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ORIGINAL ARTICLE

Sequential applications of herbicides in the management of weeds at an advanced stage of development

Aplicações sequenciais de herbicidas no manejo de plantas daninhas em estádio de desenvolvimento avançado

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ABSTRACT: Weeds such as *Spermacoce verticillata* (button broom) and *Commelina benghalensis* (benghal dayflower) are being selected in areas with intensive use of glyphosate due to the tolerance of these species to this herbicide. The ideal is the initial control of weeds; however, this is not always done, and at an advanced phenological stage, the effectiveness of the control may be reduced. The objective of this study was to evaluate the control of adult stage of *S. verticillata* and *C. benghalensis* plants using herbicides alone or with glyphosate, followed or not by sequential application of diquat and glufosinate ammonium. The experiment was performed individually for each species in a completely randomized design, with five replicates, in a 9 x 4 factorial scheme consisted of 9 treatments, with applications of chlorimuron - ethyl - 20 g ha $^{-1}$, s -metolachlor - 960 g ha $^{-1}$, carfentrazone -ethyl - 20 g ha $^{-1}$, 2,4 -D -1000 g ha $^{-1}$, chlorimuron -ethyl + glyphosate - 20 + 1,440 g ha $^{-1}$, s -metolachlor + glyphosate - 960 + 1,440 g ha $^{-1}$, carfentrazone -ethyl + glyphosate - 20 + 1,440 g ha $^{-1}$, 2,4 -D + glyphosate - 1000 + 1,440 g ha $^{-1}$ and without initial herbicide on adult plants and 4 sequential applications 15 days after the first application with diquat -200 g ha $^{-1}$,glufosinate ammonium - 200 g ha $^{-1}$, ammonium glufosinate - 400 g ha $^{-1}$ and without sequential herbicide, in adult plants of both species. For *C. benghalensis*, the carfentrazone-ethyl, carfentrazone-ethyl + glyphosate and 2,4-D + glyphosate treatments were effective, regardless of sequential application. The treatments s-metolachor and 2,4-D with glufosinate ammonium were not effective in controlling this species. Conversely, *S. verticillata* without sequential application was controlled only by chlorimuron-ethyl + glyphosate. Carfentrazone-ethyl was the least effective treatment in sequential applications for the control of this species. It is concluded that there are options for chemical control of the species *S. verticillata* and *C. benghalensis* in advanced development stages in single or sequential applications, and the species differ in relation to the effectiveness of the herbicides.

RESUMO: *Plantas daninhas como a Spermacoce verticillata (vassourinha-de-botão) e Commelina benghalensis (trapoeraba) estão sendo selecionadas em áreas com uso intensivo de glyphosate devido à tolerância destas espécies a este herbicida. O ideal é o controle inicial das plantas daninhas, entretanto, nem sempre isto é feito e em estádio fenológico avançado a eficácia do controle pode apresentar redução. O objetivo deste trabalho foi avaliar o controle de plantas adultas de S. verticillata e C. benghalensis utilizando-se herbicidas isolados ou com glyphosate, seguidos ou não de aplicação sequencial de diquat e glufosinato de amônio. O experimento foi realizado individualmente para cada espécie, em delineamento inteiramente casualizado, com cinco repetições, em esquema fatorial 9 x 4, sendo 9 tratamentos com aplicações de chlorimuron-ethyl - 20 g ha^{-1}, s-metolachlor - 960 g ha^{-1}, carfentrazone-ethyl - 20 g ha^{-1}, 2,4-D - 1000 g ha^{-1}, chlorimuron-ethyl + glyphosate - 20 + 1.440 g ha^{-1}, s-metolachlor + glyphosate - 960 + 1.440 g ha^{-1}, carfentrazone-ethyl + glyphosate - 20 + 1.440 g ha^{-1}, 2,4-D + glyphosate - 1000 + 1.440 g ha^{-1} e sem herbicida inicial sobre as plantas adultas e 4 aplicações sequenciais 15 dias após a primeira aplicação com diquat - 200 g ha^{-1}, glufosinato de amônio - 200 g ha^{-1}, glufosinato de amônio - 400 g ha^{-1} e sem herbicida sequencial, em plantas adultas de ambas as espécies. Para C. benghalensis os tratamentos carfentrazone-ethyl, carfentrazone-ethyl + glyphosate e 2,4-D + glyphosate foram eficazes, independentemente da aplicação sequencial. Os tratamentos s-metolachor e 2,4-D com glufosinato de amônio não foram eficazes no controle desta espécie. Já S. verticillata sem aplicação sequencial foi controlada apenas por chlorimuron-ethyl + glyphosate. Carfentrazone-ethyl foi o tratamento menos efetivo nas aplicações sequenciais para o controle desta espécie. Conclui-se que há opções de controle químico das espécies Spermacocea verticillata e Commelina benghalensis em estádio de desenvolvimento avançado, em aplicações únicas ou sequenciais, sendo que as espécies diferem em relação à efetividade dos herbicidas.*

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1 Introduction

The weeds *Spermacocea verticillata* (button broom) and *Commelina benghalensis* (benghal dayflower) have attracted the attention of farmers due to their high incidence in cultivation areas and difficulty in control, even with the use of chemical methods (Pacheco *et al*., 2016). Cultures tolerant to glyphosate have altered the emerging weed flora in areas with transgenic soybean and cotton due to the excessive use of this herbicide, which highlights the need to adopt practices that maintain the efficacy of glyphosate and the possibility of using it within a plan, of integrated weed management (Kalsing *et al*., 2020).

