, in a completely randomized design, in which the experimental units were pots with a capacity of 0.8 L, filled with the Humusfértil plant substrate (Toledo, PR, Brazil). The herbicides used in the experiments, their rates, and their commercial names are shown in Table 1. Adjuvant oil was used in all applications, at the doses recommended on the respective product packages.

The first experiment was carried out in fallow areas, previously grown with maize (*Zea mays* L.) between August and October, before the 2019/2020 soybean crop season, in the municipalities of Terra Roxa (24°13'10.6"S, 54°04'18.9"W) and Brasilândia do Sul (24°13'09.4"S, 53°32'01.9"W), in the state of Paraná, Brazil. A total of 18 treatments were evaluated, consisting of applications of herbicides alone and in combinations, as well as of a control.

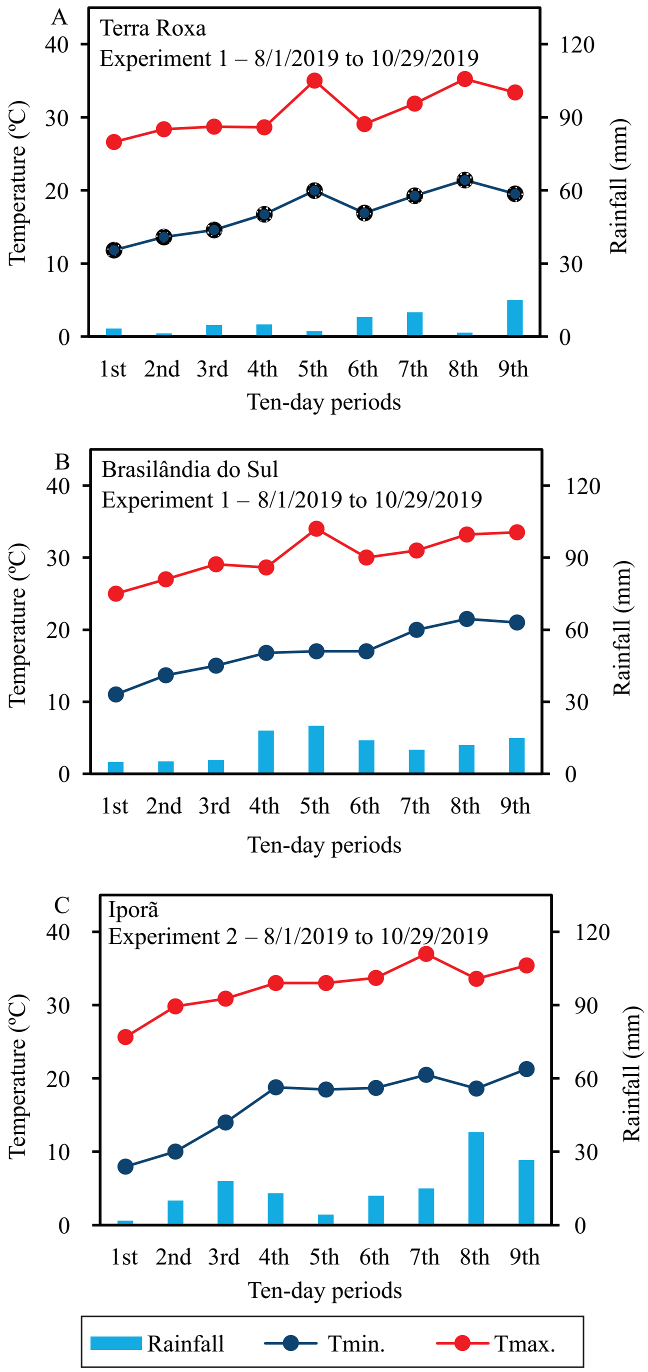

Figure 1. Rainfall and minimum (Tmin.) and maximum (Tmax.) temperatures during the period in which the first (A and B) and second (C) field experiments were carried out in the municipalities of Terra Roxa and Brasilândia do Sul and in the municipality of Iporã, in the state of Paraná, Brazil.

