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Article

Chemical Management of Broadleaf Buttonweed and Brazilian Pusley in Different Application Methods

Manejo Químico de Erva-Quente e Poaia-Branca em Diferentes Modalidades de Aplicação

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ABSTRACT - Increased use of glyphosate in transgenic soybean areas has selected resistant and tolerant weed species. The aim of this study was to evaluate chemical management strategies for controlling *Borreria latifolia* and *Richardia brasiliensis* at pre-emergence (Pre), early post-emergence ($Post_e$) and late post-emergence ($Post_l$). Six experiments were carried out in a completely randomized design with four replicates per treatment in the Pre experiments and three in the $Post_e$ and $Post_l$ experiments, for each of the species. In the Pre experiments, tests were performed with herbicides imazethapyr, sulfentrazone, chlorimuron, diclosulam, S-metolachlor and saflufenacil. In the $Post_e$ experiments, seedlings were sprayed with herbicides bentazon, fomesafen, lactofen, flumioxazin and glyphosate. In $Post_l$ experiments, adult plants received glyphosate application associated with herbicides 2,4-D, carfentrazone, imazethapyr, flumiclorac, flumioxazin, sulfentrazone, chlorimuron, saflufenacil and glufosinate, plus three sequential applications with glyphosate only and paraquat/diuron. In the experiments, there was a control treatment without application of herbicides. In the Pre experiments, the plants established at 14 and 28 days after application (DAA) were evaluated. In the $Post_e$ and $Post_l$ experiments, shoot dry matter evaluation and visual control were performed at 14 and 28 DAA. The herbicides sulfentrazone, S-metolachlor and saflufenacil suppressed the emergence of both *B. latifolia* as *R. brasiliensis*; chlorimuron-ethyl and diclosulam were effective only on *R. brasiliensis*. In $Post_e$, fomesafen, lactofen and flumioxazin reached levels of control over 90% of plants of both species. In $Post_l$, glyphosate associated with carfentrazone, flumiclorac, flumioxazin, chlorimuron-ethyl, saflufenacil, glufosinate, and sequential applications of glyphosate/glyphosate, glyphosate/paraquat+diuron, glyphosate+2,4-D/paraquat+diuron reached levels control higher than 95%.

Keywords: *Borreria latifolia*, *Richardia brasiliensis*, pre-emergence, early post-emergence, late post-emergence.

RESUMO - A intensificação do uso do herbicida glyphosate em áreas de soja RR tem selecionado espécies de plantas daninhas resistentes e tolerantes. Objetivou-se neste trabalho avaliar estratégias de manejo químico para o controle de ***Borreria latifolia*** *e* ***Richardia brasiliensis*** *com aplicações em pré-emergência (Pré), pós-emergência inicial ($Pós_i$) e pós-emergência tardia ($Pós_t$) dessas plantas. Foram conduzidos seis experimentos em delineamento inteiramente casualizado com quatro repetições nos experimentos em Pré e três em $Pós_i$ e $Pós_t$, para cada uma das espécies. Nos experimentos em Pré, foram testados os herbicidas imazethapyr, sulfentrazone, chlorimuron, diclosulam, S-metolachlor e saflufenacil. Em $Pós_i$, foram aplicados bentazon, fomesafen, lactofen, flumioxazin e glyphosate. Em $Pós_t$, plantas adultas receberam aplicações de glyphosate associadas a 2,4-D, carfentrazone,*

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imazethapyr, flumiclorac, flumioxazin, sulfentrazone, chlorimuron, saflufenacil e glufosinate, além de três aplicações sequenciais com glyphosate isolado e paraquat/diuron. Nos experimentos havia um tratamento testemunha sem aplicação de herbicidas. Nos experimentos Pré, avaliou-se o percentual de plantas emergidas aos 14 e 28 dias após a aplicação (DAA). Em Pós$_i$ e Pós$_t$ foram avaliados o controle visual aos 14 e 28 DAA e a matéria seca da parte aérea. Os herbicidas sulfentrazone, S-metolachlor e saflufenacil suprimiram a emergência tanto de ***B. latifolia*** *quanto de* ***R. brasiliensis****; chlorimuron e diclosulam foram eficientes somente sobre* ***R. brasiliensis****. Em Pós$_i$, fomesafen, lactofen e flumioxazin atingiram níveis de controle superiores a 90% sobre ambas as espécies. Em Pós$_t$, a associação de glyphosate com carfentrazone, flumiclorac, flumioxazin, chlorimuron, saflufenacil e glufosinate e as aplicações sequenciais de glyphosate/glyphosate, glyphosate/paraquat+diuron, e glyphosate+2,4-D/paraquat+diuron atingiram níveis de controle superiores a 95%.*

Palavras-chave: *Borreria latifolia*, *Richardia brasiliensis,* pré-emergência, pós-emergência inicial, pós-emergência tardia.

