Ensaios e Ciência
ISSN 1415-6938 e ISSN 2178-695X

DOI: https://doi.org/ 10.17921/1415-6938.2025v29n4p1074-1090

Pre-Sowing Control of *Commelina benghalensis* by Herbicides in Soybean Crops

Controle Químico de Commelina benghalensis em Dessecação Pré-Plantio da Cultura da Soja

Received: June 26, 2025
Accepted: November 22, 2025

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Abstract

Dayflower (*Commelina benghalensis*) is one of the main weeds that affect soybean production and stands out due to its frequency of occurrence in agricultural areas and the tolerance to the herbicide glyphosate. Therefore, the application of herbicide before sowing soybeans becomes essential in controlling dayflower due to the greater variety of herbicides that can be used. Thus, the objective of this study was to assess the efficiency of herbicides combined with glyphosate in the pre-sowing control of *C. benghalensis* and the treatments effects on soybean yield components. A randomized block experimental design was used, with seven herbicide treatments and three replications. Carfentrazone-ethyl had the highest efficacy in post-emergence control of *C. benghalensis*, but the plants regrew throughout the crop cycle. Halauxifen-methyl + diclosulam proved to be a good option to control C. benghalensis, with or without sequential application. The sequential application of glufosinate-ammonium was the most effective herbicide in controlling *C. benghalensis*. Soybean crop yield components presented no significant differences resulting from pre-sowing herbicide applications.

Keywords: *Glycine max* L. Merril. Weed. Grain Yield. Benghal Dayflower.

Resumo

A trapoeraba (*Commelina benghalensis*) é uma das principais plantas daninhas que afetam a produção de soja e se destaca devido à sua frequência de ocorrência em áreas agrícolas e a tolerância natural ao herbicida glifosato. Desta forma, a aplicação de herbicida antes da semeadura da soja torna-se elemento chave no controle da trapoeraba pela maior variedade de herbicidas que podem ser utilizados. Desta forma, objetivou-se avaliar a eficiência de herbicidas associados ao glifosato na dessecação pré-semeadura, bem como os efeitos dos tratamentos sobre os componentes de rendimento e produtividade da cultura da soja. O delineamento experimental foi o de blocos casualizados, sendo sete tratamentos herbicidas e três repetições. Dentre os herbicidas aplicados, a carfentrazona-etílica apresentou maior efeito de fitointoxicação e controle em pós-emergência de plantas de trapoeraba, porém apresentou rebrotes ao longo do desenvolvimento da cultura. O herbicida halauxifen-methyl + diclosulam apresentou-se como uma boa ferramenta para o manejo de trapoeraba nas duas modalidades aplicadas, com e sem sequencial. O tratamento com aplicação sequencial de glufosinato de amônio mostrou-se o mais eficiente no decorrer das avaliações, porém não resultou em incremento de produtividade da cultura da soja. Não foram observadas diferenças nos componentes de rendimento em função da aplicação dos herbicidas em pré-semeadura da cultura da soja.

Palavras-chave: *Glycine max* L. Merril. Planta Daninha. Rendimento de Grãos. Trapoeraba.

1 Introduction

Soybean (*Glycine max* (L.) Merrill) is widely cultivated and widespread throughout the world due to its utilization in several sectors such as food, fuel, and animal feed industries (Toloi *et al*., 2021). It is the primary crop in Brazil in terms of cultivated area and yield. Soybean production in the 2023/24 crop season was 147.4 million tons, cultivated on just over 46 million hectares (CONAB, 2024).

Weed infestation is among the main challenges in soybean crop systems, impacting crop development and causing losses of up to 80% of the production potential of soybean crops, depending on the weed species and infestation density (Braz *et al*., 2021).

Commelina benghalensis stands out among the main weeds affecting soybean crops due its frequency of occurrence and challenging control (Bermaiya *et al*., 2023). The difficulties in the chemical control of *C. benghalensis* are attributed to its tolerance to glyphosate (Perissato *et al*., 2023). Tolerance to herbicides is related to the plant's stage of development, morphology, leaf anatomy (presence of trichomes, thickness and composition of the cuticular layer) and differences in absorption, translocation, compartmentalization, and metabolism of the herbicide molecule (Jerônimo *et al*., 2021; Panigo *et al*., 2022).