The second experiment was also performed in a fallow area, previously cultivated with maize between August and October, but in the 2020/2021 crop season and in the municipality of Iporã, in the state of Paraná (23°57'38.79"S, 53°52'34.72"W). A total of 22 treatments were evaluated, consisting of applications of herbicides alone and in combinations, as well as of a control.

The third experiment was conducted in a greenhouse, in the 2019/2020 crop season, in the municipality of Palotina, also in Paraná (24°17'36.8"S, 53°50'27"W), under a controlled temperature of 25 to 30ºC, simulated rainfall of 5.0 mm per day, controlled luminosity, and controlled humidity of 70%. The 18 treatments consisted of applications of herbicides alone and in combinations, as well as of a control treatment. Two glyphosate-resistant biotypes of sourgrass were evaluated: biotypes I and II, collected at coordinates 23°05'03.1"S, 51°07'21"W and 23°14'30.1"S, 51°04'51.2"W, respectively.

The fourth experiment was carried in the same greenhouse, but in the 2020/2021 crop season, also under a controlled temperature of 25 to 30ºC,

Table 1. Herbicides, commercial name of the products, and rates used in the four experiments evaluating the control of sourgrass (*Digitaria insularis*).

Herbicide	Commercial name	Rate (g a.i. ha^{-1})(1)
Atrazine	Primóleo	2,400
Clethodim	Select 240 EC	96 or 192
Clodinafop	Topik 240 EC	60
Diquat	Reglone	400
Glufosinate	Finale	400 or 500
Glyphosate	Roundup Transorb R	1,200 or 1,280
Haloxyfop	Verdict R	60 or 120
Imazapic + imazapyr	Amplexus	19 + 26
Mesotrione	Callisto	192
Mesotrione + atrazine	Calaris	100 + 1,000
Nicosulfuron	Sanson 40 SC	40
Paraquat	Gramoxone 200	400 or 500
Saflufenacil	Heat	35
Tembotrione	Soberan	100
Tepraloxydim	Aramo 200	100 or 200

(1)The rate was in grams of active ingredient (a.i.) per hectare for most herbicides, but in grams of acid equivalent per hectare for glyphosate, haloxyfop, imazapic, and imazapyr.

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simulated rainfall of 5.0 mm per day, controlled luminosity, and controlled humidity of 70%. A total of 20 treatments were performed, consisting of applications of herbicides alone and in combinations, as well as of a control (Table 5). Two other glyphosate-resistant biotypes were used: biotypes III and IV, collected at coordinates 24°19'31.4"S, 53°49'33.6"W and 24°11'28.7"S, 53°32'09.6"W, respectively.

For all experiments, the treatments were applied at a 2.0 bar pressure using the Pesquisa CO_2 pressurized backpack sprayer (Herbicat Ltda., Catanduva, SP, Brazil), equipped with a bar with six AVI110.015 fan nozzles (Jacto, Pompeia, SP, Brazil), spaced 0.5 m apart, with an application speed of 1.0 m s^{-1}, providing a spray volume of 150 L ha^{-1}. In the field experiments, the plants were evaluated at full flowering, at a density of two to four plants per square meter. In the greenhouse experiments, the plants were at the stage considered ideal for herbicide application, with one to three tillers or three to four leaves (Sossmeier, 2020), at approximately 14 days after emergence.

Weed control was evaluated at 14 and 28 days after herbicide application (DAA) by assigning scores from 0% (no injury) to 100% (plant death), considering visible symptoms and plant development (Velini et al., 1995).

The assumptions for the analysis of variance (ANOVA) were met. Normality and homoscedasticity were checked using the tests of Shapiro-Wilk and Levene (α=0.05), respectively. The independence of residues was verified using a plot of the residues. All data were standardized using one-way ANOVA and the F-test (α=0.05). Means were compared by the Scott-Knott test at a 5% significance level. The Sisvar, version 5.6, software was used (Ferreira, 2011).