INTRODUCTION

Chemical weed management is the method most often used by farmers, especially because it is effective and has relatively quick results (Zimdahl, 2013). In many field situations, however, there has been no rotation of herbicides with different mechanisms of action over the years, causing high pressure and increasing the selection of tolerant and herbicide-resistant weeds (Coble and Schroeder, 2016). There has been intensive use of the herbicide glyphosate in agricultural systems because it offers broad-spectrum weed control and relatively low cost. Moreover, it can be widely used in areas containing glyphosate-tolerant crops, such as corn and soybeans. The increased use of glyphosate results in more limitations to weed control (Cerdeira et al., 2010), as a result of selection of herbicides with resistance and differential tolerance. Selection of tolerant and resistant weeds may be avoided through association of herbicides with different mechanisms of action, crop rotation and herbicide rotation (Constantin and Oliveira Jr., 2011; Coble and Schroeder, 2016).

In this context, applying herbicides at pre-emergence can help reduce initial interference by controlling the first weed emergence flows. The period before weed interference in soybeans can range from 8 to 33 days after emergence (Nepomuceno et al., 2007; Vitorino et al., 2017), which requires spraying at post-emergence as of early growth stages of the crop. In herbicides such as S-metolachlor, chlorimuron-ethyl and sulfentrazone, half-life in soil ranges from 15 to 180 days after application (Camargo et al., 2013). Residual activity of these herbicides may lead to an increase in the period before weed interference, thus delaying or even eliminating the need for post-emergence applications (Derr, 2012).

However, pre-emergence herbicide applications, for the most part, are not able to eliminate weed competition throughout the crop cycle. Therefore, using herbicides in crops at post-emergence is essential. The main advantage of applying selective herbicides at post-emergence is to allow control before weed interference can cause damage while avoiding visual or physiological toxicity to the crop (Schooler et al., 2008). However, in many cases, application of only one herbicide does not allow achieving the full spectrum of weed species present in an area, which is most evident in desiccation operations. The combined (mixture) or sequential use of two or more herbicides on the same crop is an improvement in weed control strategies. This practice can increase herbicide action spectrum; also, it allows the reduction of rates, leading to lower risk of phytotoxicity, lower residual effect and cost reduction (Singh et al., 2016).

The species *Borreria latifolia* (Aubl). K. Schum. and *Richardia brasiliensis* Gomes are widely found, particularly in areas with soybean crops. The two species are remarkably tolerant to glyphosate, and the response of this herbicide is well-documented in the literature (Cerdeira et al., 2010). There was 66% control of *B. latifolia* with 2,160 g a.e. ha^{-1} glyphosate at 21 days after application (Zarpellon et al., 2012). Even with high rates of glyphosate (2,160 g a.e. ha^{-1}), control of *R. brasiliensis* was only 77% at 28 days after application (Monquero et al., 2005).

As a result of low efficacy of glyphosate for control of *B. latifolia* and *R. brasiliensis*, other herbicides have to be identified as capable of controlling these weeds in soybean crops. Moreover, with increased use of genetically modified glyphosate-resistant soybean, less importance is being given to research and use of alternative herbicides, especially those applied at pre-emergence and early post-emergence. For this reason, pre-emergence and early post-emergence applications of alternative herbicides to glyphosate and tank mixtures or sequential applications may be important strategies to control these species.

Therefore, the objective of the present study was to evaluate chemical management strategies with use of different herbicides to control *B. latifolia* and *R. brasiliensis* at pre-emergence, early post-emergence and late post-emergence.

MATERIAL AND METHODS

Six experiments were conducted in pots in a greenhouse at the Federal Technological University of Paraná - UTFPR, Câmpus Pato Branco/PR, between September and December 2014. Each experiment represented a type of application for management of each weed species (*Borreria latifolia* and *Richardia brasiliensis*): pre-emergence applications (Pre), early post-emergence applications ($Post_e$) and late post-emergence applications ($Post_l$) (common during desiccation). The tests were conducted in a completely randomized design with four replications per treatment in Pre experiments and three replications in $Post_e$ and $Post_l$ experiments.

In all experiments, seeds of *B. latifolia* were subjected to dormancy breaking through heating at 60 °C for 30 min and subsequent immersion in potassium nitrate (KNO_3) 2% for three hours (Gallon et al., 2018). The species *R. brasiliensis* did not require dormancy breaking.