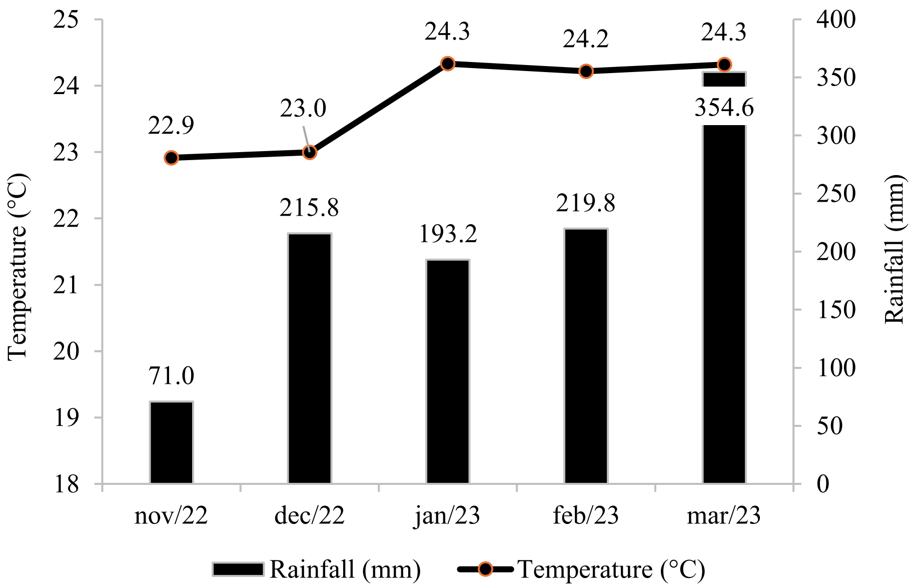
Herbicide combinations applied in single or sequential applications generally broaden the spectrum of weed control, as one herbicide can optimize the action of another, presenting synergistic or complementary effects (Barbieri *et al*., 2022). Synergistic effects of the herbicide mixture in the control of *C. benghalensis* were observed for glyphosate + 2,4-D (Santos *et al*., 2002; Freitas *et al*., 2018), glyphosate + metsulfuron methyl (Freitas *et al*., 2018), glyphosate + carfentrazone ethyl (Rocha *et al*., 2007), and specifically in Roundup Ready (RR) soybean crops, the combinations of glyphosate in tank mixtures with chlorimuron-ethyl, cloransulam-methyl, lactofen and imazethapyr favored the control of C. benghalensis (Maciel *et al*., 2011).

In this context, the objective of this study was to assess the efficiency of herbicides combined with glyphosate in the pre-sowing control of *C. benghalensis* and the effects of the treatments on soybean yield components.

2 Material and Methods

The experiment was conducted from November 2022 to March 2023, in an area naturally infested with *Commelina benghalensis* at Agua Mansa Farm, Rio Verde, Goiás, Brazil (17° 55' 20.16" S and 51° 08' 56.22" W) and 762 m of altitude. The region has an Aw climate, tropical, with concentrated rainfall during the summer (October to April) and a well-defined dry season in the winter (May to September), according to the Köppen-Geiger classification (REF). Mean annual temperatures vary from 21 to 33 °C and mean annual rainfall depths vary from 1,500 to 1,800 mm. Monthly climate data on rainfall depths and mean temperatures during the experimental period are shown in Figure 1.

Figure 1 - Climate data collected during the experimental period: rainfall (mm) and mean temperature (°C)



Source: Meteorological Station of the MRE Agropesquisa (2023).

In an area with homogeneous infestation of *Commelina benghalensis*, a randomized block experimental design was installed, with seven treatments and three replications, totaling 21 experimental units, consisting of plots of 3 × 5 m, with an evaluation area of 15 m^2.

The herbicides were applied using a CO_2-pressurized backpack sprayer equipped with a spray boom containing six XR-11002 extended-range flat-fan nozzles, spaced 0.5 m apart, positioned at a height of 0.4 m from the plant surface. The application rate was equivalent to 150 L ha^{-1}, and the working pressure used was 1.2 bar. All treatments were applied on the same day, 20 days before sowing, except for treatment 7, which included an additional application on the day of soybean planting (sequential application), to verify the additive effects or not, of this application in the control of *C. benghalensis*. The herbicide treatments tested in the experiment and their respective rates are described in Table 1.

Table 1 – Treatments and herbicides used in the experiment and their respective rates of active ingredient or acid equivalent

Herbicide	**Commercial Product**	**Concentration (g kg^{-1} 7or g L^{-1})**	**Formulation**	**Rate (g ha^{-1})**
Glyphosate[1]	Glyphotal	480.0	SL	1500.0
Halauxifen-methyl + Diclosulam	Paxeo	115.0 + 580.0	WG	6.06 + 31.9
2,4-D dimethylamine	Aminol	806.0	SL	670.0
Flumioxazin	Flumyzin	500.0	SC	40.0
Carfentrazone-ethyl	Aurora	400.0	EC	30.0
Saflufenacil	Heat	700.0	WG	35.0
Halauxifen-methyl + Diclosulam + Glufosinate-ammonium[2]	Paxeo + Finale	115.0 + 580.0 + 200.0	WG	6.06 + 31.9 + 400.0

[1]All treatments were applied with 1,500.0 g a.e. ha^{-1} of glyphosate in tank mix. [2] Glufosinate-ammonium applied 20 days after the first application (sequential application).
Source: research data.

Soybean seeds of the cultivar Pionner 96R29 IPRO™, which has a mean cycle 115 days, were sown on November 24, 2022 (20 days after the herbicide applications), under crop season conditions, without irrigation system, using a 5-row seed-fertilizer drill (JM2670 POP; JumilTM, Batatais, Brazil), with spacing of 0.5 m between rows and 15 plants per linear meter, totaling a population of 300,000 plants ha^{-1}. All phytosanitary management during the experimental period was carried out using agricultural chemicals registered for the crop, to prevent the occurrence of pests and diseases. Post-emergence herbicide was applied after the last evaluation of *C. benghalensis* plant dry weight, 35 days after emergence, when the soybean crop was at the V_7 phenological stage to maintain the achieved results until harvest.

