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ORIGINAL ARTICLE

Soybean pre-plant desiccation: sequential versus tank-mix for *Conyza* spp. and *Digitaria insularis* at advanced stages[1]

Dessecação pré-plantio da soja: aplicações sequenciais vs. mistura em tanque para *Conyza* spp. e *Digitaria insularis* em estádios avançados

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HIGHLIGHTS:

Auxin herbicides antagonize haloxyfop-p-methyl, lowering D. insularis control at BBCH 60–69 to below 80%.
Halauxifen-methyl + diclosulam synergize haloxyfop-p-methyl, achieving >80% control of Conyza spp. and D. insularis.
Sequential applications at 10–20 day intervals outperform tank-mixes for managing resistant Conyza spp. and D. insularis.

ABSTRACT: Interactions between broadleaf herbicides and ACCase inhibitors may reduce the control of perennial grasses in pre-plant burndown programs. This study aimed to compare sequential and tank-mix herbicide strategies for managing advanced infestations of *Conyza* spp. and *Digitaria insularis* prior to soybean planting. A randomized block design with four replications was adopted, including a non-treated control. Fourteen treatments were evaluated: 2,4-D + glyphosate; dicamba + glyphosate; fluroxypyr + clethodim + glyphosate; triclopyr + glyphosate; atrazine + mesotrione + glyphosate; halauxifen-methyl/diclosulam + glyphosate; 2,4-D + glyphosate + haloxyfop; dicamba + glyphosate + haloxyfop; triclopyr + glyphosate + haloxyfop; atrazine + mesotrione + glyphosate + haloxyfop; diclosulam + halauxifen + glyphosate + haloxyfop; atrazine + mesotrione + 2,4-D; atrazine + mesotrione + 2,4-D + haloxyfop. Treatments 1, 2, 4, 5, 6, and 12 received sequential haloxyfop at 10 days after treatment (DAT), followed by ammonium glufosinate at 20 DAT. In contrast, treatments 3, 7, 8, 9, 10, 11, and 13 received glufosinate only at 10 DAT. The auxinic herbicides 2,4-D, dicamba, and triclopyr antagonized haloxyfop-p-methyl, significantly reducing control of *D. insularis*. Conversely, halauxifen-methyl/diclosulam and atrazine/mesotrione, when used alone or in combination with haloxyfop, demonstrated compatibility and superior grass suppression. Control of *Conyza* spp. exceeded 80% in all treatments except 2,4-D + glyphosate and fluroxypyr + clethodim + glyphosate. Halauxifen-methyl/diclosulam and atrazine/mesotrione constitute viable alternatives for mixed infestations, improving burndown efficacy and supporting herbicide resistance management in soybean production systems.

Key words: herbicide antagonism, sequential application, chemical control, auxin herbicides

RESUMO: A interação entre herbicidas auxínicos e inibidores da ACCase pode reduzir o controle de gramíneas perenes; entretanto, novas formulações podem minimizar esse antagonismo, potencializando programas de dessecação voltados ao manejo de *Conyza* spp. e *Digitaria insularis*. Este estudo avaliou estratégias sequenciais e em mistura em tanque para controle de infestações avançadas de ambas as espécies em pré-plantio da soja. O experimento foi conduzido em delineamento em blocos ao acaso, com quatro repetições e testemunha sem aplicação. Foram avaliados 14 tratamentos: 2,4-D + glifosato; dicamba + glifosato; fluroxipir + clethodim + glifosato; triclopyr + glifosato; atrazina + mesotriona + glifosato; halauxifen-metílico/diclosulam + glifosato; 2,4-D + glifosato + haloxyfop-p-metílico; dicamba + glifosato + haloxyfop-p-metílico; triclopyr + glifosato + haloxyfop-p-metílico; atrazina + mesotriona + glifosato + haloxyfop-p-metílico; diclosulam + halauxifen-metílico + glifosato + haloxyfop-p-metílico; atrazina + mesotriona + 2,4-D; e atrazina + mesotriona + 2,4-D + haloxyfop-p-metílico. Os tratamentos 1, 2, 4, 5, 6 e 12 receberam haloxyfop-p-metílico aos 10 dias após a aplicação (DAA) e glufosinato de amônio aos 20 DAA; os demais receberam apenas glufosinato aos 10 DAA. 2,4-D, dicamba e triclopyr apresentaram antagonismo com haloxyfop-p-metílico, reduzindo o controle de *D. insularis*. Por outro lado, halauxifen-metílico/diclosulam e atrazina/mesotriona mostraram compatibilidade e maior supressão de gramíneas. O controle de *Conyza* spp. foi superior a 80% em todos os tratamentos, exceto 2,4-D + glifosato e fluroxypyr + clethodim + glifosato. Halauxifen-metílico/diclosulam e atrazina/mesotriona configuram alternativas viáveis para infestações mistas, com melhor supressão e suporte ao manejo da resistência em sistemas de produção da soja.