For the experiments with pre-emergence applications, the seeds were placed in gerboxes with two layers of germination paper, moistened with two and a half times their weight of distilled water. Then, they were left in a growth chamber at 25 °C in the dark for 24 hours. Just before the application, 20 seeds were sown equidistantly at a depth of 0.5 cm in pots with 5 dm^3 capacity and 330 cm^2 area, containing soil classified as an Oxisol (Latossolo Vermelho distroférrico, Brazilian Soil Classification System) (Embrapa, 2013) collected on the surface layer (0-20 cm) of a crop area without the presence of the study species, and then sieved. The soil was previously sterilized, and placed in a covered gutter with a perforated pipe at the center for supply of boiling water steam for 12 hours, in order to impair seed viability. Before application of the treatments, water was added to the pots at a depth of approximately 10 mm. These are the properties of the soil used in the experiments: pH: 5.3; organic matter: 33.5 g dm^{-3}; clay: 55.7%; sand: 3%; and silt: 41.3%.

In $Post_e$ and $Post_l$ experiments, the seeds of *B. latifolia* and *R. brasiliensis* were left to germinate in a growth chamber at 25 °C and a photoperiod of 12 hours following dormancy breaking and germination procedures, as previously described. Approximately 15 days after germination, one seedling of each species was transplanted into 5 dm^3 polyethylene pots containing soil whose characteristics were described above.

At the time of application, the plants from the $Post_e$ experiment had two and three pairs of fully expanded leaves. The experimental plants of $Post_l$ were beginning their reproductive cycle, with approximately 25 leaves (considering the main stem and branches). The herbicide treatments used in pre-emergence, $Post_e$ and $Post_l$ experiments are described in Tables 1, 2 and 3, respectively.

The treatments were applied with a CO_2 backpack sprayer at constant pressure of 300 kPa, fitted to a 1 m bar with three fan spray nozzles 110.02, spaced apart at 0.50 m, with total spray volume of 200 L ha^{-1}. In sequential management, the second application was performed ten days after the first.

Applications in the Pre and $Post_e$ experiments were held on Dec.1, 2014, and applications in the $Post_l$ experiments were performed on Dec.2, 2014 and Dec.12, 2014 (the latter were the sequential applications). The weather conditions at the beginning and end of applications were as follows: first day - air temperature (T°C) of 28.0 and 25.8 and relative air humidity (% RH) of 74.0 and 78.4; and second day - T°C 29.5 and 26.7%, and RH of 70.0 and 75.2. In the application of sequential treatments, the conditions at the beginning and end of applications were: T°C of 27.5 and 26.7; and RH% of 79.0 and 80.2. The experiments were watered daily with a manual sprinkler, and moisture in each pot was monitored and kept at about 80% field capacity.

Table 1 - Treatments used in pre-emergence control experiment (Pre) of *Borreria latifolia* and *Richardia brasiliensis*

Treatment	Commercial product	Rates	
		(g ha^{-1} a.i.)	(L (kg) ha^{-1} c.p.)
Control[(1)]	-	-	-
Imazethapyr	Pivot® 100 SL	100	0.2
Sulfentrazone	Boral® 500 SC	600	1.2
Chlorimuron	Panzer® 250 WDG	22.5	0.09
Diclosulam	Spider® 840 WG	35	0.042
S-metolachlor	Dual Gold®	1920	2.0
Saflufenacil	Heat®	60	0.085

[(1)] No herbicide application.

Table 2 - Treatments used in the early post-emergence (Poste) control experiment in early post-emergence ($Post_e$) in *Borreria latifolia* and *Richardia brasiliensis*

Treatment	Commercial product	Rates		Adjuvant /concentration
		(g ha^{-1} a.i)	(L(kg) ha^{-1} c.p.)	
Control[(1)]	-	-	-	-
Bentazon	Basagran 600®	720	1.2	Assist 1.0 L ha^{-1}
Fomesafen	Flex®	250	1.0	Energic 0.2% v/v
Lactofen	Cobra®	202.5	0.85	-
Flumioxazin	Sumisoya®	60	0.12	Agral 0.25% v/v
Glyphosate	Roundup Original®	960*	2.0	-

[(1)] No herbicide application. * Commercial product 360 g L^{-1} and for a total dose of 720 g a.e. ha^{-1}.

Table 3 - Treatments used in the late post-emergence control experiment ($post_l$) in *Borreria latifolia* and *Richardia brasiliensis*

Single application	Sequential application[(2)]	Commercial product	Rates		Adjuvant /concentration
			(g ha^{-1} a.i)	(L(kg) ha^{-1} c.p.)	
Control[(1)]	-	-	-	-	-
Gly***	-	Roundup Original®	1440*	3.0	-
Gly	Gly	Roundup/Roundup	1440/1440	3.0/3.0	-
Gly	Paraquat+Diuron	Roundup/Gramocil	1440/400+200	3.0/2.0	Agral 0.1%**
Gly+2,4-D	-	Roundup+DMA	1440+806	3.0+1.0	-
Gly+2,4-D	Paraquat+Diuron	Rdp+DMA/Gramocil	1440+806/400+200	3.0+1.0/2.0	Agral 0.1%**
Gly+Carfentrazone	-	Roundup+Aurora	1440+30	3.0+0.15	Assist 0.5%
Gly+Imazethapyr	-	Roundup+Pivot	1440+100	3.0+0.2	-
Gly+Flumiclorac	-	Roundup+Radiant	1440+60	3.0+0.6	Assist 0.2%
Gly+Flumioxazin	-	Roundup+Sumisoya	1440+25	3.0+0.05	Agral 0.25%
Gly+Sulfentrazone	-	Roundup+Boral	1440+200	3.0+0.4	-
Gly+Chlorimuron	-	Roundup+Panzer	1440+22.5	3.0+0.45	Assist 0.05%
Gly+Saflufenacil	-	Roundup+Heat	1440+60	3.0+0.085	Dash 0.5%
Gly+Glufosinate	-	Roundup+Finale	1440+500	3.0+2.5	Hoefix 0.2%