The percentage of control of *C. benghalensis* plants were evaluated at 7, 14, 21, and 28 days after application of the herbicide treatments through visual evaluations in each plot, using a scale of grades, following the methodology described by the Brazilian Society of Weed Science (SBCPD, 1995); on this scale, '0' indicates the absence of lesion symptoms (chlorosis and necrosis), and '100' indicates the death of the plant. Pre-emergence control was performed at 7, 14, 21, and 28 days after application through visual evaluations and determination of infestation percentages in plots with regrowth of C. *benghalensis* plants.

Soybean plant height was measured from the ground to the highest point of the plant in 20 randomly chosen consecutive plants in the central row of each plot at 35 days after soybean emergence, corresponding to 55 days after herbicide applications. The dry weight of *C. benghalensis* was evaluated using plants within a 0.5 × 0.5 m frame, which was cast twice to determine a representative area in each plot. The plants within the frame were cut at ground level and dried in forced-air circulation oven at 70 °C for 72 hours.

Aerial images were obtained during a flight conducted at 35 days after emergence of soybean plants, using an unmanned aerial vehicle (Phantom 4 AdvancedTM, DJI, Shenzhen, China) equipped with an RGB (red-green-blue) sensor (20 MP CMOS; DJI, Shenzhen, China). Flights were conducted between 09:00 and 11:00 hours when >80% of the experimental area was free of clouds, at an altitude of 30 m, with 80% lateral and frontal overlap (pixels of 1.0 cm). The acquired images were converted into orthophotos using the software Pix4D 3.2.23 and subsequently analyzed through the image processing software QGIS.

Two vegetation indices calculated from visible spectrum bands (RGB) were utilized: MPRI (Modified Photochemical Reflectance Index) defined by the equation (G-R) / (G+R), according to Chen *et al*. (2008) and VARI (Visible Atmospherically Resistant Index) defined by the equation (G-R) / (G+R-B), according to Gitelson *et al*. (2003). Spectral reflectance of sampled points was obtained through the mean values of pixels within each plot (3 × 5 m). Sampling in each plot was conducted by creating a vector layer of 3 × 5 m for extraction of pixels corresponding to each vegetation index and spectral band. Mean pixel values were extracted using zonal statistics, and then the vector file (.shp) was exported as a spreadsheet file (.xlxs) for statistical analysis.

Soybean crop yield components evaluated before harvesting, at 115 days after sowing were: number of pods per plant, number of grains per pod, and 1,000-grain weight, using the mean of 10 consecutive plants in the row. According to Lamego *et al*. (2004), the effects of weed interference on the characteristics of cultivated plants can compromise the development of reproductive structures and affect productivity components. Two 3-m rows of plants were harvested from each plot, pods were threshed, grains were weighed, grain weights were adjusted to 13% moisture, and yield was converted to kg ha^{-1}.

All data were manually collected, except for aerial images, which were obtained using the drone, and later worked on in processing software, and subsequently organized into spreadsheets for experiment evaluations. The obtained data were subjected to analysis of variance, and the significant effects by the 'F' test were subjected to the Tukey's test at a 0.05 probability level, using the software SISVAR.

3 Results and Discussion

The results of the treatment with carfentrazone-ethyl were statistically different from those of the other treatments regarding the percentage of post-emergence control of *Commelina benghalensis* plants (Table 2). This herbicide reached the highest control percentage in all evaluations, with 100% control at 28 days after application (DAA). This result is consistent with those reported by Sousa *et al*. (2017), who found 100% control of *C. benghalensis* plants at 30 DAA with a mixture of glyphosate + carfentrazone-ethyl. Ronchi *et al.* (2002) and Rocha *et al.* (2007) also found efficient control of *Commelina* species with the mixture of glyphosate + carfentrazone-ethyl at rates 960 + 30 g ha^{-1}. Carfentrazone-ethyl belongs to the chemical group of triazolinones, and its mechanism of action involves the inhibition of protoporphyrinogen oxidase (PROTOX). Plants treated with this herbicide accumulate protoporphyrinogen IX, which is involved in the formation of singlet oxygen, responsible for membrane peroxidation (Traxler *et al.*, 2023). It causes rapid dehydration of susceptible species, and symptoms can be observed on the same day of application (Zhao *et al*., 2020).

Table 2 – Post-emergence control (%) of *Commelina benghalensis* evaluated at 7, 14, 21, and 28 days after application (DAA) of different herbicides

Herbicide	**Rate (g ha^{-1})**	**7**	**14**	**21**	**28**
		------------------ DAA -------------------			
Glyphosate	1500	0.0 c	0.0 d	1.6 d	8.3 g
Halauxifen + diclosulam	6.06 + 31.9	0.0 c	6.6 cd	33.3 b	43.3 d
2,4-D	670.0	0.0 c	6.6 cd	11.6 cd	25.0 f
Flumioxazin	40.0	0.0 c	8.3 c	15.0 c	33.3 e
Carfentrazone-ethyl	30.0	66.6 a	76.6 a	90.0 a	100.0 a
Saflufenacil	35.0	11.6 b	18.3 b	28.3 b	56.6 c
Halauxifen + Diclosulam + Glufosinate-ammonium	6.06 + 31.9 + 400.0	0.0 c	8.3 c	26.6 b	73.3 b
CV (%)	--	21.06	14.33	12.62	4.68

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test ($\alpha = 0.05$). CV - Coefficient of variation.
Source: research data.