S. verticillata belongs to the family Rubiaceae, native to tropical Americas, introduced in other regions of the world, occurring from the United States to South America. In the Amazon, it is one of the most common species in native or cultivated pastures, especially in degraded areas, or in the process of degradation (Fontes & Tonatto, 2016). These plants are rustic and grow in acidic and alkaline soils, with semi prostrate or erect habits, and can reach 80 cm in height (Nepomuceno *et al.*, 2018). Observations performed in the field have shown the inefficiency of chemical control over bud broom in cotton and soybean crops in the region formed by the states of Maranhão, Tocantins, Piauí and Bahia, considered the great national agricultural frontier today. This region is responsible for much of the grain and fiber production in the country (Marques, 2010; Santos, 2016; Fadin *et al*., 2018).

Martins (2009) observed that the use of the herbicide s-metolachlor applied pre-emergence was an effective option for the control of the *S. verticillata* weed, as well as the herbicides applied post emergence, such as glyphosate + 2,4-D, carfentrazone-ethy and chlorimuron-ethyl. According to Fadin *et al*. (2018), *S. verticillata* plants with 4-6 leaves were very sensitive to glyphosate, paraquat, flumioxazin and the associations of glyphosate with flumioxazin and chloransulam. However, applications performed on pre-flowering plants resulted in less effective control, especially with the use of glyphosate, due to the lower absorption and translocation of the herbicide compared to younger plants.

The species *C. benghalensis* can also be considered a weed that is difficult to control. Semiprostrate, with a semisucculent and perennial stem measuring 30 to 70 cm in height, originates in Southeast Asia and spreads through normal rhizome-shaped seeds (Kissmann & Groth, 2000). Species of the genus *Commelina* have been selected, and their frequency has increased in areas with successive applications of glyphosate, such as coffee, citrus, eucalyptus and transgenic crops (Monquero *et al.*, 2005; Costa *et al*., 2021), as it is tolerant to herbicides, and it is necessary to use other herbicides in combination with glyphosate for effective control of this species (Ramires *et al*., 2011). According to Maciel *et al.* 2011 for *C. benghalensis*, the single application of glyphosate did not provide satisfactory control, with a maximum efficacy of 64.4% at 40 days after application, for a dose of 720 g ha^{-1}. Most control has been shown to be inefficient in a single application for the control of species of this genus in the adult phase, with rare exceptions such as the use of 2,4-D (Osipe *et al*., 2017).

The combination of herbicides with different mechanisms of action may help in the control and suppression of resistant biotypes or species tolerant to glyphosate. Additionally, the use of sequential applications involving more than one herbicide can increase the effectiveness of weed control and can be an important tool in integrated management (Osipe *et al.*, 2017).

It is important to note that the efficacy of weed control by herbicides is based on the phenological stage (Fleck *et al.*, 2008). It is not uncommon to use desiccants approximately 10 days before sowing followed by sequential application. The use of glyphosate at 10 - 20 days before sowing of corn followed by contact herbicides such as diquat provided greater control efficiency, allowing for sowing under clean conditions (Procópio *et al.*, 2007).

Fundamentally, the second application works to correct resprouting problems and newly emerged weed flows. According to Oliveira Júnior *et al.* (2006), an additional point is the fact that species that are difficult to control can be controlled in perfect sequential management.

Therefore, the objective of this study was to evaluate whether the sequential applications of the herbicides diquat and glufosinate ammonium can assist in the control of adult plants of *S. verticillata* and *C. benghalensis* treated with herbicides alone or in mixture with glyphosate.

2 Material and Methods

The experiments were conducted in a greenhouse. The experimental unit consisted of a pot with a volumetric capacity of 5 L filled with soil samples from a dark red Latosol. The chemical analysis of the samples was performed by the Soil Chemistry and Fertility laboratory, with P = 10 mg dm^{-3}, organic matter = 29 g dm^{-3}, pH = 5.3, K = 2.2 mmol $_c$ dm^{-3}, Ca = 29 mmol $_c$ dm^{-3}, Mg = 15 mmol $_c$ dm^{-3}, H+Al = 29 mmol $_c$ dm^{-3}, SB = 46.3 mmol $_c$ dm^{-3}, CEC = 75.2 and V% = 61.