Palavras-chave: antagonismo de herbicidas, aplicação sequencial, controle químico, herbicidas auxínicos

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Introduction

In the agricultural context of southern Mato Grosso do Sul, difficulties in controlling *Conyza* spp. before soybean sowing has intensified (Piasecki et al., 2019). In Brazil, resistance of this genus to 2,4-D has been documented since 2015 (Queiroz et al., 2020; Heap, 2024). Field reports indicate that the exclusive use of auxinic herbicides has become progressively ineffective for highly developed plants. Biotypes exceeding 15 cm in height (BBCH 51–59) show 30–45% lower susceptibility to systemic herbicides, especially under dry pre-planting conditions (Gazola et al., 2022). These characteristics directly affect management decisions, demanding alternative strategies to the auxinic herbicides traditionally used in burndown programs (Albrecht et al., 2020; Leal et al., 2022; Souza et al., 2023).

Similarly, *Digitaria insularis* has become a recurrent problem during soybean burndown, with glyphosate-resistant populations nationally widespread since 2018 (Lucio et al., 2019; Barros et al., 2021; Heap, 2024). At advanced phenological stages, perennial tillering and rhizome reserves, combined with reduced systemic herbicide translocation, hinder effective control. Thus, management decisions must consider not only the choice of herbicides but also the plant developmental stage and compatibility between broadleaf and grass herbicides when applied simultaneously.

New management strategies for *Conyza* spp. include the use of auxinic products in three categories: (1) herbicides registered for pastures, such as fluroxypyr and triclopyr (Todd et al., 2020); (2) herbicides that were previously obsolete in new formulations, such as dicamba (Mueller et al., 2019); and (3) new auxin drugs, such as the combination of halauxifen and diclosulam (Cassol et al., 2024). ACCase inhibitors remain widely used for controlling *D. insularis* due to their efficacy in controlling Poaceae and high selectivity for soybeans, despite resistance in some regions (Lopes et al., 2021).

In many agricultural areas, *D. insularis* and *Conyza* spp. infest fields concomitantly, creating a scenario of mixed flora that makes desiccation difficult in soybean pre-sowing because, while *Conyza* spp., a eudicot, is controlled by broad-leaved herbicides, *D. insularis*, a monocot, is frequently controlled by ACCase-inhibiting herbicides (Leal et al., 2020). Such mixed infestations require specific management strategies for *D. insularis* and *Conyza* spp. in pre-sowing desiccation. However, the combination of broadleaf herbicides and ACCase inhibitors can result in antagonism, reducing the effectiveness of graminicides, which is associated with auxin-induced physiological responses that reduce ACCase inhibitor absorption and translocation to meristematic tissues (Lopes et al., 2021).

In this context, many producers opt for combinations of broadleaf herbicides and graminicides. However, this strategy may reduce the efficacy of *D. insularis* control. In certain situations, this loss of efficacy results in an increase in the dose of ACCase-inhibiting herbicides (Polito et al., 2021). Currently, there are options for combining broadleaf products and graminicides that do not result in antagonism and, consequently, do not reduce the effectiveness in controlling *D. insularis*. Examples of this are the commercial mixture of clethodim + fluroxypyr and methyl halauxifen + diclosulam, which do not show reduced efficacy to ACCase inhibitors (Agrofit, 2024).

However, information on tank-mixes and sequential applications still needs clarification, since inadequate recommendations can lead to application errors, poor control, and financial losses. In this context, this study aimed to compare the efficacy of different sequential and tank-mix herbicide strategies for managing *Conyza* spp. and *Digitaria insularis* at advanced phenological stages, by assessing visual weed control and regrowth after application.

Material and Methods

The experiment was conducted in the field from Setember 11, 2022, to December 14, 2022, at the Experimental Farm of Agricultural Sciences (FAECA) of the Federal University of Grande Dourados (UFGD) in Dourados, Mato Grosso do Sul, Brazil, located at 22º 18' 14.6" S, 54º 37' 14.2" W, at approximately 430 m above sea level. The region's climate is classified as tropical monsoon (Am) according to the Köppen climate classification, characterized by significant rainfall during most months of the year. The temperature and rainfall data were obtained from the FAECA-UFGD weather station (22º 16' 31" S, 54º 49' 06" W), located approximately 500 m from the experimental area, and are presented in Figure 1.

Soil samples were collected from the 0–20 cm layer 15 days before the experiment was established in an Oxisol (United States, 2014), corresponding to a Latossolo Vermelho-Amarelo according to the Brazilian Soil Classification System (EMBRAPA, 2018). Chemical properties were determined following the methodologies described by Teixeira et al. (2017) and are presented in Table 1.