Results and Discussion

In the first experiment, in the municipality of Terra Roxa, the treatments showed a low efficacy at 14 and 28 DAA (Table 2). This result could be due to the lack of rainfall during the experimental period (Figure 1), considering that water stress alters plant development,

Table 2. Percentage of control of perennial sourgrass (*Digitaria insularis*) in the first experiment at 14 and 28 days after the application (DAA) of herbicides alone and in combinations in the 2019/2020 crop season, in the municipalities of Terra Roxa and Brasilândia do Sul, in the state of Paraná, Brazil(1).

Herbicide	Rate (g a.i. ha^{-1})(2)	Adjuvant oil (L ha^{-1})	Weed control (%)			
			Terra Roxa		Brasilândia do Sul	
			14 DAA	28 DAA	14 DAA	28 DAA
Control treatment	-	-	0.0c	0.0d	0.0e	0.0d
Clethodim	192	Lanzar (0.5)	7.8c	35.0a	16.0c	73.8a
Haloxyfop(2)	120	Joint Oil (0.5)	6.3c	34.3a	10.8d	67.5a
Mesotrione + atrazine	100 + 1,000	Assist EC (0.5)	20.5b	13.8c	20.5c	23.8c
Tepraloxydim	100	Assist EC (0.5)	5.3c	15.0c	36.3a	28.8c
Tepraloxydim	200	Assist EC (0.5)	6.3c	22.8c	30.5b	77.5a
Glufosinate	500	Mees (0.5)	41.5a	33.0a	25.8b	15.0d
Saflufenacil	35	Mees (0.5)	16.3b	5.0d	24.8b	11.3d
Mesotrione + glufosinate	192 + 500	Assist EC (0.5)	30.5a	40.0a	14.8c	18.8d
Saflufenacil + haloxyfop	35 + 120	Joint Oil (0.5)	15.5b	34.5a	38.3a	18.8d
Saflufenacil + clethodim	35 + 192	Lanzar (0.5)	13.0b	38.8a	38.5a	52.5b
Saflufenacil + clodinafop	35 + 60	Mees (0.5)	14.5b	25.0b	32.5b	44.8b
Glufosinate + haloxyfop	500 + 120	Joint Oil (0.5)	41.8a	39.8a	19.0c	30.0c
Glufosinate + clethodim	500 + 192	Lanzar (0.5)	41.3a	43.0a	19.8c	33.8c
(Mesotrione + atrazine) + glufosinate	(100 + 1,000) + 500	Mees (0.5)	24.3b	30.0b	17.0c	32.5c
(Mesotrione + atrazine) + paraquat	(100 + 1,000) + 500	Assist EC (0.5)	39.5a	7.5d	25.5b	61.3a
(Mesotrione + atrazine) + clethodim	(100 + 1,000) + 192	Lanzar (0.5)	18.0b	24.3b	9.3d	69.3a
(Mesotrione + atrazine) + haloxyfop	(100 + 1,000) + 120	Joint Oil (0.5)	18.8b	17.0c	18.0c	73.8a
Coefficient of variation (%)			33.8	25.7	28.0	25.0

(1)Means followed by equal letters do not differ from each other by the Scott-Knott test, at a 5% significance level. (2)The rate was in grams of active ingredient (a.i.) per hectare for most herbicides, but in grams of acid equivalent per hectare for haloxyfop, imazapic, and imazapyr.

which influences herbicide absorption and action (Pereira et al., 2010; Vitorino et al., 2012). Souza et al. (2013) concluded that several environmental factors can interfere on the effectiveness of herbicides, as temperature, light, soil moisture, relative air humidity, frost, and the occurrence of rainfall after spraying.

Still in the first experiment, but in the municipality of Brasilândia do Sul, the best treatment was the application of 200 g a.i. ha^{-1} tepraloxydim. Statistically similar results were observed for tepraloxydim (doubled rate), clethodim, haloxyfop, (mesotrione + atrazine) + paraquat, and (mesotrione + atrazine) + clethodim. However, none of the treatments showed an efficacy above 80%, which may be related to the advanced development stage of the plants at the time of herbicide application, when many of them were already clumped (Table 2). According to Nunes et al. (2021), compared with plants from seeds, those from rhizomes have a thicker epidermis on the adaxial and abaxial surfaces, as well as a thicker leaf blade, which makes their control through the application of herbicides more difficult.