The treatment with halauxifen + diclosulam + glufosinate-ammonium reached a control percentage of 73.3% at 28 DAA, significantly differing from the treatment halauxifen + diclosulam (43.3%) (Table 2), the treatment with sequential application conducted on the day of planting, increased control by 30%, reinforcing the need for a sequential application after using a systemic herbicide for weeds below the ideal control stage.

The treatments with flumioxazin and saflufenacil reached low control levels in all evaluations, except at 28 DAA when saflufenacil resulted in 56.6% control. Morichetti *et al.* (2017) observed that saflufenacil, applied either pre- or post-emergence in the dose of 50 g ha^{-1} was ineffective for *C. benghalensis*, with maximum control of 79% to the 28 days after treatment. Glyphosate treatment is the standard used by producers to control *C. benghalensis* and was also used as standard in this assay. This herbicide has shown to be ineffective in controlling this species, as *C. benghalensis* inherently presents tolerance to glyphosate, confirming the findings by Carvalho *et al.* (2008).

The treatments halauxifen + diclosulam and halauxifen + diclosulam + glufosinate-ammonium reached optimal control levels for *C. benghalensis* in the pre-emergence, above 81% according to the degrees of control proposed in the ALAM scale (1974) (Table 3). This is attributed to the presence of diclosulam in the formulation of the commercial product (Paxeo®), which is an ALS-inhibiting herbicide widely used as a pre-emergence herbicide in soybean crops. These treatments reached 100% control up to 14 days after emergence and maintain 85% control after the last evaluation (28 days after soybean emergence) (Table 3).

Table 3 – Pre-emergence control (%) of *Commelina benghalensis* evaluated at 7, 14, 21, and 28 days after the application (DAA) of different herbicides

Herbicide	**Rate (g ha^{-1})**	**7**	**14**	**21**	**28**
		----------------------DAA--------------------			
Glyphosate	1500	0.0 c	0.0 c	0.0 c	0.0 c
Halauxifen + Diclosulam	6.06 + 31.9	100.0 a	100.0 a	91.6 a	86.6 b
2,4-D	670.0	0.0 c	0.0 c	0.0 c	0.0 c
Flumioxazin	40.0	30.0 b	25.0 b	11.6 b	0.0 c
Carfentrazone-ethyl	30.0	0.0 a	0.0 a	0.0 c	0.0 c
Saflufenacil	35.0	0.0 c	0.0 c	0.0 c	0.0 c
Halauxifen + Diclosulam + Glufosinate-ammonium	6.06 + 31.9 + 400.0	100.0 a	100.0 a	96.6 a	91.6 a
CV (%)	--	3.30	5.88	6.61	6.61

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test (α = 0.05). CV – Coefficient of variation.
Source: research data.

According to Mendes *et al.* (2023), the diclosulam is considered moderately persistent, with half-life of 49 days in soil. Therefore, the use of this herbicide can reduce the impact of weeds in the early stages of crop development, contributing to more effective canopy closure and early soybean maturation (Jaremtchuk *et al*., 2008). According to Patel *et al*. (2023), the use of pre-emergence herbicides in pre-sowing management promotes flexibility in the post-emergence weed control schedule and, in some cases, eliminates the need for application of post-emergence herbicides.

The treatment with flumioxazin showed a low control level at 7 days, which decreased until completely losing its residual effect in the soil, reaching 0% control at 28 days after soybean emergence. This can be explained by the lower flumioxazin rate used. Some studies have indicated that flumioxazin exhibits efficient residual effects when applied at rates of 50 g ha^{-1} or higher and has rapid dissipation in the soil, with a half-life ranging from 11 to 26 days (Chen *et al*., 2022; Eason *et al*., 2022). The treatments glyphosate, 2,4-D, carfentrazone-ethyl, and saflufenacil presented no residual activity in the soil, explaining the lack of pre-emergence control of *C. benghalensis*.

The treatment halauxifen + diclosulam + glufosinate-ammonium significantly differed from the others regarding plant height at 35 days after soybean emergence. The effects of the other treatments were like each other, differing only from the treatment with application of glyphosate alone, which had the lowest mean (51.1 cm), denoting competition of *C. benghalensis* plants with the soybean crop for water and nutrients, which can affect the crop growth and development.

The treatments halauxifen + diclosulam and halauxifen + diclosulam + glufosinate-ammonium resulted in the lowest dry weights of *C. benghalensis* plants: 2.3 g and 1.1 g, respectively (Table 4). This reinforces the importance of using a pre-emergence herbicide for *C. benghalensis* control before planting the soybean crop, allowing the crop to develop free from competition with weeds in the early crop development stages. This is consistent with the study of Fleck *et al.* (2004), who reported that the negative effects of competition on crop development generally decrease over time between the crop emergence and weed emergence.