[(1)] No herbicide application. [(2)] Second application performed sequentially 10 days after the first. * Commercial product 360 g a.e. L^{-1}, in a total rate of 1,080 g a.e. ha^{-1}. ** Adjuvant added only to the sequential treatment. *** Glyphosate.

In the Pre experiment, normal emerged plants were counted without being removed, in each evaluation at 7, 14 and 28 days after application (DAA). In the $Post_e$ and $Post_l$ experiments, visual control evaluations were performed at 7, 14 and 28 DAA after the initial treatments, i.e., the first evaluation of treatments with sequential application was made prior to the second sequential application. Visual control assessments were carried out by at least two evaluators.

First, extreme levels (minimum and maximum) of control were determined for each experiment. The scale proposed by Frans et al. (1986) was used; where 0 represents no effect of herbicide symptoms on plants and 100 represents plant death.

In the Pre-emergence experiments, germination reduction percentage was calculated, as compared to the control without herbicide. After the last evaluation, shoots were collected from the plants of the $Post_e$ and $Post_l$ experiments. They were subsequently dried in a forced air circulation oven at 60 °C to constant weight. Shoot dry matter (SDM) was then quantified. After that, SDM percentage was estimated as compared to the control. For the variables germination reduction and SDM reduction, the values for the control were disregarded for statistical analysis.

The normality of variables was assessed by the Shapiro-Wilk test (Shapiro and Wilk, 1965), and when the assumptions were met, the data were subjected to analysis of variance by the F-test ($p \leq 0.05$). The means were compared by Tukey's test at 5% probability of error. Analyses were performed with the software Winstat (Machado and Conceição, 2005).

RESULTS AND DISCUSSION

Pre-emergence herbicide applications.

There was a significant ($p<0.05$) reduction in germination compared to the control without herbicide application, at the three evaluation times for the species *B. latifolia* and *R. brasiliensis* (Table 4). In the assessment carried out at 7 DAA, the herbicides saflufenacil, chlorimuron-ethyl and sulfentrazone caused a high reduction (over 90%) in emergence of *B. latifolia*. However, at 14 DAA, only saflufenacil and sulfentrazone were effective against the species, with 97% and 88% reduction, respectively. In this evaluation, all other herbicides reduced less than 50% of seedling emergence of the species; imazethapyr, in particular, caused only 6% reduction. There was a large increase in the level of S-metolachlor efficiency at 28 DAA. In this evaluation, it led to complete mortality of the seedlings which had emerged previously. Together, S-metolachlor, saflufenacil and sulfentrazone were the most effective herbicides for control of the species *B. latifolia* in the post-emergence application. Imazethapyr caused only 14% reduction of emergence when compared to the control; thus, it was the least efficient treatment. Chlorimuron-ethyl was not so efficient, either: on average, it reduced emergence by 50% in the last two evaluations.

Similarly to that findings in the present study, the herbicides S-metolachlor and sulfentrazone, when applied at the recommended rate, caused 100% reduction of emergence of *Borreria densiflora*, a species whose characteristics are similar to those of *B. latifolia*. However, the herbicide diclosulan, which showed only 72% of control in this study (Table 4), controlled *B. densiflora* effectively with only 25% of the rate (Martins and Christoffoleti, 2014).

The herbicides sulfentrazone, diclosulam and saflufenacil completely inhibited the emergence of *R. brasiliensis* in all evaluations (Table 4). Chlorimuron-ethyl and S-metolachlor also had similar efficacy for this species because, although they allowed emergence of plants along the initial

Table 4 **-** Emergence reduction (% compared to control) of *Borreria latifolia* e *Richardia brasiliensis*, at 7, 14 and 28 days after pre-emergence herbicide applications