The seeds of *S. verticillata* and *C. benghalensis* were purchased from a company specializing in the production of weed seeds. The experiments were individualized for each weed species. Each experimental unit consisted of five plants of each weed species sown in separate pots. The first

application of the herbicides was performed when the plants were classified as adults at the beginning of flowering (code 51 of the universal coding of the phenological stages of crops and weeds – BBCH scale), characterizing a late application in the plants. Sequential applications were performed fifteen days after the first application.

The experimental design was completely randomized, with five replicates, in a 9 x 4 factorial scheme, with 9 treatments and 4 sequential applications of different active ingredients 15 days after the first application (Table 1).

Table 1. Chemical treatments used to control *Spermacoce verticillata* and *Commelina benghalensis*.

Tabela 1. Tratamentos quimicos utilizados para controle de *Spermacoce verticillata* and *Commelina benghalensis*.

Initial application	Dose g a.i ha^{-1}	Sequential application	Dose g a.i ha^{-1}
Carfentrazone-ethyl[1]	20	-	-
Carfentrazone-ethyl	20	Diquat	200
Carfentrazone-ethyl	20	Glufosinate ammonium	200
Carfentrazone-ethyl	20	Glufosinate ammonium	400
[1]Chlorimuron-ethyl	20	-	-
Chlorimuron-ethyl	20	Diquat	200
Chlorimuron-ethyl	20	Glufosinate ammonium	200
Chlorimuron-ethyl	20	Glufosinate ammonium	400
2,4-D	1000	-	-
2,4-D	1000	Diquat	200
2,4-D	1000	Glufosinate ammonium	200
2,4-D	1000	Glufosinate ammonium	400
S-Metolachlor	960	-	-
S-Metolachlor	960	Diquat	200
S-Metolachlor	960	Glufosinate ammonium	200
S-Metolachlor	960	Glufosinate ammonium	400
Carfentrazone-ethyl + Glyphosate	20 + 1440	-	-
Carfentrazone-ethyl + Glyphosate	20 + 1440	Diquat	200
Carfentrazone-ethyl + Glyphosate	20 + 1440	Glufosinate ammonium	200
Carfentrazone-ethyl + Glyphosate	20 + 1440	Glufosinate ammonium	400
[1]Chlorimuron-ethyl + Glyphosate	20 + 1440	-	-
Chlorimuron-ethyl + Glyphosate	20 + 1440	Diquat	200
Chlorimuron-ethyl + Glyphosate	20 + 1440	Glufosinate ammonium	200
Chlorimuron-ethyl + Glyphosate	20 + 1440	Glufosinate ammonium	400
2,4-D + Glyphosate	1000 + 1440	-	-
2,4-D + Glyphosate	1000 + 1440	Diquat	200
2,4-D + Glyphosate	1000 + 1440	Glufosinate ammonium	200
2,4-D + Glyphosate	1000 + 1440	Glufosinate ammonium	400
S-Metolachlor + Glyphosate	960 + 1440	-	-
S-Metolachlor + Glyphosate	960 + 1440	Diquat	200
S-Metolachlor + Glyphosate	960 + 1440	Glufosinate ammonium	200
S-Metolachlor + Glyphosate	960 + 1440	Glufosinate ammonium	400
Control	-	-	

[1] addition of 0.5% v/v adjuvants

[1] adição de 0,5% v/v de adjuvantes

The herbicides were applied with a backpack sprayer pressurized with CO_2 equipped with a spray nozzle with four nozzles spaced at 0.5 m, and flat jet fan nozzles, model TeeJet 110.02, were applied 0.5 m from the target. The relative humidity and air temperature during the application were 55.6 % and 25 °C in the first application and 65.5% and 27 °C in the sequential application, respectively. A spray volume of 200 L ha^{-1} and a pressure of 40 psi were used. The evaluation of control by treatments was performed using a visual scale of plant injury, from 0 to 100%, with 0% in the absence of visible symptoms and 100% in plant death (ALAM, 1974). The evaluations were performed at 7, 14, 21, 28 and 35 days after the first application of the herbicides (DAA), i.e., at 7, 14 and 21 days after the application of the sequential herbicides (DAS). At 35 DAA, the plants were cut close to the soil, and the dry mass was obtained by means of a forced air circulation oven (60 °C for 72 hours).

The control efficacy data were subjected to the residual normality test and subsequently transformed into arc sin $\sqrt{}$ (X/100). The mass values were adjusted to reduce the dry biomass of the aerial part in relation to the control, obtained as a percentage, by the following equation:

100 – [(treatment mass (g) × 100) ÷ control mass (g)]

The data were subjected to analysis of variance, and the means were compared by the Scott-Knott test at 5% probability significance.

3 Results and Discussion

At 7 and 14 DAA, herbicides alone or in combination in the control of *S. verticillata* were ineffective. The control percentage ranged from 3.6% (s-metolachlor) to 45.2% (carfentrazone-ethyl) (Table 2). The data corroborate those of Fadin *et al.* (2018), who found that chlorimuron-ethyl (20 g ea ha^{-1}), carfentrazone-ethyl (20 g ea ha^{-1}) and s-metolachlor (960 g ea ha^{-1}) applied alone did not show effective control over *S. verticillata* plants in three phenological stages during application (2-4 leaves, 4-6 leaves and flowering).