Table 4 – Soybean plant height (PH) and dry weight of *Commelina benghalensis* plants (DW) evaluated at 35 days after emergence of soybean plants as a function of different herbicides treatment

Herbicide	**Rate (g ha^{-1})**	**PH (cm)**	**DW (g)**
Glyphosate	1500	51.1 c	15.9 a
Halauxifen + Diclosulam	6.06 + 31.9	58.9 ab	2.3 c
2,4-D	670.0	56.4 b	6.3 bc

Flumioxazin	40.0	57.9 b	8.4 b
Carfentrazone-ethyl	30.0	57.3 b	8.5 b
Saflufenacil	35.0	57.6 b	8.5 b
Halauxifen + Diclosulam + Glufosinate-ammonium	6.06 + 31.9 + 400.0	61.0 a	1.1 c
CV (%)	--	1.62	28.13

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test ($\alpha = 0.05$). CV – Coefficient of variation.
Source: research data.

Santos *et al*. (2016) found that combining diclosulam and glyphosate contributed to reduction in initial competition with invasive weeds; however, a sequential herbicide application after soybean crop emergence was necessary. The treatment glyphosate presented the highest mean dry weight of *C. benghalensis* plants, reinforcing the weed's tolerance to glyphosate, allowing for normal development even after herbicide application.

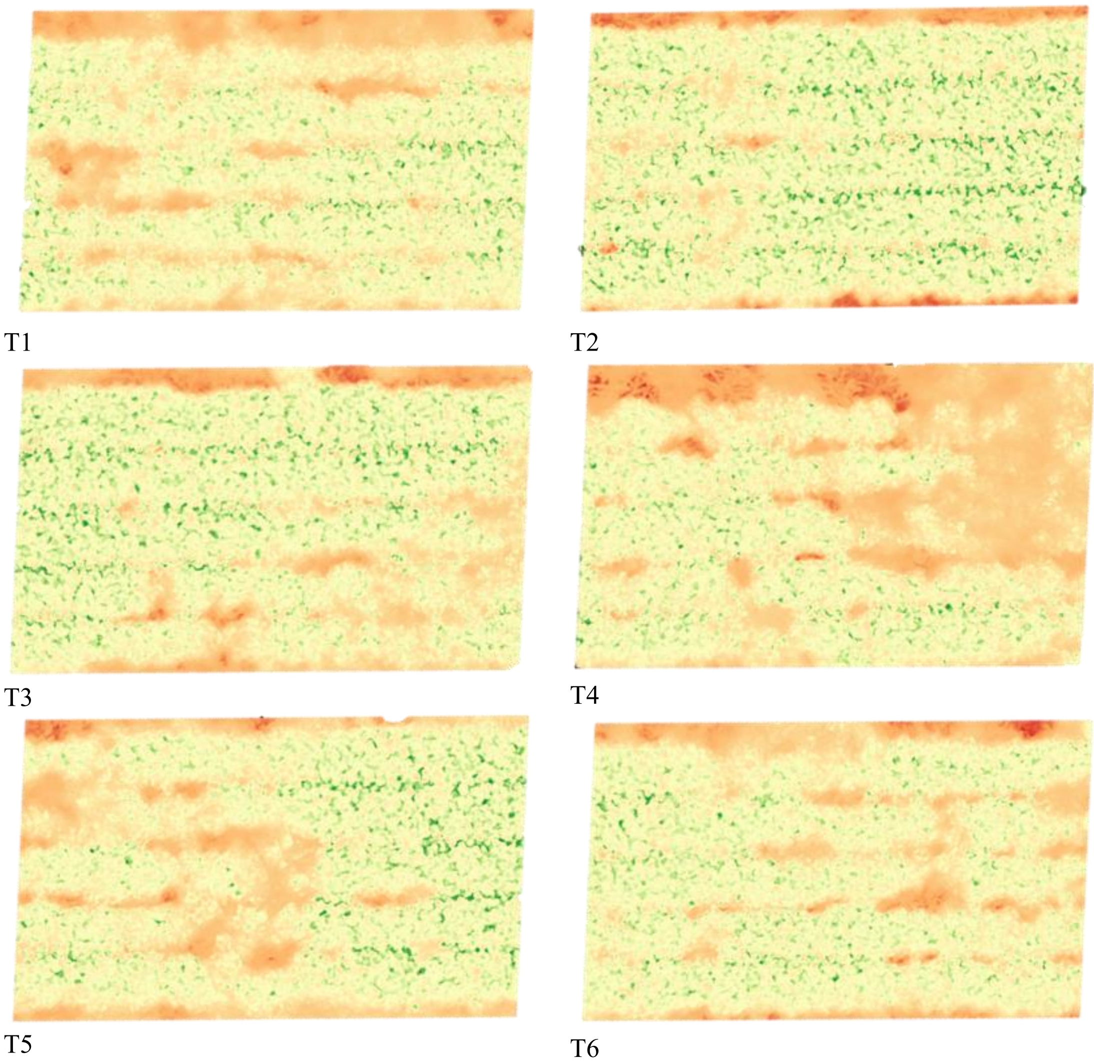
The mean dry weight found for application of carfentrazone-ethyl was also high, which can be explained by the regrowth of some established plants in the area; additionally, this herbicide presented no residual effect on new *C. benghalensis* seedlings. *C. benghalensis* plants subjected to application of carfentrazone-ethyl at 30 g ha-1 sprouted after a few days, during the initial development of soybean plants. Budd *et al*. (1979) evaluated the regeneration of C. benghalensis plants and found that stems cut up to 2 cm deep in the soil exhibited good regeneration.