The experiment was conducted in a field naturally infested with *Conyza* spp. at a density of 10 plants m^{-2} and *Digitaria insularis* at 3 plants m^{-2}, in an area previously cultivated with maize under a no-tillage system. The experiment followed a randomized block design with four replicates and 14 treatments, including a non-treated control (Table 2).

The experimental units consisted of 3 × 5 m plots, with a total area of 15 m^2 per plot. Herbicide applications occurred on *Conyza* spp. and *Digitaria insularis* plants. *Conyza* spp. plants were taller than 15 cm and classified as BBCH stages 50–59 according to the Biologische Bundesanstalt und Chemische Industrie (BBCH) scale (Hess et al., 1997), and *D. insularis* flowering is classified as 60-69 (BBCH).

The herbicide treatments were applied using a backpack sprayer pressurized with CO_2 at 2.5 bar, equipped with a spray boom fitted with four TeeJet 110.015 fan nozzles spaced 0.5 m apart, delivering 150 L ha^{-1}. The first application was conducted on September 11, 2022, under environmental conditions of 58% relative humidity, a temperature of 22 °C, and a wind speed of 2.0 km h^{-1}. The second application, conducted on September 21, 2022, took place under 63% relative humidity, a temperature of 24 °C, and a wind speed of 1.2 km h^{-1}. The third and final application was performed on November 4, 2022, under 65% relative humidity, a temperature of 25 °C, and a wind speed of 1.5 km h^{-1}.

The control of *D. insularis* and *Conyza* spp. was determined using a visual scale, in which scores were assigned as percentages

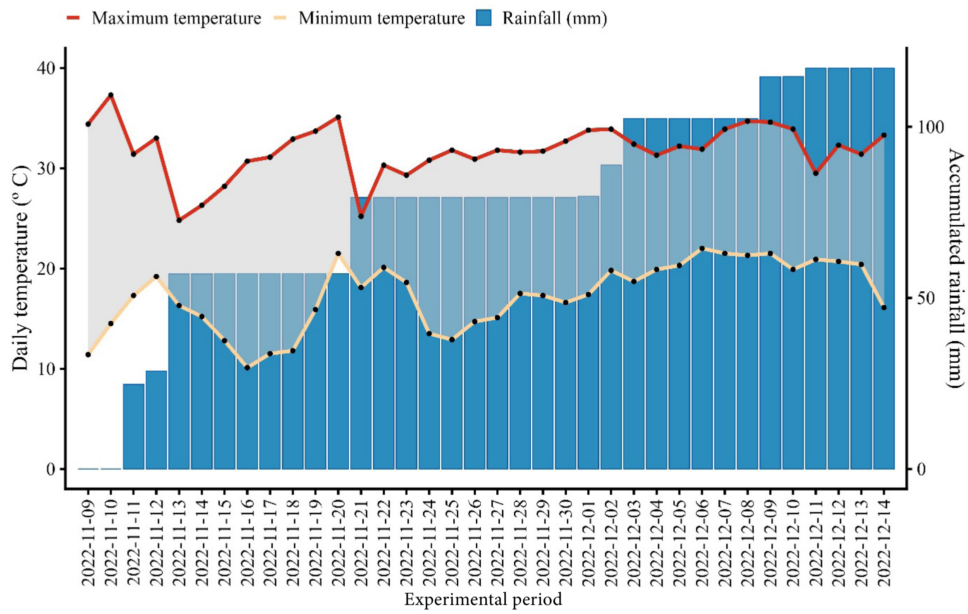


Figure 1. Historical daily series of accumulated rainfall and minimum and maximum temperatures in the municipality of Dourados, Mato Grosso do Sul, Brazil, for the experimental period

Table 1. Chemical attributes of the soil at the experimental site

Ca^{2+}	Mg	H+Al	SB	CEC	Al	K	P	BS	pH
		$cmol_c$ dm^{-3}				mg dm^{-3}		%	$CaCl_2$
4.56	2.08	7.08	6.74	13.82	0.12	18	40.73	48.8	5.08

pH measured in $CaCl_2$; OM – Organic matter - Determined by Walkley-Black method; K^+ extracted with Mehlich-1; Ca^{2+} and Mg^{2+} extracted with 1 M KCl; Al^{3+} and H^++Al^{3+} determined by SMP method; SB - Sum of bases; CEC - Effective cation exchange capacity; BS - Base saturation