Treatment	*Borreria latifolia*			*Richardia brasiliensis*		
	Emergence reduction (%)					
	7 DAA	14 DAA	28 DAA	7 DAA	14 DAA	28 DAA
Control[(1)]	0.0	0.0	0.0	0.0	0.0	0.0
Imazethapyr	29.2 c*	5.8 c	13.9 d	33.3 b*	26.9 c	34.3 b
Sulfentrazone	95.8 a	88.2 a	97.7 a	100.0 a	100.0 a	100.0 a
Chlorimuron	87.5 ab	47.1 b	51.2 c	100.0 a	88.5 a	100.0 a
Diclosulam	70.8 b	32.4 b	72.1 b	100.0 a	100.0 a	100.0 a
S-metolachlor	41.7 c	50.0 b	100.0 a	94.4 a	65.4 b	100.0 a
Saflufenacil	100.0 a	97.1 a	97.7 a	100.0 a	100.0 a	100.0 a
CV (%)	13.5	15.7	6.8	9.9	11.3	5.0

[(1)] No herbicide application. * Means followed by the same letter in the column do not differ by Tukey's test ($p<0.05$).

and intermediate evaluations, they had full control at 28 DAA. Emergence was expected in plants treated with S-metolachlor application, because this herbicide is absorbed into seedlings through the hypocotyl when, during emergence, the seedlings pass through the layer of soil that contains the product (Bollman et al., 2008). The 28 day control window, i.e., the maximum time estimated in the experiment, exceeds the period before weed interference occurs in soybean crops, which is eight days when considering the shortest period reported (Vitorino et al., 2017). This allows later post-emergence applications during the crop cycle. Thus, one can reduce the use of herbicides, minimize weed interference and increase the productive potential and profitability of the crop. As found for *B. latifolia*, imazethapyr was the least effective herbicide tested, with mean inhibition of only 30% of emergence of *R. brasiliensis* (Table 4).

R. brasiliensis plants kept in a fallow area produced 228 million seeds per hectare after the first cycle (Monquero and Christoffoleti, 2003), showing the potential of this species to restock the seed bank. This finding reinforces the importance of pre-emergence herbicide applications to prevent new flows of weed emergence, because these weeds not only compete with the crop but also increase the seed bank, if they reach the end of the cycle. Knowledge is needed about both weed biology and herbicide performance on weeds over time, in order to effectively select proper herbicide rates to obtain the required residual effect, in the case of chemical management at pre-emergence (Martins and Christoffoleti, 2014).

Pre-emergence herbicide applications are an important alternative to reduce the continued use of post-emergence herbicides with the same mechanism of action. Such practice can help reduce selection pressure of resistant biotypes, a common problem in many glyphosate-resistant soybean crops, in which glyphosate is used continuously and indiscriminately (Walsh and Powles, 2007; Constantin and Oliveira Jr., 2011; Coble and Schroeder, 2016). Moreover, pre-emergence herbicide applications, depending on residual activity in the soil, prevent accumulation of areas to be applied in the period in which post-emergence herbicides are effective (Derr, 2012); thus crops can be planned more effectively.

In general, sulfentrazone, S-metolachlor and saflufenacil were effective in inhibiting the seedling emergence of the species *R. latifolia* and *B. brasiliensis*; they were good options for integrating weed management strategies in areas cultivated with soybeans. Furthermore, the herbicides applied at pre-emergence in this study are alternatives for integrated management of not only two species, but also other weed species such as *Bidens pilosa*, *Commelina benghalensis* and *Ipomoea grandifolia* in genetically modified soybeans, which represent more than 90% of the soybeans grown in Brazil (Silva et al., 2015).

Early post-emergence herbicide applications

There was effect ($p<0.05$) of herbicide applications for visual control analysis and percentage reduction in shoot dry matter (SDM) in the two study species (Table 5). In general, all study herbicides controlled species *B. latifolia* effectively. At 7 DAA, the treatment with the herbicide lactofen showed 60% of control; thus, it was better than the others, which offered between 28% and 45% of control. The herbicides lactofen and bentazon were more effective than the others at 14 DAA, providing approximately 90% of control of the species. In the final evaluation, at 28 DAA, the herbicide fomesafem showed 100% control, similarly to the treatments with the herbicides bentazon, lactofen, and flumioxazin, which provided control levels above 97%. Glyphosate provided 93% control, and showed no statistical difference from the herbicides bentazon, lactofen and flumioxazin. The herbicides bentazon, fomesafen and lactofen reduced shoot dry matter by over 90% compared to the control (Table 5); they did not differ among themselves, confirming the results observed for visual control.

As was the case in the present work, Ramires et al. (2011) found that the use of glyphosate alone (960 g a.e. ha^{-1}) resulted in 87% of control at 35 DAA over *B. latifolia* plants between the one-leaf and the three-leaf stages. The associations of the herbicides chlorimuron-ethyl, imazethapyr, fomesafen, lactofen, flumiclorac-pentyl and bentazon with glyphosate were efficient in controlling *B. latifolia* in one-to three-leaf plants, while the best results for four-to six-leaf plants were found when glyphosate was associated with fomesafen, lactofen and flumiclorac-pentyl (Ramires et al., 2011).