Martins & Christoffoleti (2014) reported that the presence of lateral buds along the main nodes of the *S. densiflora* stem hinders the contact of the herbicide with the lower leaves, which allows the survival of the plant even after application of the treatments. According to the authors, the control of the species after the phenological stage of 3 pairs of leaves is challenging, even using systemic herbicides.

At 21 DAA, without the use of sequential herbicides, the most effective treatment was the combination of chlorimuron-ethyl + glyphosate, with 73.7% control. The control of this treatment remained constant at 28 DAA and reached 87.5% in the evaluation at 35 DAA. The other treatments maintained a control below the acceptable level.

The treatments involving chlorimuron-ethyl + glyphosate with sequential applications of diquat and glufosinate ammonium showed an increase in their results, with efficacy above 95%. In turn, chlorimuron-ethyl applied alone had a satisfactory result, in the last evaluation, with the use of the highest dose of glufosinate ammonium (88.77%).

The mechanism of action of glyphosate is quite unique, as it is the only herbicide capable of specifically inhibiting 5-enolpyruvylchikimate-3-phosphate synthase (EPSPs), which is responsible for the reaction of conversion of shikimate-3-phosphate and phosphoenolpyruvate into EPSP and inorganic phosphate in the shikimic acid route (Geiger & Fuchs, 2002). With the selection of tolerant species or biotypes resistant to glyphosate, other herbicides have been combined with glyphosate to improve the control of some weed species, including chlorimuron-ethyl. This herbicide acts on the inhibition of acetolactate synthase (ALS) and inter disrupts protein synthesis, which in turn interferes with DNA synthesis and cell growth (Rodrigues & Almeida, 2018).

Regarding the other treatments, considering the application if the herbicide diquat, the herbicides s-metolachlor + glyphosate, 2.4-D and 2.4-D + glyphosate showed control above 80.0% in the evaluation at 7 DAS. At 14 DAS, there was an increase in the control of these treatments, and at 21 DAS, 2.4 D (92.5%) and 2.4-D + glyphosate (98.7%) showed better control than s-metolachlor + glyphosate (86.2%) sequentially to diquat. Diquat increased the efficacy of s-metolachor and carfentrazone-ethyl alone, at a low level (28.7% to 63.7%) for the control of the species.

The herbicide diquat, from the same chemical group as paraquat (bipyridyl), is classified as an inhibitor of photosystem I in the photochemical step of the photosynthesis process, promoting electron deviation. The main characteristics of this product are its high water solubility, rapid adsorption by the soil colloids that allows the application and planting of the system, accelerated absorption in the leaves due to its rapid passage through the cuticle, faster action in the presence of light and non-selectivity and translocation in relation to the target (Marchi et al., 2008).

For the sequential glufosinate ammonium at the highest dose, the treatments s-metolachlor, s-metolachlor + glyphosate, 2.4-D and 2.4-D + glyphosate presented a control greater than 90% at 7 DAS. At the highest dose, in addition to these treatments, carfentrazone-ethyl + glyphosate also had a control above 90.0%. In the other evaluations, the control was maintained, and at 21 DAS, the treatments s-metolachlor, s-metolachlor + glyphosate, 2.4-D, 2.4-D + glyphosate and carfentrazone-ethyl + glyphosate showed a control above 92.5% at the lowest dose and did not differ from the highest dose

of glufosinate ammonium applied sequentially. According to the results obtained by Kalsing *et al.* (2020), 2.4-D + glyphosate showed low control of this species. The application of glufosinate ammonium after this combination of herbicides also did not result in satisfactory control. According to the authors, the results varied greatly according to the location, and in general,the largest controls were obtained with the use of sequential applications compared to the single application.

Table 2. Control percentage (%) of *Spermacoce verticillata* at 7, 14, 21, 28 and 35 days after treatment with initial herbicides (DAA) and 7, 14 and 21 days after application of the sequential treatments (DAS).

Tabela 2. Porcentagem de controle (%) de *Spermacoce verticillata* aos 7, 14, 21, 28 e 35 dias após os tratamentos iniciais com herbicidas (DAA) e 7, 14 e 21 dias após a aplicação dos tratatamentos sequenciais (DAS).