Table 2. Doses and products used in desiccation applications

Treatment	1st Application[1]	Dose (g ai ha^{-1})	10 DAT[2]	Dose (g ai ha^{-1})	20 DAT[3]	Dose (g ai ha^{-1})
T1	2,4-D	1,000	Haloxyfop	150	Ammonium glufosinate	400
T2	Dicamba	480	Haloxyfop	150	Ammonium glufosinate	400
T3	Fluroxypyr / Clethodym	300 + 210	Haloxyfop	150	Ammonium glufosinate	400
T4	Triclopyr	720	Haloxyfop	150	Ammonium glufosinate	400
T5	Atrazine / Mesotrione	500 + 50	Haloxyfop	150	Ammonium glufosinate	400
T6	Diclosulam / Halauxifen-methyl	20.3 + 3.86	Haloxyfop	150	Ammonium glufosinate	400
T7	2,4-D + Haloxyfop-p-methyl	1,000 + 150	Ammonium glufosinate	400	—	—
T8	Dicamba + Haloxyfop-p-methyl	480 + 150	Ammonium glufosinate	400	—	—
T9	Triclopyr + Haloxyfop-p-methyl	720 + 150	Ammonium glufosinate	400	—	—
T10	Atrazine / Mesotrione + Haloxyfop-p-methyl	500 + 50 + 150	Ammonium glufosinate	400	—	—
T11	Diclosulam / Halauxifen-methyl + Haloxyfop-p-methyl	20.3 + 3.86 + 150	Ammonium glufosinate	400	—	—
T12	Atrazine / Mesotrione + 2,4-D	500 + 50 + 1,000	Haloxyfop	150	Ammonium glufosinate	400
T13	Atrazine / Mesotrione + 2,4-D + Haloxyfop-p-methyl	500 + 50 + 1,000 + 150	Ammonium glufosinate	400	—	—
T14	Control	—	—	—	—	—

[1] Addition of mineral oil (0.5% v/v); [2] Second application 10 days after first treatment (10 DAT); [3] Third application 20 days after first treatment (20 DAT); a.i – active ingredient

of weed species control, with 100% representing complete control of the species, according to a standard visual assessment scale (Alam, 1974). Visual evaluations were performed at 7, 14, 21, 28, and 35 days after the first application (DAT).

The significance of the fixed effects was assessed using the F test from the deviance analysis of the fitted GAMLSS models. Because the interaction between treatment and days after treatment (DAT) was included in the model, comparisons among treatments were performed within each level of DAT whenever the interaction term was significant. Estimated marginal means were obtained using the emmeans package, and their 95% confidence intervals were used to evaluate differences among treatments. To assess the effect of DAT, response variables were modeled using a beta regression within the GAMLSS framework with a logit link function for the mean. A significance level ($\alpha = 0.05$) was adopted for all inferential procedures.

Rather than applying letter-based mean separation methods, the differences among treatments were visualized through a caterpillar plot, which displays the ranked estimated means with their respective confidence intervals. This graphical approach allows a clear identification of treatment differences while maintaining statistical rigor. In the absence of a significant treatment × DAT interaction, comparisons were based solely on the main effects. All analyses were conducted in R (R Core Team, 2021), with model fitting performed using the GAMLSS framework (Rigby & Stasinopoulos, 2005).

Results and Discussion

Figure 2 presents the control data of *Conyza* spp. Compared with the evaluation period at 7 days after the first application (DAT), treatments 13 (atrazine/mesotrione + 2,4-D + haloxyfop-p-methyl), 12 (atrazine/mesotrione + 2,4-D), and 7 (2,4-D + glyphosate + haloxyfop-p-methyl) did not differ from each other according to statistical analysis and showed control percentages ranging from 43 to 56%, the highest in this evaluation period. These treatments differed from 11 (diclosulam/halauxifen-methyl + glyphosate + haloxyfop), 9 (triclopyr + glyphosate + haloxyfop-p-methyl), 4 (triclopyr + glyphosate), and 3 (fluroxypyr/clethodim + glyphosate), which exhibited control percentages lower than 50%.

At 14 DAT (Figure 2), no treatment resulted in control greater than 80%, a situation only observed after 21 DAT, where in the treatments that had been administered two applications, they had already received sequential glufosinate ammonium salt (performed at 15 DAT), where treatment 13 (atrazine/mesotrione + 2,4-D + haloxyfop-p-methyl) achieved effective control of more than 80% for *Conyza* spp.; however, it was not significantly different from treatments 11 (diclosulam/halauxifen-methyl + glyphosate + haloxyfop-p-methyl), 10 (atrazine/mesotrione + glyphosate + haloxyfop-p-methyl), 9 (triclopyr + glyphosate + haloxyfop-p-methyl) and 7 (2,4D + glyphosate + haloxyfop-p-methyl). Treatments 1 (2,4-D + glyphosate), 2 (dicamba + glyphosate), 3 (fluroxypyr/clethodim + glyphosate), 4 (triclopyr + glyphosate), 5 (atrazine/mesotrione + glyphosate), and 6 (diclosulam/halauxifen-methyl + glyphosate) were statistically similar and presented control percentages lower than 73%.