Table 5 - Control (%) of *Borreria latifolia* and *Richardia brasiliensis* at 7, 14 and 28 DAA (days after application) and shoot dry matter reduction (SDMR) (% relative to control) after application of herbicides at early post-emergence (Pos_e)

Treatment	*Borreria latifolia*				*Richardia brasiliensis*			
	Control (%)			SDMR (%)	Control (%)			SDMR (%)
	7 DAA	14 DAA	28 DAA		7 DAA	14 DAA	28 DAA	
Control[(1)]	0.0 d*	0.0 c	0.0 c	0.0	0.0 c	0.0 d	0.0 c	0.0
Bentazon	30.0 bc	90.0 a	96.7 ab	91.3 a	31.7 b	40.0 c	76.7 b	66.6 c
Fomesafen	45.0 b	66.7 b	100.0 a	90.3 a	78.3 a	90.0 a	96.7 a	97.1 a
Lactofen	61.7 a	88.3 a	98.3 ab	92.2 a	83.3 a	96.7 a	98.3 a	98.4 a
Flumioxazin	36.7 bc	75.0 b	96.7 ab	85.1 b	76.7 a	77.0 ab	96.7 a	96.1 a
Glyphosate	28.3 c	68.3 b	93.3 b	83.8 b	15.0 bc	45.0 bc	87.0 ab	89.8 b
CV (%)	14.3	9.5	2.9	1.4	17.4	15.9	11.6	2.4

[(1)] No herbicide application. * Means followed by the same letter in the column do not differ by Tukey's test ($p<0.05$).

Preliminary studies on early post-emergence applications of imazethapyr, chlorimuron-ethyl, fomesafen and glyphosate showed that the weed *B. densiflora* becomes tolerant to these herbicides at the stage of four-to-five leaf pairs, which hinders proper control (Martins and Christoffoleti, 2014). That is, at earlier stages (of one-to-three leaf pairs), the plants are susceptible to the action of the herbicides. In more developed plants, there were many lateral buds along the main stem of the plants, i.e., two pairs of leaves at each node related to the pair of main leaves, causing an umbrella effect on these shoots, which ensures plant survival, even after application (Christoffoleti and Martins, 2014).

At 7 DAA, the herbicides fomesafen, lactofen and flumioxazin had control levels above 75% over *R. brasiliensis* (Table 5). It was found that the herbicides fomesafen and lactofen showed control above 90% at 14 DAA, while bentazon and glyphosate achieved only 40% and 45%, respectively. In the last evaluation, at 28 DAA, the herbicides fomesafen, lactofen, and flumioxazin showed control over 96%, unlike the treatment with the herbicide glyphosate, which showed 87% control. Also in the last evaluation, weed control provided by bentazon was increased in comparison to the previous evaluation: 76%, a rate which is similar to that of glyphosate. The most efficient herbicides in terms of SDM reduction were fomesafen, lactofen and flumioxazin: 97%, 98% and 96%, respectively. Glyphosate reduced dry matter by 90%, which is a lower rate than that of the cited herbicides. The herbicide bentazon reduced SDM by 66% only, in comparison to the control, i.e., it was the least efficient herbicide used in this research.

In another study, the application of glyphosate alone on four-leaf *R. brasiliensis* plants provided control levels of 60% at 7 DAA and 90% at 14 DAA, and reduced SDM accumulation by 83% (Monquero et al., 2001). These results are similar to the findings in this experiment (Table 5). The results of the present study showed that the species *R. brasiliensis* is less tolerant to glyphosate when it is applied at early post-emergence. In another study, the application of herbicides bentazon and flumioxazin alone or mixed with glyphosate on four-leaf *R. brasiliensis* plants offered control above 94% at 14 DAA (Monquero et al., 2001). However, in the present study, application of bentazon alone led to control of only 76%. According to Jha et al. (2008), two applications of glyphosate are required to prevent RR soybean yield loss from a mixed population of adult plants of species of the genera *Amaranthus* and *Richardia*. Also, they highlighted the difficulty in controlling those species with this herbicide. However, excessive use of glyphosate increases selection pressure, leading to the emergence of more tolerant biotypes (differential tolerance). Thus, it is crucial to use herbicides with different mechanism of action, e.g., fomesafen, lactofen or flumioxazin (Protox inhibitors), which showed satisfactory levels of control over both species when applied at early post-emergence.