In the second experiment, the highest weed control was verified with the application of glyphosate mixed with clethodim or haloxyfop, complemented with a sequential application of paraquat, at 7 DAA. This result may be due to a possible synergistic effect of glyphosate on the action of graminicides (Bianchi et al., 2020), as well as to the use of paraquat in sequential application, which favoured the effective control observed (Table 3). However, in 2021, when paraquat was banned from Brazil, the diquat and glufosinate burndown herbicides became the main options (Albrecht et al., 2022).

The treatments using glyphosate combined with (imazapic + imazapyr) or mesotrione + (imazapic + imazapyr) presented the best control scores at 28 DAA (Table 3), highlighting the importance of herbicide

Table 3. Percentage of control of perennial sourgrass (*Digitaria insularis*) in the second experiment at 14 and 28 days after the application (DAA) of herbicides alone and in combinations in the 2020/2021 crop season, in the municipality of Iporã, in the state of Paraná, Brazil[(1)].

Herbicide	Rate	Adjuvant oil	Weed control (%)	
	(g a.i. ha^{-1})[(2)]	(L ha^{-1})	14 DAA	28 DAA
Control treatment	-		0.0e	0.0d
Clethodim	192	Lanzar (0.5)	30.0d	30.0c
Haloxyfop	120	Joint Oil (0.5)	28.8d	36.3c
Glyphosate + clethodim	1,200 + 192	Lanzar (0.5)	68.8b	88.8a
Glyphosate + haloxyfop	1,200 + 120	Joint Oil (0.5)	77.5b	89.5a
Glyphosate + (imazapic + imazapyr)	1,200 + (19 + 26)	Assist HC (0.5)	81.8b	96.3a
Glyphosate + tepraloxydim	1,200 + 200	Assist HC (0.5)	55.0c	66.5a
Glyphosate + mesotrione + (imazapic + imazapyr)	1,200 + 192 + (19 + 26)	Assist HC (0.5)	78.8b	93.8a
Glyphosate+ mesotrione + glufosinate	1,200 + 192 + 500	Mees (0.5)	86.8a	87.0a
Glyphosate + (mesotrione + atrazine) + paraquat	1,200 + (100 + 1,000) + 500	Assist HC (0.5)	51.3c	52.5b
Glyphosate + (mesotrione + atrazine) + haloxyfop	1,200 + (100 + 1,000) + 120	Joint Oil (0.5)	68.8b	91.3a
Glyphosate + (mesotrione + atrazine) + clethodim	1,200 + (100 + 1,000) + 192	Lanzar (0.5)	77.0b	86.0a
Glyphosate + clethodim + glufosinate	1,200 + 192 + 500	Lanzar (0.5)	86.8a	91.0a
Glyphosate + haloxyfop + glufosinate	1,200 + 120 + 500	Joint Oil (0.5)	86.0a	87.0a
Glyphosate + saflufenacil + clethodim	1,200 + 35 + 192	Lanzar (0.5)	80.8b	89.5a
Glyphosate + tembotrione + (imazapic + imazapyr)	1,200 + 100 + (19 + 26)	Assist HC (0.5)	74.0b	88.8a
Glyphosate + clethodim seq. glufosinate	1,200 + 192 seq. 500	Lanzar (0.5) seq. Mees (0.5)	91.5a	96.3a
Glyphosate + clethodim seq. paraquat	1,200 + 192 seq. 400	Lanzar (0.5) seq. Agral (0.2)	97.5a	96.5a
Glyphosate + clethodim seq. diquat	1,200 + 192 seq. 400	Lanzar (0.5) seq. Agral (0.2)	92.3a	94.0a
Glyphosate + haloxyfop seq. glufosinate	1,200 + 120 seq. 500	Joint Oil (0.5) seq. Mees (0.5)	91.5a	97.3a
Glyphosate + haloxyfop seq. paraquat	1,200 + 120 seq. 400	Joint Oil (0.5) seq. Agral (0.2)	93.0a	92.5a
Glyphosate + haloxyfop seq. diquat	1,200 + 120 seq. 400	Joint Oil (0.5) seq. Agral (0.2)	92.0a	88.5a
Coefficient of variation (%)			16.5	15.2