Percentage of *S. verticillata* control before and after application of the herbicide sequences						
Treatments	% control before sequential applications		No sequential	Diquat	GA[1] 200	GA 400
	7 DAA	14 DAA	Evaluations at 21 DAA (7 DAS)			
Control	0.00 fA	0.00 fA	0.00 dA	0.00 eA	0.00 eA	0.00 dA
Chlorimuron-ethyl	5.63 dB	15.00 eA	3.75 cC	26.25 dB	72.50 cA	77.50 cA
Chlorimuron-ethyl + glyphosate	7.50 dB	31.25 cA	73.75 aD	85.00 aC	91.25 bB	99.00 aA
S-metolachlor	2.81 eA	3.63 dA	0.00 dD	61.25 bC	92.50 bB	100.00 aA
S-metolachlor + glyphosate	12.50 cB	31.88 cA	40.00 bD	81.25 aC	90.00 bB	98.75 aA
Carfentrazone-ethyl	32.50 bA	45.25 aA	38.75 bC	71.25 bA	56.25 dB	81.25 cA
Carfentrazone-ethyl + glyphosate	39.69 aA	37.50 bA	42.50 bC	41.25 cC	75.00 cB	91.25 bA
2.4-D	15.00 cB	37.50 bA	46.25 bB	87.75 aA	95.75 bA	97.25 aA
2.4-D + glyphosate	10.94 cB	39.06 bA	41.25 bC	92.75 aB	100.00 aA	100.00 aA
CV (%)	31.56		10.86			
F (Treatments)= 249.61** F (Sequential application) = 328.18** F (Treat X Seq. Appl.) = 17.60**						

	Evaluations at 28 DAA (14 DAS)			
	No sequential	Diquat	GA[1] 200	GA 400
Control	0.00 cA	0.00 dA	0.00 dA	0.00 dA
Chlorimuron-ethyl	4.50 cC	28.75 cB	77.50 bA	88.25 bA
Chlorimuron-ethyl + glyphosate	75.00 aB	90.00 aA	98.25 aA	99.00 aA
S-metolachlor	3.75 cC	38.75 cB	95.25 aA	100.00 aA
S-metolachlor + glyphosate	51.25 bC	89.50 aB	98.25 aA	99.50 aA
Carfentrazone-ethyl	32.50 bB	61.25 bA	25.00 cB	55.00 cA
Carfentrazone-ethyl + glyphosate	33.75 bB	25.00 cB	79.50 bA	93.75 bA
2.4-D	27.50 bB	90.75 aA	93.25 aA	98.50 aA
2.4-D + glyphosate	38.75 bC	92.50 aB	100.00 aA	100.00 aA
CV (%)	16.99			
F (Treatments) = 110.76** F (Sequential application) = 138.84** F (Treat X Seq. Appl.) = 9.48**				

	Evaluations at 35 DAA (21 DAS)			
	No sequential	Diquat	GA[1] 200	GA 400
Control	0.00 dA	0.00 eA	0.00 dA	0.00 cA
Chlorimuron-ethyl	3.75 dB	82.50 bA	78.75 bA	88.75 bA
Chlorimuron-ethyl + glyphosate	87.50 aA	96.25 aA	97.50 aA	99.00 aA
S-metolachlor	2.50 dC	28.75 dB	93.25 aA	100.00 aA
S-metolachlor + glyphosate	40.00 bC	86.25 bB	92.50 aA	99.50 aA
Carfentrazone-ethyl	35.00 bB	63.75 cA	37.50 cB	75.00 bA
Carfentrazone-ethyl + glyphosate	43.75 bB	57.50 cB	93.25 aA	94.75 bA
2.4-D	13.75 cB	92.50 aA	92.75 aA	99.00 aA
2.4-D + glyphosate	40.00 bB	98.75 aA	100.00 aA	100.00 aA
CV (%)	17.47			
F (Treatments) = 93.90** F (Sequential application) = 132.76** F (Treat X Seq. Appl.) = 8.91**				

[1] GA: glufosinate ammonium; CV (%): coefficient of variation.

Means followed by the same lowercase letters in the column and uppercase letters in the row do not differ by the Scott-Knott test at 5% significance.

[1] GA: glufosinato de amônio; CV (%): coeficiente de variação.

Médias seguidas pelas mesmas letras minúsculas na coluna e letras maiúsculas na linha não diferem pelo teste de Scott-Knott com 5% de significância.

Glufosinate ammonium has a rapid desiccation effect on susceptible plants, and its mechanism of action is the inhibition of glutamine synthetase. Glufosinate ammonium is a non-selective contact herbicide with a broad spectrum of control over weeds. In Brazil and worldwide, this herbicide is widely used in desiccation preplanting, perennial crops or post emergence of annual crops containing Liberty Link technology (Silva *et al.* 2007).

The dry mass results show better control with the sequential application compared to the initial single application (Table 3). The treatments with s-metolachlor, s-metolachlor, carfentrazone-ethyl + glyphosate and 2.4-D alone and with glyphosate without the use of sequential herbicides showed the lowest reductions in dry biomass.

Table 3. Reduction (%) of *Spermacocea verticillata* shoot dry weight at 35 days after the initial application, compared to the control.
Tabela 3. Redução (%) do peso seco da parte aérea de *Spermacocea verticillata* aos 35 dias após a aplicação inicial, em relação ao controle.