Late post-emergence herbicide applications

There was effect ($p<0.05$) of treatments when the herbicides were applied at late post-emergence for visual control analyses, as well as percentage reduction in shoot dry matter (SDM) for both species (Table 6). At 7 DAA, the associations of glyphosate with carfentrazone-ethyl

Table 6 **-** Control (%) of *Borreria latifolia* at 7, 14 and 28 DAA (days after application) and shoot dry matter reduction (SDMR) (% relative to control) after late post-emergence (Pos_l) herbicide application

Single application	Sequential application	Control (%)			SDMR (%)
		7 DAA	14 DAA	28 DAA	
Control[(1)]	-	0.0 e*	0.0 e	0.0 D	0.0
Gly**	-	46.7 c	56.7 cd	76.7 C	65.9 d
Gly	Gly	43.3 cd	75.7 b	96.7 A	77.2 c
Gly	Prqt+Diuron	46.7 c	90.0 a	100.0 A	87.0 ab
Gly+2,4-D	-	36.7 cd	50.0 d	78.3 Bc	74.5 c
Gly+2,4-D	Prqt+Diuron	40.0 cd	81.7 ab	100.0 A	90.6 a
Gly+Carfentrazone	-	85.0 a	86.7 a	100.0 A	91.5 a
Gly+Imazethapyr	-	48.3 c	81.7 ab	95.0 Ab	76.6 c
Gly+Flumiclorac	-	80.0 ab	83.3 ab	100.0 A	90.2 a
Gly+Flumioxazin	-	78.3 ab	88.3 a	95.0 Ab	81.3 bc
Gly+Sulfentrazone	-	66.7 b	70.0 bc	76.7 C	80.2 bc
Gly+Chlorimuron	-	26.7 d	85.0 a	95.0 A	79.0 c
Gly+Saflufenacil	-	81.7 ab	88.3 a	100.0 A	90.2 a
Gly+Glufosinate	-	85.0 a	90.0 a	100.0 A	90.2 a
CV (%)		11.2	6.5	6.6	9.7

[(1)] No herbicide application. * Means followed by the same letter in the column do not differ by Tukey's test ($p<0.05$). ** Glyphosate.

and glufosinate provided 85% control of *B. latifolia*. This treatment stood out among the others and had similar results to those of associations with flumiclorac, flumioxazin and saflufenacil, which reached 80% control. At 14 DAA, except for application of glyphosate alone, associations of glyphosate with 2,4-D and sulfentrazone, and sequential application also with glyphosate, all other treatments showed over 80% control over the plants of this species, i.e., they did not differ from one another. In the last evaluation (28 DAA), only treatments with glyphosate alone and glyphosate associated with 2,4-D and sulfentrazone showed control levels below 80%, unlike the other treatments. All other study treatments showed potential for use to control *B. latifolia* in later stages of development (Table 6).

The success of sequential applications to control glyphosate-tolerant species, such as those from the genus *Borreria*, had already been reported by Monquero et al. (2005). The use of sequential application for weed management is also important to avoid problems with antagonism (when a product impairs the efficiency of the other) of glyphosate with contact herbicides, which are traditionally used in this kind of management. However, the use of mixed herbicides has great advantages, such as lower production costs, broader spectrum and increased time of pest control on the crops, lesser environmental impact, as well as less likelihood of occurrence of resistant biotypes selected by successive applications of a single molecule (Hatzios and Penner, 1985).

The treatments associated with glyphosate that caused the greatest SDM reduction were carfentrazone, flumiclorac, saflufenacil, glufosinate, and the treatments with sequential application of paraquat+diuron, with an average of 90% reduction (Table 6). A single application of glyphosate or a sequential application of glyphosate, or in association with 2,4-D and imazethapyr, had negative results, providing reductions below 77%, unlike the other treatments.

In the study of Petter et al. (2007), the treatment with glyphosate (1,080 g a.e. ha^{-1}) + 2,4-D (241.8 g ha^{-1}) had the lowest level of control of *B. latifolia* compared to the others, similarly to the results of the present experiment. However, control levels above 90% were found with several application systems with glyphosate/2,4-D followed by sequential application of paraquat+diuron or glyphosate (Petter et al., 2007).

Control levels of *R. brasiliensis* at 7 DAA (Table 7) in the treatments in which glyphosate was applied in association with carfentrazone, flumiclorac, flumioxazin, saflufenacil and glufosinate, were greater than 76%, which were good results in comparison to the other treatments. The treatments with application of glyphosate alone reached a maximum of 15% control in the same evaluation. In the second evaluation, at 14 DAA, in addition to the associations mentioned

Table 7 **-** Control of *Richardia brasiliensis* at 7, 14 and 28 DAA (days after application) and shoot dry matter reduction (SDMR) (% relative to control) after late post-emergence (Pos_l) herbicide application