[(1)]Means followed by equal letters do not differ from each other by the Scott-Knott test, at a 5% significance level. [(2)]The rate was in grams of active ingredient (a.i.) per hectare for most herbicides, but in grams of acid equivalent per hectare for haloxyfop, imazapic, and imazapyr. Seq., sequential application of the indicated herbicide.

combinations. Melo et al. (2012) found a synergistic effect when applying glyphosate and clethodim in the control of glyphosate-resistant sourgrass. Other studies showed the efficacy of (imazapic + imazapyr) in weed control (Albrecht et al., 2020a). Cassol et al. (2019) concluded that the application of glyphosate and graminicides, followed by a sequential application of glufosinate, paraquat, or diquat, was efficient in controlling sourgrass at the full-flowering stage. In this sense, the haloxyfop and clethodim graminicides stand out when combined not only with glyphosate but also with herbicides with other modes of action (Bauer et al., 2021).

In the third experiment, at 28 DAA, the control of biotype I of sourgrass was below 50% with the application of (mesotrione + atrazine), which was considered ineffective, but above 88.8% for the other treatments. For biotype II, most of the treatments resulted in a maximum weed control score at 28 DAA. The application of diquat alone and of (mesotrione + atrazine) + clethodim allowed of a control of 90.3 and 86.8%, respectively. Most of the other treatments led to a control of almost 100%, with the exception of (mesotrione + atrazine), which showed a low weed control, as also observed for biotype I of sourgrass (Table 4).

Regarding herbicide combinations, those with clethodim and haloxyfop increased weed control, showing a synergistic effect, either by acting on different mechanisms of the plant at the same time or favouring the process of herbicide absorption and translocation in the weed (Bianchi et al., 2020). The combination of clethodim and glyphosate is known to be effective in weed control (Onofre et al., 2021), including a synergistic effect on sourgrass (Bianchi et al., 2020). Furthermore, burndown herbicides, as glufosinate, paraquat, and diquat, are important in weed control, especially glufosinate (Albrecht et al., 2020a). Cassol et al. (2019) reported an equivalent efficacy of clethodim and haloxyfop when combined with glyphosate. In addition, Bauer et al. (2021) observed the efficacy of clethodim and haloxyfop in different

Table 4. Percentage of control of biotypes I and II of sourgrass (*Digitaria insularis*) in the third experiment at 14 and 28 days after the application (DAA) of herbicides alone and in combinations in the 2019/2020 crop season, in a greenhouse in the municipality of Palotina, in the state of Paraná, Brazil[1].

Herbicide	Rate (g a.i. ha^{-1})[2]	Adjuvant oil (L ha^{-1})	Weed control (%)			
			Biotype I		Biotype II	
			14 DAA	28 DAA	14 DAA	28 DAA
Control treatment	-	-	0.0f	0.0d	0.0h	0.0d
Clethodim + glyphosate	96 + 1,280	Lanzar (0.5)	68.8c	100a	65.0e	100a
Haloxyfop + glyphosate	60 + 1,280	Joint Oil (0.5)	62.3c	100a	64.3e	100a
(Mesotrione + atrazine)	(100 + 1,000)	Assist EC (0.5)	36.3e	49.0c	29.3g	36.3c
Glufosinate	400	Mees (0.5)	94.3a	100a	92.8b	100a
Paraquat	400	Agral (0.2)	100a	100a	100a	100a
Diquat	400	Agral (0.2)	86.8b	91.3b	84.3c	90.3b
Atrazine + glufosinate	2,400 + 400	Mees (0.5)	81.5b	100a	75.0d	100a
Mesotrione + glufosinate	192 + 400	Assist EC (0.5)	88.5b	100a	92.0b	100a
Clethodim + glufosinate	96 + 400	Lanzar (0.5)	86.0b	100a	91.5b	100a
Haloxyfop + glufosinate	60 + 400	Joint Oil (0.5)	93.0a	100a	90.8b	100a
(Mesotrione + atrazine) + glufosinate	(100 + 1,000) + 400	Assist EC (0.5)	67.3c	100a	71.0d	100a
(Mesotrione + atrazine) + clethodim	(100 + 1,000) + 96	Lanzar (0.5)	33.8e	88.8b	36.0g	86.8b
(Mesotrione + atrazine) + haloxyfop	(100 + 1,000) + 60	Joint Oil (0.5)	38.5e	95.0b	34.5g	97.5a
Saflufenacil + clethodim	35 + 96	Lanzar (0.5)	53.3d	100a	50.5f	100a
Saflufenacil + haloxyfop	35 + 60	Joint Oil (0.5)	52.0d	100a	49.0f	100a
Nicosulfuron + clethodim	40 + 96	Lanzar (0.5)	36.8e	100a	39.5g	97.8a
Nicosulfuron + haloxyfop	40 + 60	Joint Oil (0.5)	41.5e	98.0a	37.3g	98.0a
Coefficient of variation (%)			7.9	4.5	7.8	4.8