To control *Conyza* spp., at 28 DAT (Figure 2), some treatments presented a control percentage greater than 80%, namely, 13 (atrazine/mesotrione + 2,4-D + haloxyfop-p-methyl), 12 (atrazine/mesotrione + 2,4-D), 11 (diclosulam/halauxifen-methyl + glyphosate + haloxyfop-p-methyl), 9 (triclopyr + glyphosate + haloxyfop-p-methyl), 8 (dicamba + glyphosate + haloxyfop-p-methyl), and 7 (2,4-D + glyphosate + haloxyfop-p-methyl), and there was no significant difference between them. Treatments 6 (diclosulam/halauxifen-methyl + glyphosate), 4 (triclopyr + glyphosate), and 2 (dicamba + glyphosate) were statistically similar, with control percentages exceeding 80%. Treatments 5 (atrazine/mesotrione + glyphosate), 3 (fluroxypyr/clethodim + glyphosate), and 1 (2,4-D + glyphosate) showed similar control levels, with control percentages lower than 80%.

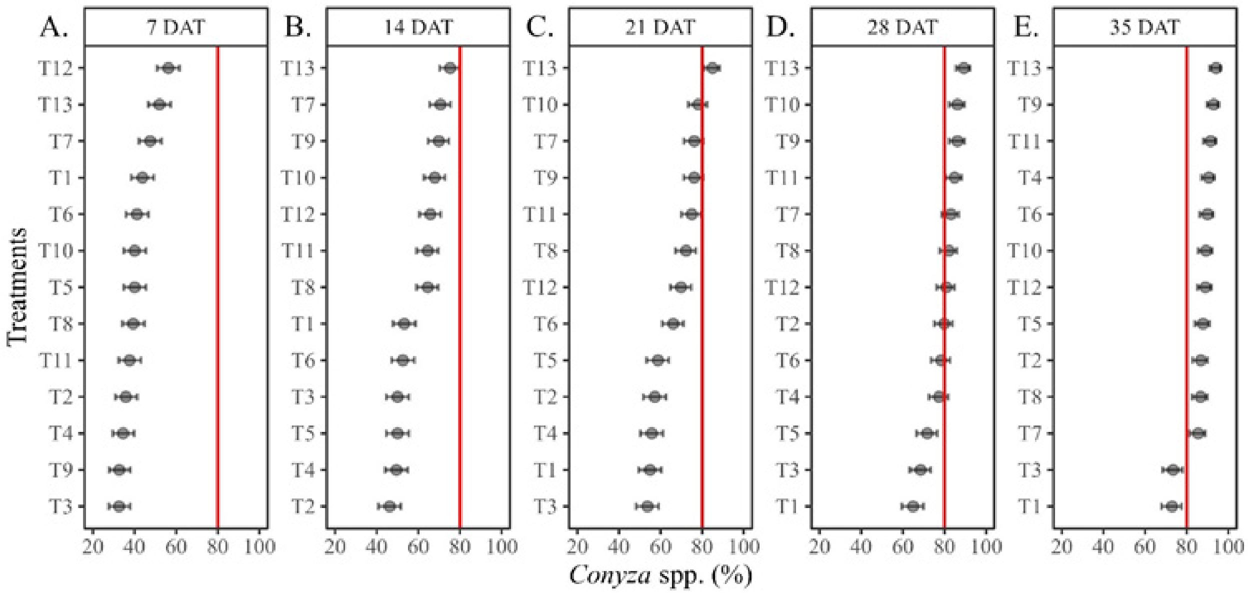
In the last visual evaluation, performed at 35 DAT (Figure 2), only treatments 1 (2,4-D + glyphosate) and 3 (fluroxypyr + clethodim + glyphosate) showed control levels below 80%, indicating sub-optimal performance on *Conyza* spp. (76 and 71%, respectively). All other treatments reached control levels above 80% and were therefore classified as effective for *Conyza* spp. management under the conditions of this study.

Figure 3 presents the results of the regression fit for the percent control of *Conyza* spp. as a function of the evaluation periods starting from the first application. All the treatments increased over time. An analysis of the coefficient x for the different DATs revealed that treatment 9 (triclopyr + glyphosate + haloxyfop-p-methyl) resulted in the greatest increase in control over time, starting at 39% at 7 DAT and increasing to 93% at 35 DAT, representing an absolute increase of 54 percentage points over the evaluation period. Compared with the control group, treatment 1 (2,4-D + glyphosate) resulted in the lowest growth rate; at 7 DAT, the growth rate was 44%, and at 35 DAT, the growth rate was increased by 28% at 28 days. As observed in Figure 3, treatment 13 (atrazine/mesotrione + 2,4-D + haloxyfop-p-methyl) achieved satisfactory control of more than 80% at 19 DAT, which was the first treatment to achieve control of the species.