Single application	Sequential application	Control (%)			SDMR (%)
		7 DAA	14 DAA	28 DAA	
Control[(1)]	-	0.0 f*	0.0 E	0.0 d	0.0
Glyphosate (Gly)	-	11.7 ef	51.7 C	80.0 c	66.5 d
Gly**	Gly	11.7 ef	71.7 B	95.0 a	79.2 c
Gly	Prqt+Diuron	15.0 de	90.0 A	100 a	90.7 a
Gly+2,4-D	-	30.0 c	76.7 ab	95.0 a	72.9 cd
Gly+2,4-D	Prqt+Diuron	33.3 c	90.0 a	100 a	90.1 ab
Gly+Carfentrazone	-	76.7 ab	90.0 a	100 a	90.3 ab
Gly+Imazethapyr	-	25.0 cd	83.3 ab	91.7 ab	70.9 cd
Gly+Flumiclorac	-	80.0 ab	90.0 a	100 a	90.2 ab
Gly+Flumioxazin	-	83.3 ab	90.0 a	98.3 a	75.3 cd
Gly+Sulfentrazone	-	71.7 b	71.7 b	81.7 bc	79.6 c
Gly+Chlorimuron	-	25.0 cd	80.0 ab	100 a	80.4 bc
Gly+Saflufenacil	-	88.3 a	90.0 a	100 a	90.2 ab
Gly+Glufosinate	-	86.7 a	90.0 a	100 a	90.2 ab
CV (%)		8.6	6.0	4.0	7.4

[(1)] No herbicide application. * Means followed by the same letter in the column do not differ by Tukey's test ($p<0.05$). ** Glyphosate.

above, associations with 2,4-D, imazethapyr and chlorimuron and sequential treatments of glyphosate/paraquat+diuron, or glyphosate+2,4-D/paraquat+diuron were also relevant. They all provided control levels between 80% and 90%. At 28 DAA, all treatments tested, except for glyphosate alone or associated with sulfentrazone, showed over 90% control (Table 7).

The treatments that caused the highest reductions in SDM of *R. brasiliensis* were sequential applications of glyphosate/paraquat+diuron, or glyphosate+2,4-D/paraquat+diuron and associations of glyphosate with carfentrazone, flumiclorac, saflufenacil and glufosinate, with average reduction of 90%. Sequential application of glyphosate alone or associated with 2,4-D, imazethapyr, flumioxazin, sulfentrazone, and chlorimuron resulted in SDM reduction between 70% and 80%, unlike the aforementioned treatments. The treatment with application of glyphosate alone reduced SDM by 66%, the lowest rate among the study herbicide treatments, which indicates tolerance of the weed species *R. brasiliensis* to the herbicide (Table 7).

The association of the herbicides glyphosate+chlorimuron-ethyl at the rates of 720+28 g ha^{-1} led to 96% control at 28 DAA (Vitorino et al., 2012), even with lower rates than the ones used in the present study. The applications of glyphosate alone or mixed with flumioxazin were effective in controlling *Bidens pilosa, Richardia brasiliensis, Digitaria horizontalis* and *Brachiaria decumbens*. Also, the presence of flumioxazin in the mixture may have accelerated plant death (Constantin and Oliveira Jr., 2011).

Importantly, the glyphosate rate usually used by farmers for weed control is 1,080 g a.e. ha^{-1}, but the rates used over the years are being increased, depending on the selection process caused by the frequent use of the herbicide. The results of the experiments, in all application methods tested, show that herbicides with different mechanisms of action are available in the market, e.g., Protox (protoporphyrinogen oxidase) inhibitors, ALS (acetolactate synthase), GS (glutamine synthetase), PSI (photosystem I), PSII (photosystem II) and synthetic auxins, which can be used more often to improve control levels of glyphosate-tolerant species. Applications of 2,4-D, glyphosate and glufosinate-ammonium offer broad-spectrum control and have the potential to control nine of the ten most problematic weeds in soybean in the USA; thus, they play a major role in resistance management (Norsworthy et al., 2012; Riar et al., 2013).

Importantly, management strategies that do not employ chemical treatments should also be considered for weed management purposes. Alternative weed management practices include cultivation of crop species with greater competitive potential which are adapted to the region, grass cover crops, and intercropping with suppressive cover crops with positive allelopathic effects, use of certified seeds, cleaning of tillage and harvesting equipment, etc. Although it is unlikely that crop rotation can replace the use of herbicides and eliminate selection pressure on farming systems, it is a management practice that reduces the use of herbicides over the years (Pacheco et al., 2016).

In general, it was found that there are effective herbicide options for chemical management of the two species in three study application methods. In the pre-emergence applications, the herbicides sulfentrazone, s-metolachlor and saflufenacil are effective in inhibiting the emergence of both *B. latifolia* and *R. brasiliensis*, while chlorimuron-ethyl and diclosulam are only effective for *R. brasiliensis*. At early post-emergence, fomesafen, lactofen and flumioxazin efficiently control plants of both species, while bentazon is effective only for *B. latifolia*. At late post-emergence, the association of glyphosate with herbicides carfentrazone-ethyl, flumiclorac-pentyl, flumioxazin, chlorimuron-ethyl, saflufenacil, glufosinate and sequential applications of glyphosate/glyphosate, glyphosate/paraquat+diuron, and glyphosate+2,4-D/paraquat+diuron are effective in controlling *B. latifolia* and *R. brasiliensis*.

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