[1]Means followed by equal letters do not differ from each other by the Scott-Knott test, at a 5% significance level. [2]The rate was in grams of active ingredient (a.i.) per hectare for most herbicides, but in grams of acid equivalent per hectare for haloxyfop, imazapic, and imazapyr.

combinations on sourgrass control. However, it is difficult to determine the most effective combination for all situations since several factors should be taken into account, including the history of the herbicides used in each area.

The results of the fourth experiment are shown in Table 5. An effective weed control was verified due to the application of graminicides combined with glyphosate and herbicide inhibitors of protoporphyrinogen oxidase (PPO), carotenoid biosynthesis, photosystem II, or glutamine synthetase. However, Bauer et al. (2021) concluded that the addition of saflufenacil (PPO inhibitor) did not increase the efficacy of glyphosate + ACCase inhibitors in sourgrass control, although no antagonistic effect was observed, which should be further investigated. Even though this herbicide does not affect the control of sourgrass, it is effective in controlling broadleaf weeds. According to Roskamp et al. (2012), combinations of graminicides with glyphosate and herbicide inhibitors have a broad spectrum of action, being important in weed control in areas infested with sourgrass and broadleaf weeds.

The highest rate of glufosinate (700 g a.i. ha^{-1}) controlled 100% of biotype IV of sourgrass and 86% of biotype III, both at 28 DAA. For biotype IV, a possible antagonism between glufosinate and atrazine or glufosinate and mesotrione was observed due to a relatively low weed control. For this biotype, the same rate of glufosinate alone was more effective than in combinations. However, this effect was not well studied, lacking a theoretical basis in the literature.

According to the obtained results, glufosinate is present in most of the best treatments, i.e., when sourgrass control was above 80%. Therefore, this herbicide is a solid alternative to replace paraquat when aiming to control sourgrass among tolerant soybean cultivars, even at post-emergence (Albrecht et al., 2022; Siqueira et al., 2021).

However, the single application of herbicides, even at high rates, is not sufficient for an effective control of

Table 5. Percentage of control of biotype III of sourgrass (*Digitaria insularis*) in the fourth experiment at 14 and 28 days after the application (DAA) of herbicides alone and in combinations in the 2020/2021 crop season, in a greenhouse in the municipality of Palotina, in the state of Paraná, Brazil(1).