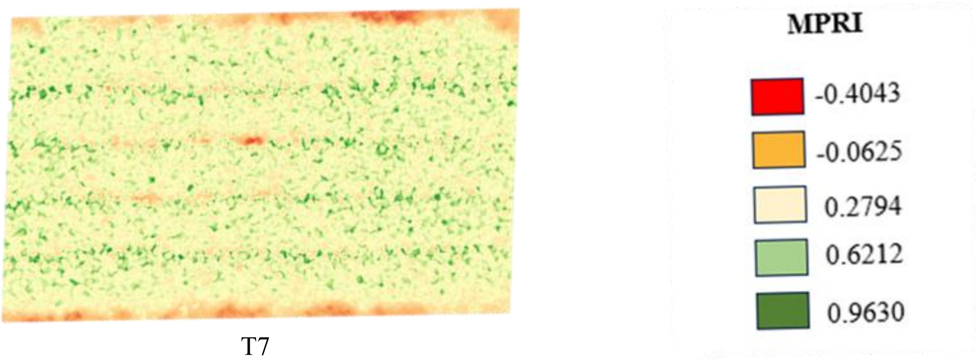
Both underground and aerial *C. benghalensis* seeds can be affected by soil and herbicide managements, as *C. benghalensis* produces, on average, 2% underground and 95% aerial seeds (Walker; Evenson, 1985) with underground seeds having a higher germination potential than aerial seeds Budd *et al.* (1979). This may be explained by the specificity of the herbicide, which provides satisfactory initial control with rapid necrosis of *C. benghalensis* leaves, but lacks systemic characteristics to translocate to the root and kill the plant and has no residual effects in the soil to control the regrowth of *C. benghalensis* plants, allowing weed germination and establishment in soybean crops.

The spectral responses of the treatments in the red band at 35 days after soybean crop emergence were different (Figure 2). The treatment halauxifen + diclosulam + glufosinato-ammonium presented the lowest reflectance, indicating a higher presence of green biomass at the time of evaluation, denoting a higher chlorophyll content in soybean plants. This result is consistent with Horler *et al*. (1983), who reported that healthy plants reflect little red light because chlorophyll absorbs light in this wavelength (625 to 740 nm), showing high reflectance only in the infrared wavelength.

The treatment saflufenacil presented the highest reflectance in the red band. The remaining treatments exhibited statistically equal spectral responses. The spectral response of soybean plants showed no differences for green and blue light spectra. Evaluation of vegetation indices showed significant differences for herbicide treatments. The Modified Photochemical Reflectance Index (MPRI) presented the following values: -0.4043, -0.0625, 0.2794, 0.6212, and 0.9630. According to dos Santos *et al.* (2018), values close to -1, showing reddish and orange colors, represent absence of vegetation or bare soil; values close to 0, showing whitish and yellowish colors, indicate low vegetation density; and values close to 1, showing bluish and greenish colors, indicate medium to high vegetation density.

Figure 2 - Modified Photochemical Reflectance Index (MPRI) of experimental plots T1, T2, T3, T4, T5, T6, and T7 at 35 days after emergence of soybean plants as a function of different herbicides. T1 – Glyphosate; T2 – Halauxifen-methyl + Diclosulam; T3 – 2,4-D; T4 – Flumioxazin; T5 – Carfentrazone-ethyl; T6 – Saflufenacil; T7 – Halauxifen-methyl + Diclosulam + Glufosinate-ammonium





T7

Source: the authors.

The treatments halauxifen + diclosulam + glufosinate-ammonium and halauxifen + diclosulam presented spectral responses (MPRI) of 0.23 and 0.25, respectively (Table 5). This denotes high vegetation density, which was confirmed by the analyses of dry weight of C. benghalensis plants and soybean plant heights at 35 days after emergence, when these two treatments presented the lowest dry weights and the highest soybean plant heights. Thus, there was less competition for resources between the soybean plants and *C. benghalensis* weeds, allowing the crop to develop free from competition, resulting in higher spectral responses for these treatments (Figure 2). The other treatments had similar responses for MPRI.