Thus, it was initially observed that plants of *Conyza* spp. were in an advanced stage of development, with heights greater than 10 cm. Under these conditions, no treatment applied before sequential application achieved control greater than 80%, highlighting the need for sequential management for efficacy (Alam, 1974). This recommendation is important because although smaller plants (less than 10 cm) can be controlled with auxinic herbicides combined with PROTOX inhibitors, sequential application remains essential for more developed plants (Albrecht et al., 2020).

Under the regional conditions of southern Mato Grosso do Sul, this practice is particularly important, as the early sowing of corn, soon after the sowing of soybean, causes a germination flow of *Conyza* spp. due to the decrease in temperature and the low amount of rainfall. This phenomenon occurs from May until pre-sowing desiccation, and the presence of *Conyza* spp. in several phenological stages hinders uniform management (Schneider et al., 2021; Gazola et al., 2022).

In addition, the delay in soybean and corn sowing in Mato Grosso do Sul, caused by water restrictions (Palharani et



*T1 - 2,4-D (1,000 g ai ha⁻¹) followed by Haloxyfop (150 g ai ha⁻¹) and Ammonium glufosinate (400 g ai ha⁻¹); T2 - Dicamba (480 g ai ha⁻¹) followed by Haloxyfop (150 g ai ha⁻¹) and Ammonium glufosinate (400 g ai ha⁻¹);T3 - Fluroxypyr (300 g ai ha⁻¹) + Clethodym (210 g ai ha⁻¹) followed by Haloxyfop (150 g ai ha⁻¹) and Ammonium glufosinate (400 g ai ha⁻¹);T4 - Triclopyr (720 g ai ha⁻¹) followed by Haloxyfop (150 g ai ha⁻¹) and Ammonium glufosinate (400 g ai ha⁻¹);T5 - Atrazine (500 g ai ha⁻¹) + Mesotrione (50 g ai ha⁻¹) followed by Haloxyfop (150 g ai ha⁻¹) and Ammonium glufosinate (400 g ai ha⁻¹);T6 – Diclosulam (20.3 g ai ha⁻¹) + Halauxifen-methyl (3.86 g ai ha⁻¹) followed by Haloxyfop (150 g ai ha⁻¹) and Ammonium glufosinate (400 g ai ha⁻¹); T7 - 2,4-D (1,000 g ai ha⁻¹) + Haloxyfop-p-methyl (150 g ai ha⁻¹) followed by Ammonium glufosinate (400 g ai ha⁻¹); T8 - Dicamba (480 g ai ha⁻¹) + Haloxyfop-p-methyl (150 g ai ha⁻¹) followed by Ammonium glufosinate (400 g ai ha⁻¹); T9 - Triclopyr (720 g ai ha⁻¹) + Haloxyfop-p-methyl (150 g ai ha⁻¹) followed by Ammonium glufosinate (400 g ai ha⁻¹);T10 - Atrazine (500 g ai ha⁻¹) + Mesotrione (50 g ai ha⁻¹) + Haloxyfop-p-methyl (150 g ai ha⁻¹) followed by Ammonium glufosinate (400 g ai ha⁻¹);T11 - Diclosulam (20.3 g ai ha⁻¹) + Halauxifen-methyl (3.86 g ai ha⁻¹) + Haloxyfop-p-methyl (150 g ai ha⁻¹) followed by Ammonium glufosinate (400 g ai ha⁻¹); T12 - Atrazine (500 g ai ha⁻¹) + Mesotrione (50 g ai ha⁻¹) + 2,4-D (1,000 g ai ha⁻¹) followed by Haloxyfop (150 g ai ha⁻¹) and Ammonium glufosinate (400 g ai ha⁻¹);T13 - Atrazine (500 g ai ha⁻¹) + Mesotrione (50 g ai ha⁻¹) + 2,4-D (1,000 g ai ha⁻¹) + Haloxyfop-p-methyl (150 g ai ha⁻¹) followed by Ammonium glufosinate (400 g ai ha⁻¹);T14 - Control. Error bars represent standard deviation (±SD)

Figure 2. Percentages of *Conyza* spp. in response to different herbicide treatments at 7, 14, 2, 28 and 35 days after first application (DAT)

al., 2023; Monteiro et al., 2025), reduces the interval between desiccation and planting, requiring caution regarding herbicide residue to avoid phytotoxicity. Although atrazine + mesotrione + 2,4-D efficiently controlled *Conyza* spp. at 21 DAT, the interval between desiccation with atrazine and soybean planting should be 30 days to prevent phytotoxic damage (Agrofit, 2024).