Reduction (%) of *S. verticillata* shoot dry weight				
		Sequential application		
Treatments	No sequential	Diquat	GA[1] 200	GA 400
Chlorimuron-ethyl	32.73 bB	95.15 aA	92.05 aA	89.47 aA
Chlorimuron-ethyl + glyphosate	80.37 aA	81.49 aA	88.28 aA	79.81 aA
S-metolachlor	10.00 cC	35.66 bB	92.93 aA	87.68 aA
S-metolachlorl + glyphosate	34.10 bB	82.83 aA	83.58 aA	79.70 aA
Carfentrazone-ethyl	67.05 aB	85.18 aA	24.33 bC	98.00 aA
Carfentrazone-ethyl + glyphosate	47.63 bB	78.93 aA	86.73 aA	85.40 aA
2.4-D	46.83 bB	87.90 aA	89.83 aA	89.55 aA
2.4-D + glyphosate	31.38 bB	90.05 aA	92.18 aA	91.65 aA
CV (%)	15.40			
F (Treatments) = 2.14** F (Sequential application) = 25.00** F (Treat X Seq appl) = 3.31**				

[1] GA: glufosinate ammonium; CV (%): coefficient of variation.

Means followed by the same lowercase letters in the column and uppercase letters in the row do not differ by the Scott-Knott test at 5% significance.

[1] GA: glufosinato de amônio; CV (%): coeficiente de variação.

Médias seguidas pelas mesmas letras minúsculas na coluna e letras maiúsculas na linha não diferem pelo teste de Scott-Knott com 5% de significância.

In the evaluations at 7 and 14 DAA, considering the initial applications (before sequential applications), carfentrazone-ethyl and carfentrazone-ethyl + glyphosate were effective in controlling *Commelina benghalensis* (Table 4). The combination of 2.4-D + glyphosate showed a high control (91.2%) at 14 DAA (Table 4). Working with another species tolerant to glyphosate, Agostineto *et al.* (2016) found that the mixture of the herbicides carfentrazone-ethyl and saflufenacil with glyphosate increases the control of *Ipomea hederifolia* in relation to the application of the herbicides alone. The mixture of carfentrazone-ethyl + glyphosate at a dose of 0,05 + 2 L ha $^{-1}$ provided effective and rapid control of *I. hederifolia* especially when the plants were at the 6-8 leaf stage.

Carfentrazone-ethyl is an herbicide of the chemical group of aryl triazolinones, whose mechanism of action is related to the inhibition of the enzyme protoporphyrogen oxidase (PPO), responsible for one of the steps of chlorophyll synthesis. Inhibition of PPO results in the formation of singlet oxygen, which promotes lipid peroxidation and rupture of cell membranes, causing cell death (Silva *et al.*, 2007). In Brazil, carfentrazone is registered for cotton, irrigated rice, potato, coffee, citrus, corn and soybean crops, with excellent control of *C. benghalensis* and eudicotyledonous weeds, especially *Ipomoea spp*. (Christoffoleti *et al*., 2006; Silva *et al*., 2007), which are species considered difficult to control by the herbicide glyphosate.

Considering the treatments with sequential herbicides, the control percentage at 7 DAS showed high efficacy of carfentrazone-ethyl and carfentrazone-ethyl + glyphosate, both with 100% control. The combination of 2.4-D + glyphosate showed efficient control above 90.0% in all evaluations (Table 4). Martins *et al.* (2012) observed a high control of *C. benghalensis* by 2.4-D (720 g ha^{-1}); however, in their study, the stems were transplanted at 10 cm, and the application was performed at 25-35 cm. Takano *et al.* (2013) found that at 28 DAA, the higher the developmental stage of *C. benghalensis* the more difficult it was to control with 2.4D alone, and the addition of glyphosate was crucial to accelerate and improve the control.

The sequential application with the herbicide diquat showed satisfactory control for the treatments that were not effective in a single application (2.4-D, s-metolachlor, s-metolachlor + glyphosate, chlorimuron-ethyl and chlorimuron-ethyl + glyphosate). The sequential application of ammonium glufosinate at the lowest dose was not effective in increasing the control of treatments; chlorimuron-ethyl promoted a control above 80%.

However, at the highest dose of glufosinate ammonium there was an improvement in the control of the herbicides chlorimuron-ethyl, chlorimuron-ethyl + glyphosate, and s-metolachlor + glyphosate. The treatments with carfentrazone-ethyl and carfentrazone-ethyl + glyphosate maintained the control of *C. benghalensis* in the evaluations at 14 and 21 DAS (Table 4), regardless of the sequential application with 100% control of the plants. Freitas *et al.* (2018) observed that the best initial controls (up to 28 DAA) of *C. benghalensis* occurred with the use of carfentrazone-ethyl alone or in combination with glyphosate. However, at 60 DAA, the control levels of these treatments significantly decreased to approximately 5%.

Table 4. Control percentage (%) of *Commelina benghalensis* at 7, 14, 21, 28 and 35 days after application (DAA) of the initial herbicide treatments and 7, 14 and 21 days after application of the sequential treatments (DAS).