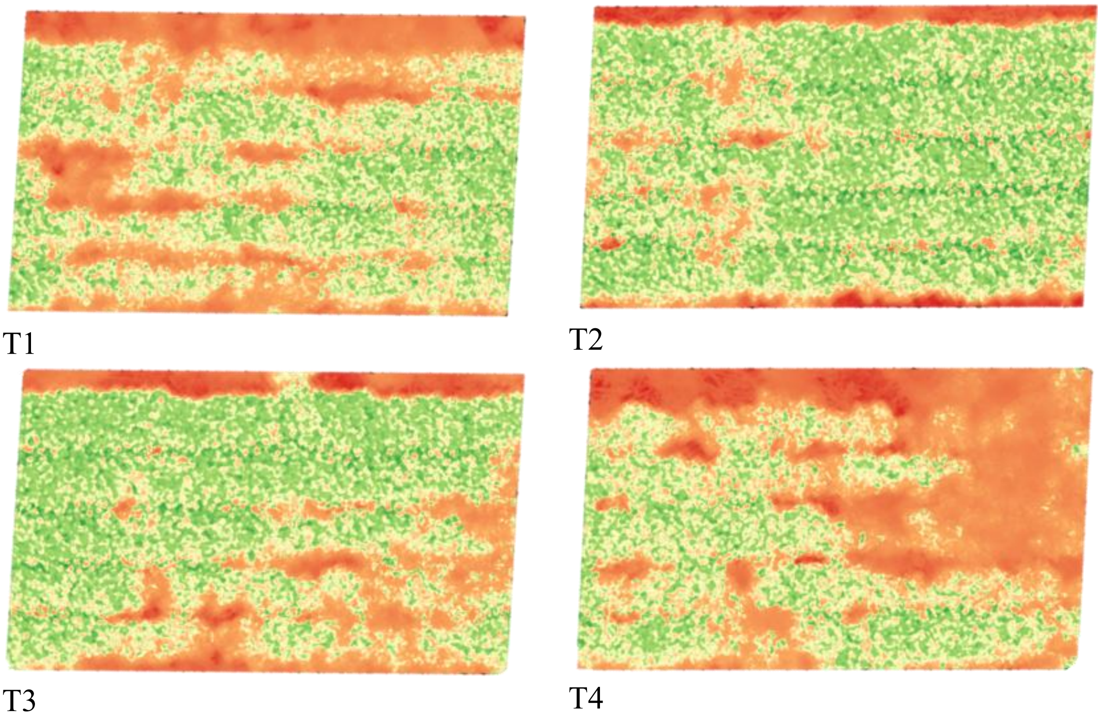
Table 5 – Spectral responses of soybean plants in the visible wavelength range and vegetation indices at 35 days after emergence as a function of different herbicides

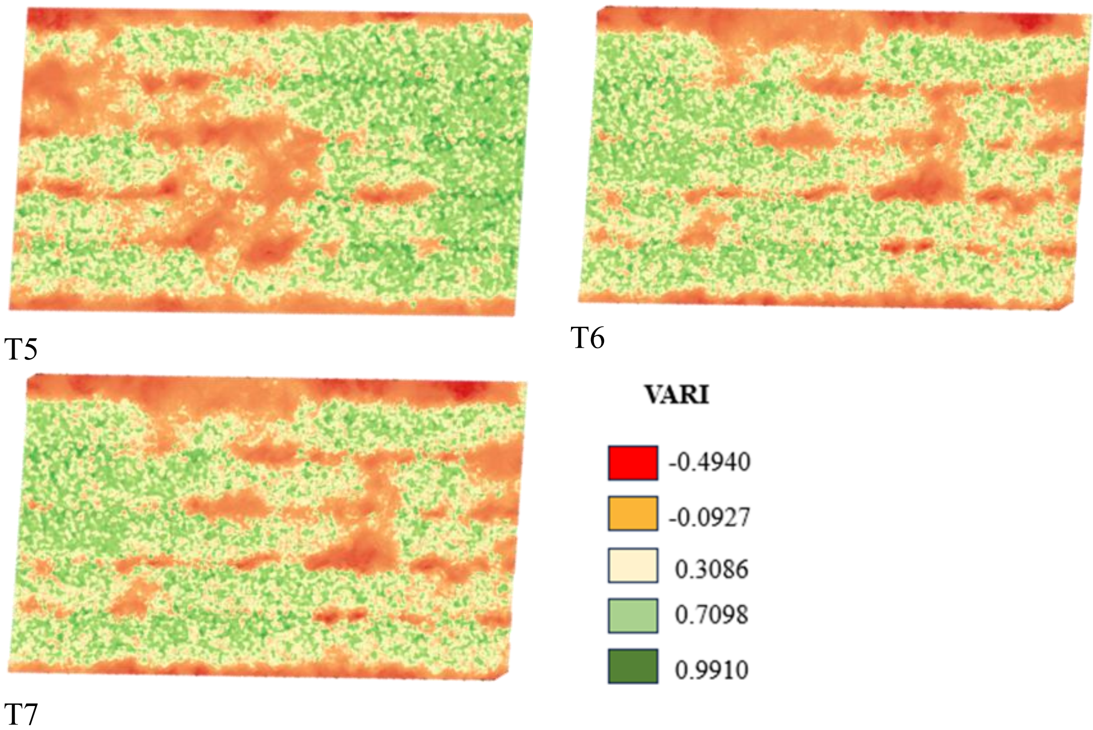
Treatment	**Red**	**Green**	**Blue**	**MPRI**	**VARI**
Glyphosate	87.1 ab	116.0 a	52.7 a	0.16 ab	0.20 abc
Halauxifen + Diclosulam	72.4 ab	112.5 a	51.8 a	0.25 a	0.33 ab
2,4-D	85.7 ab	117.5 a	50.6 a	0.17 ab	0.23 abc
Flumioxazin	82.4 ab	116.5 a	53.2 a	0.19 ab	0.25 abc
Carfentrazone-ethyl	88.4 ab	115.9 a	56.2 a	0.16 ab	0.21 abc
Saflufenacil	91.2 b	117.4 a	54.7 a	0.14 b	0.18 c
Halauxifen + Diclosulam + Glufosinate-ammonium	70.4 a	112.7 a	51.9 a	0.23 a	0.34 a
CV (%)	8.49	2.22	7.94	19.36	19.94

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test ($\alpha = 0.05$). CV – Coefficient of variation.
Source: research data.