Peruzzo et al. (2019) reported that the use of atrazine in areas with low rainfall, at a rate of 570 g ai ha^{-1}, causes phytotoxicity, reducing soybean height, dry matter, and leaf area linearly with increasing dose. Thus, the application of atrazine before desiccation can affect crop yield due to the residue remaining in the soil, especially during periods of low rainfall (Francischini et al., 2020).

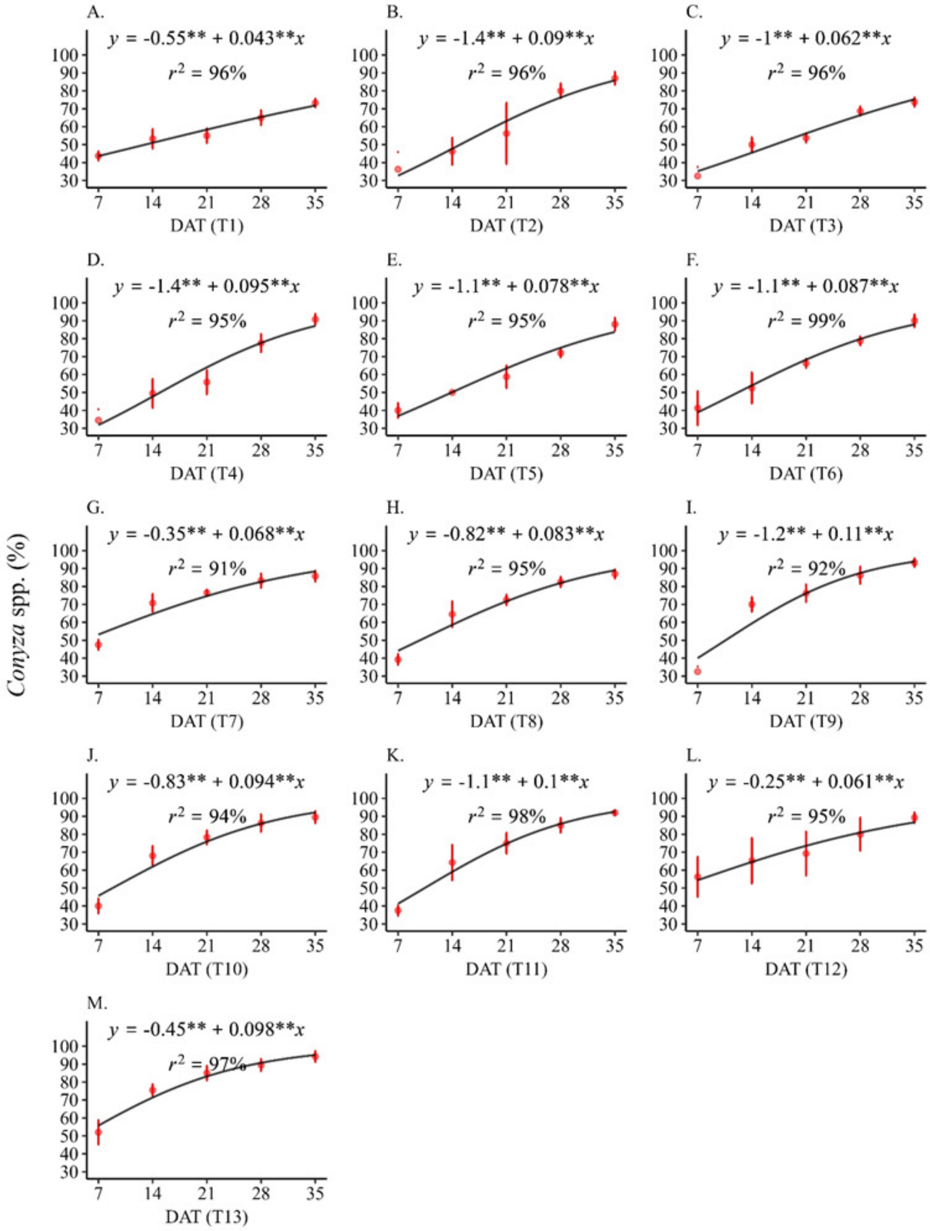
At 35 DAT, dicamba and triclopyr, with or without haloxyfop, effectively controlled *Conyza* spp., emerging as alternatives to 2,4-D, especially with the advent of tolerant soybean cultivars. Pretto et al. (2020) corroborated these findings, indicating that dicamba and triclopyr, when associated with glyphosate, achieve 100% control of *Conyza* spp. However, it is essential to observe the safe period between desiccation and sowing: 60 days for dicamba and 20 days for triclopyr in nontolerant soybean (Agrofit, 2024).