Tabela 4. Porcentagem de controle (%) de *Commelina benghalensis* aos 7, 14, 21, 28 e 35 dias após os tratamentos iniciais com herbicidas (DAA) e 7, 14 e 21 dias após a aplicação dos tratatamentos sequenciais (DAS).

Percentage of *C. benghalensis* control before and after application of the herbicide sequences						
Treatments	% control before sequential applications		No sequential	Diquat	GA[1] 200	GA 400
	7 DAA	14 DAA	Evaluation 21 DAA (7 DAS)			
Control	0.00 gA	0.00 fA	0.00 fA	0.00 dA	0.00 eA	0.00 fA
Chlorimuron-ethyl	22.50 eB	46.25 dA	33.75 dC	96.25 bA	83.75 bB	96.25 bA
Chlorimuron-ethyl + glyphosate	42.50 cB	75.00 cA	85.00 cB	87.00 cB	68.75 cC	95.75 bA
S-metolachlor	10.00 fB	30.00 eA	20.00 eC	94.50 cA	65.00 cB	66.25 dB
S-metolachlor + glyphosate	20.00 eA	32.50 eA	18.75 eD	92.50 cA	63.75 cC	81.25 cB
Carfentrazone-ethyl	100.00 aA	100.00 aA	100.00 aA	100.00 aA	100.00 aA	100.00 aA
Carfentrazone-ethyl + glyphosate	100.00 aA	100.00 aA	100.00 aA	100.00 aA	100.00 aA	100.00 aA
2.4-D	31.25 dB	50.00 dA	21.25 eC	97.00 bA	51.25 dB	52.50 eB
2.4-D + glyphosate	78.75 bA	91.25 bA	92.50 bB	99.50 aA	97.50 aA	97.75 bA
CV (%)	8.95			8.58		
F (Treatments) = 441.82** F (Sequential application) = 128.60** F (Treat X Seq Appl.) = 19.22** F (7DAA)=594.28** F (14DAA)=159.11**						

	No sequential	Diquat	GA[1] 200	GA 400
	Evaluation 28 DAA (14 DAS)			
Control	0.00 fA	0.00 cA	0.00 dA	0.00 dA
Chlorimuron-ethyl	41.25 cB	99.00 aA	94.50 aA	99.00 aA
Chlorimuron-ethyl + glyphosate	52.50 cC	97.50 aA	80.75 bB	98.00 aA
S-metolachlor	21.25 dC	85.00 bA	58.75 cB	61.25 cB
S-metolachlor + glyphosate	10.00 eC	92.50 bA	75.00 bB	88.75 bA
Carfentrazone-ethyl	100.00 aA	100.00 aA	100.00 aA	100.00 aA
Carfentrazone-ethyl + glyphosate	100.00 aA	100.00 aA	100.00 aA	100.00 aA
2.4-D	37.50 cC	95.75 aA	60.00 cB	75.00 cB
2.4-D + glyphosate	87.00 bB	100.00 aA	99.50 aA	98.75 aA
CV (%)			10.34	
F (Treatments) = 294.97** F (Sequential application) = 108.33** F (Treat X Seq Appl.) = 10.89**				

	No sequential	Diquat	GA[1] 200	GA 400
	Evaluation 35 DAA (21 DAS)			
Control	0.00 dA	0.00 cA	0.00 eA	0.00 dA
Chlorimuron-ethyl	13.75 cB	100.00 aA	92.50 aA	99.50 aA
Chlorimuron-ethyl + glyphosate	78.75 bB	99.50 aA	86.25 bB	99.50 aA
S-metolachlor	10.00 cC	82.50 bA	22.50 dC	45.00 cB
S-metolachlor + glyphosate	10.00 cC	83.50 bA	56.25 cB	90.00 bA
Carfentrazone-ethyl	100.00 aA	100.00 aA	100.00 aA	100.00 aA
Carfentrazone-ethyl + glyphosate	100.00 aA	100.00 aA	100.00 aA	100.00 aA
2.4-D	12.50 cC	93.25 bA	28.75 dC	47.50 cB
2.4-D + glyphosate	95.00 aA	100.00 aA	100.00 aA	99.50 aA
CV(%)			14.76	
F (Treatments) = 180.24** F (Sequential application) = 63.69** F (Treat X Seq Appl.) = 9.42**				

[1] GA: glufosinate ammonium; CV (%): coefficient of variation.

Means followed by the same lowercase letters in the column and uppercase letters in the row do not differ by the Scott-Knott test at 5% significance.

[1] GA: glufosinato de amônio; CV (%): coeficiente de variação.

Médias seguidas pelas mesmas letras minúsculas na coluna e letras maiúsculas na linha não diferem pelo teste de Scott-Knott com 5% de significância.