The Visible Atmospherically Resistant Index (VARI) presented the following values: -0.4940, -0.0927, 0.3086, 0.7098, and 0.9910. This index showed the same variation as MPRI, with values close to -1 representing absence of vegetation or bare soil, values close to 0 indicating low vegetation density, and values close to 1 indicating medium to high vegetation density. This index is based on the variability of plant vigor and stress, assuming the leaf development of a crop in an area (Abrahão *et al*., 2009). The treatments halauxifen + diclosulam + glufosinate-ammonium and halauxifen + diclosulam also presented high spectral responses to this index (0.34 and 0.33, respectively) (Table 5), denoting high vigor of soybean plants in these treatments compared to the other herbicide treatments (Figure 3). The analysis of this index confirmed the other evaluations conducted on the same day, in which the treatments halauxifen + diclosulam + glufosinate-ammonium and halauxifen + diclosulam presented the best means for weed dry weight and soybean plant height. The treatment saflufenacil presented the lowest mean reflectance (VARI): 0.18 (Table 5). The spectral responses (VARI) of the other herbicide treatments presented no differences.

Figure 3 - Visible Atmospherically Resistant Index (VARI) of experimental plots T1, T2, T3, T4, T5, T6 and T7 at 35 days after emergence of soybean plants. T1 Glyphosate; T2 – Halauxifen-methyl + Diclosulam; T3 – 2,4-D; T4 – Flumioxazin; T5 – Carfentrazone-ethyl; T6 – Saflufenacil; T7 – Halauxifen-methyl + Diclosulam + Glufosinate-ammonium





Source: the authors.

The treatments presented no significant difference for any yield component evaluated (Table 6). Contrastingly, Pereira *et al*. (2020) found 1,000-grain weight significantly higher when using glufosinate-ammonium compared to the other evaluated herbicides. The treatment carfentrazone-ethyl was among the best treatments in the initial evaluations; however, it did not result in differences in yield components and in grain yield. The use of halauxifen-methyl + diclosulam for pre-emergence control of *C. benghalensis*, allowing the crop to develop without competition for resources, did not result in significant differences in the evaluated yield components.

Table 6 – Number of pods per plant (NPP), number of grains per pod (NGP), 1,000-grain weight (GW) and grain yield (GY) of soybean crop as a function of pre-sowing application of different herbicides

Herbicide	**Rate (g ha^{-1})**	**Components of Yield**			
		NPP	**NGP**	**GW (g)**	**GY (kg ha^{-1})**
Glyphosate	1500	32.3 a	2.56 a	188.9 a	3,077.0 a
Halauxifen + Diclosulam	6.06 + 31.9	38.6 a	2.76 a	190.7 a	3,576.4 a
2,4-D	670.0	31.0 a	2.43 a	192.2 a	3,268.0 a
Flumioxazin	40.0	38.0 a	2.50 a	193.2 a	3,114.4 a
Carfentrazone-ethyl	30.0	32.6 a	2.53 a	194.9 a	3,123.1 a

Saflufenacil	35.0	31.6 a	2.70 a	195.8 a	3,355.7 a
Halauxifen + Diclosulam + Glufosinate-ammonium	6.06 + 31.9 + 400.0	36.3 a	2.70 a	198.4 a	3,763.0 a
CV (%)	--	8.51	8.48	3.19	10.36

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test (α = 0.05). CV – Coefficient of variation.
Source: the authors.

The treatments halauxifen + diclosulam + glufosinate-ammonium and halauxifen + diclosulam showed the same efficiency for pre-emergence control and better post-emergence control due to the use of glufosinate-ammonium in the sequential application. However, this additional application did not result in differences in yield components or grain yield. Carmo *et al.* (2023) found different results, with significant increases in grain yield when applying glufosinate-ammonium before soybean seeding.

The findings of the present study denote the need for including pre-emergence herbicide and planning a sequential application for efficient pre-sowing control of *C. benghalensis* in soybean crops. According to Procópio *et al*. (2006), the application of herbicides with residual action in soils should be carefully analyzed; for instance, areas with high weed density may make it difficult for droplets to reach the soil surface, resulting in decreased efficiency of pre-emergence herbicides. Sousa *et al.* (2017) also found that sequential application of a contact herbicide after application of a systemic herbicide is an excellent option for controlling C. benghalensis plants.

4 Conclusion

Pre-sowing application of halauxifen + diclosulam for soybean crops resulted in the lowest mean dry weights of *C. benghalensis* plants at 35 days after emergence of the soybean crop and in better pre-emergence control of *C. benghalensis*.

The sequential application with glufosinate-ammonium at 20 days following the application of halauxifen + diclosulam does not lead to an increase in soybean grain yield.

The use of unmanned aerial vehicles for evaluating the efficiency of herbicide applications in controlling *C. benghalensis* plants showed to be a potential alternative due to the use of low-cost sensors that can complement or correlate the information obtained by field professionals.

Acknowledgements
The authors thank Instituto Federal Goiano Campus Rio Verde and the MRE Agropesquisa team for supporting this project.

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