Herbicide	Rate (g a.i. ha^{-1})(2)	Adjuvant oil (L ha^{-1})	Weed control (%)			
			Biotype I		Biotype II	
			14 DAA	28 DAA	14 DAA	28 DAA
Control treatment	-	-	0.0c	0.0c	0.0c	0.0d
Glyphosate + (imazapic + imazapyr)	1,200 + (19 + 26)	Assist EC (0.5)	45.0b	81.3a	40.8b	75.8b
Glyphosate + (mesotrione + atrazine) + glufosinate	1.200 + (50 + 500) + 500	Assist EC (0.5)	62.0b	50.8b	92.8a	100a
Glyphosate + (mesotrione + atrazine) + clethodim	1.200 + (100 + 1.000) + 192	Dash HC (0.5)	69.5b	87.5a	85.0a	100a
Glyphosate + (mesotrione + atrazine) + haloxyfop	1.200 + (100 + 1.000) + 120	Joint Oil (0.5)	75.8b	100a	88.0a	100a
Glyphosate + mesotrione + (imazapic + imazapyr)	1.200 + 192 + (19 + 26)	Assist EC (0.5)	52.5b	92.8a	44.3b	82.3b
Glyphosate + mesotrione + glufosinate	1.200 + 192 + 500	Mee (0.5)	67.5b	100a	49.5b	43.3c
Glyphosate + saflufenacil + clethodim	1.200 + 35 + 192	Dash HC (0.5)	74.0a	95.5a	84.3a	100a
Glyphosate + atrazine + glufosinate	1.200 + 2.400 + 500	Mee (0.5)	68.3b	57.5b	62.0b	48.8c
Glyphosate + clethodim	1.200 + 192	Dash HC (0.5)	89.8a	100a	91.5a	100a
Glyphosate + clethodim + glufosinate	1.200 + 192 + 500	Dash HC (0.5)	88.0a	96.3a	91.3a	100a
Glyphosate + tembotrione + (imazapic + imazapyr)	1.200 + 100 + (19 + 26)	Assist EC (0.5)	52.5b	74.5a	45.8b	75.5b
Glyphosate + haloxyfop	1.200 + 120	Joint Oil (0.5)	62.5b	95.0a	95.0a	100a
Glyphosate + haloxyfop + glufosinate	1.200 + 120 + 500	Joint Oil (0.5)	75.3a	91.3a	80.5a	100a
Glyphosate + saflufenacil + haloxyfop	1.200 + 35 + 120	Joint Oil (0.5)	86.5a	96.3a	84.8a	98.8a
Glufosinate	500	Mees (0.5)	74.0a	50.3b	84.5a	87.5b
Diquat	500	Agral (0.2)	58.8b	42.5b	56.3b	47.0c
Saflufenacil + glufosinate	35 + 500	Mees (0.5)	95.3a	100a	88.3a	100a
Glufosinate	700	Mees (0.5)	84.5a	86.3a	84.8a	100a
Clethodim + saflufenacil + glufosinate	192 + 35 + 500	Dash HC (0.5)	91.3a	100a	86.8a	100a
Coefficient of variation (%)			25.1	21.7	18.6	17.6

(1)Means followed by equal letters do not differ from each other by the Scott-Knott test, at a 5% significance level. (2)The rate was in grams of active ingredient (a.i.) per hectare for most herbicides, but in grams of acid equivalent per hectare for haloxyfop, imazapic, and imazapyr.

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sourgrass plants in the full-flowering stage, requiring sequential applications, which, in some situations, may not be enough for weed control (Zobiole et al., 2016; Mendes et al., 2020). Many failures in weed control are attributed to unfavourable environmental conditions or to plants being in the full-flowering stage (Cassol et al., 2019; Bauer et al., 2021). Advanced stages of development (two to four tillers) also make it difficult to control sourgrass using glyphosate, requiring rates 3.5 times greater than those applied at the initial stage of two to four leaves (Cavalieri et al., 2021). In this scenario, combining chemical control and mowing is an alternative to control plants at the full-flowering stage (Correia et al., 2015), leading to the depletion of their rhizomes and, after regrowth, to a more effective control of the formed clump. Therefore, all possible control strategies should be used and combined. The association of herbicides with cover crops in the off-season is also important for the control of glyphosate-resistant sourgrass (Correia, 2023), preventing the growth and recurrence of the weed.

Conclusions

1. The use of glufosinate in sequential application or in combination with other herbicides favours a better control of sourgrass (*Digitaria insularis*).
2. Diquat or glufosinate, in sequential application, are options to substitute paraquat in sourgrass control.

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