For the sequential treatments, the herbicide diquat maintained high control in the evaluations performed at 14 and 21 DAS for the treatments that were not efficient in isolated application, such as chlorimuron-ethyl, chlorimuron-ethyl + glyphosate and 2.4-D. For s-metolachor and s-metolachor + glyphosate, the control remained in the 82.0% range. Chloroacetamides, such as s-metolachlor, are residual herbicides used to control weeds pre-emergence in soybean, corn, coffee, beans and sugarcane crops. The primary mechanism of action of these herbicides is the inhibition of the synthesis of long-chain fatty acids and is most commonly used for the control of monocots (Silva *et al.*, 2007).

The s-metolachor alone or in mixture with glyphosate and 2.4-D did not present efficient control even with the sequential use of glufosinate ammonium. However, at the highest dose of glufosinate ammonium, there was an increase in the efficacy of the chlorimuron-ethyl (99.5%), chlorimuron-ethyl + glyphosate (99.5%) and s-metolachlor + glyphosate (90%) treatments. Maciel *et al.* (2011) found that mixtures of glyphosate with the herbicides chlorimuron, chloransulam-methyl, lactofen and imazethapyr satisfactorily controlled *C. benghalensis*, *Tridax procumbens* and *Cenchrus echinatus* plants.

The shoot dry mass results of *C. benghalensis* plants corroborate the visual evaluations (Table 5). Thus, the treatments carfentrazone ethyl, carfentrazone ethyl + glyphosate and 2.4-D + glyphosate can be recommended for the control of adult *C. benghalensis* plants without the need for sequential application.

The mixture of glyphosate with other herbicides has become common practice. With 2.4-D being the most commonly used, 2.4-D is a synthetic auxin that causes various disorders (abnormal tissue growth, phloem obstruction, root system death, leaf epinastia, etc.), which leads to the death of sensitive plants (Rodrigues & Almeida, 2018).

Table 5. Reduction (%) of *Commelina benghalensis* shoot dry weight at 35 days after the initial application, compared to the control.
Tabela 5. Redução (%) do peso seco da parte aérea de *Commelina benghalensis* aos 35 dias após a aplicação inicial, em relação ao controle.

Reduction (%) of *C. benghalensis* shoot dry weight[1]				
	Sequential Application			
Treatments	No Sequential	Diquat	GA 200	GA 400
Chlorimuron-ethyl	22.15 dB	100.00 aA	96.15 aA	98.75 aA
Chlorimuron-ethyl + glyphosate	81.10 bB	97.50 aA	87.28 aB	99.98 aA
S-metolachlor	18.30 dC	89.63 aA	30.65 cB	40.43 cA
S-metolachlor + glyphosate	16.30 dB	76.15 bA	55.08 bA	76.73 bA
Carfentrazone-ethyl	100.00 aA	100.00 aA	100.00 aA	100.00 aA
Carfentrazone-ethyl + glyphosate	100.00 aA	100.00 aA	100.00 aA	100.00 aA
2,4-D	61.08 cB	95.43 aA	71.48 bB	82.13 bA
2,4-D + glyphosate	96.53 aA	100.00 aA	100.00 aA	99.13 aA
CV (%)	11.04			
F (Treatments) = 32.96** F (Sequential Application) = 45.09** F (Treat X Seq Appl) = 7.95**				

[1] GA: glufosinate ammonium; CV (%): coefficient of variation.

Means followed by the same lowercase letters in the column and uppercase letters in the row do not differ by the Scott-Knott test at 5% significance.

[1] GA: glufosinato de amônio; CV (%): coeficiente de variação.

Médias seguidas pelas mesmas letras minúsculas na coluna e letras maiúsculas na linha não diferem pelo teste de Scott-Knott com 5% de significância.

The herbicide 2.4-D showed efficacy with sequential application of the herbicide diquat. For chlorimuron-ethyl, sequential application with diquat or glufosinate ammonium at doses of 200 and 400 g ai ha $^{-1}$ showed satisfactory control of the adult species. None of the sequential treatments was effective for s-metolachor + glyphosate in the control of adult *C. benghalensis*. The s-metolachlor showed good control of the species after sequential application of diquat or at the highest dose of glufosinate ammonium. According to Brunharo *et al.* (2020), the adjustment of sequential herbicide programs to address specific weed challenges may be a viable strategy to improve weed control without increasing the use of herbicides with the same mechanism of action.

4 Conclusion

For *C. benghalensis*. the herbicides carfentrazone ethyl, carfentrazone ethyl + glyphosate and 2.4-D + glyphosate was effective, regardless of sequential application. Sequential applications were important for the herbicides chlorimuron-ethyl (covering all sequential treatments), chlorimuron + glyphosate and s-metolachlor + glyphosate (with diquat and the highest dose of glufosinate ammonium), s-metolachlor and 2.4-D with sequential application of diquat.

The treatments effective in the control of *S. verticillata* involved s-metolachlor, s-metolachlor + glyphosate, and carfentrazone ethyl + glyphosate with sequential applications of glufosinate

ammonium at two doses: 2.4 D; 2.4-D + glyphosate and chlorimuron-ethyl with all sequential treatments and chlorimuron-ethyl + glyphosate with or without sequential applications.

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