Krenchinski et al. (2019) reported that the combination of diclosulam + halauxifen with glyphosate, which is applied 15 days before sowing, achieves more than 90% control in *Conyza* spp. in stage V3 without affecting soybean yield. This combination also has a short carryover period (7–14 days) and is effective for biotypes with multiple resistance (Adegas et al., 2022; Heap, 2024).

In the present study, the treatments with two applications, atrazine + mesotrione + 2,4-D + haloxyfop and diclosulam + halauxifen + haloxyfop, resulted in greater speed and efficacy of the control at 28 DAT than the three applications did. In the last evaluation, however, all the treatments were similar, being viable for the management of *Conyza* spp. The inclusion of haloxyfop did not result in antagonism with the broadleaf herbicides, a phenomenon already established in the literature (Pedrollo et al., 2022).

Finally, although dicamba + haloxyfop and halauxifen + diclosulam + haloxyfop showed superior efficacy, the interval between desiccation and sowing must be considered to ensure crop safety at planting. A pre-sowing interval of approximately 14 to 28 days is commonly recommended for auxinic herbicides under pre-plant conditions, especially when environmental conditions slow degradation (Heap, 2024). Cassol et al. (2024) reinforce this recommendation, noting that although fluroxypyr has a slower action than dicamba does, it does not have a range restriction for soybeans, whereas dicamba requires 30-45 days (Agrofit, 2024; Cassol et al., 2024).

For *D. insularis*, at 7 DAT, treatments 3 (fluroxypyr/clethodim + glyphosate), 10 (atrazine/mesotrione + glyphosate + haloxyfop-p-methyl), 11 (diclosulam/halauxifen-methyl + glyphosate + haloxyfop-p-methyl), and 13 (atrazine/mesotrione + 2.4D + haloxyfop-p-methyl) were not significantly different;



*T1 – 2,4-D (1,000 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1}); T2 – Dicamba (480 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T3 – Fluroxypyr (300 g ai ha^{-1}) + Clethodym (210 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T4 – Triclopyr (720 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T5 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T6 – Diclosulam (20.3 g ai ha^{-1}) + Halauxifen-methyl (3.86 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T7 – 2,4-D (1,000 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T8 – Dicamba (480 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T9 – Triclopyr (720 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T10 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T11 – Diclosulam (20.3 g ai ha^{-1}) + Halauxifen-methyl (3.86 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T12 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + 2,4-D (1,000 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T13 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + 2,4-D (1,000 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1}); T14 – Control. ** – Significant at $p \leq 0.01$ by the t-test. Vertical bars represent the standard deviation (SD)

Figure 3. Beta regression analysis with logit linkage function (1/{1 + exp[-y]}) for *Conyza* spp. control, as a function of DAT in each treatment

these treatments resulted in the highest percentages of *D. insularis* in the control, but were less than 50%. Treatments 1 (2,4D + glyphosate), 2 (dicamba + glyphosate), 4 (triclopyr + glyphosate), 6 (diclosulam/halauxifen-methyl + glyphosate), and 8 (dicamba + glyphosate + haloxyfop-p-methyl) were statistically similar and resulted in the lowest control percentages, being less than 35% (Figure 4).

At 14 and 21 DAT, no treatment resulted in more than 80% control of *D. insularis*. In the visual evaluation at 28 days (Figure 4), treatments 13 (atrazine/mesotrione + 2,4D + haloxyfop-p-methyl), 11 (diclosulam/halauxifen-methyl + glyphosate + haloxyfop-p-methyl), 10 (atrazine/mesotrione + glyphosate + haloxyfop-p-methyl), 9 (triclopyr + glyphosate + haloxyfop-p-methyl), and 3 (fluroxypyr/clethodim + glyphosate) showed no significant difference, and only the latter resulted in a control greater than 80% for *D. insularis*.

In the last evaluation performed at 35 days (Figure 4), treatments 3 (fluroxypyr/clethodim + glyphosate), 5 (atrazine/mesotrione + glyphosate), 6 (diclosulam/halauxifen-methyl + glyphosate), and 11 (diclosulam/halauxifen-methyl + glyphosate

+ haloxyfop-p-methyl) were not significantly different, resulting in a control greater than 80% for *D. insularis*. Treatments 1 (2,4D + glyphosate), 2 (dicamba + glyphosate), 4 (triclopyr + glyphosate), 7 (2,4-D + glyphosate + haloxyfop-p-methyl), 8 (dicamba + glyphosate + haloxyfop-p-methyl), 9 (triclopyr + glyphosate + haloxyfop-p-methyl), 10 (atrazine/mesotrione + glyphosate + haloxyfop-p-methyl), 12 (atrazine/mesotrione + 2,4-D), and 13 (atrazine/mesotrione + 2.4D + haloxyfop-p-methyl) did not differ statistically from each other and, at the end of the experiment, resulted in less than 80% control for *D. insularis*.

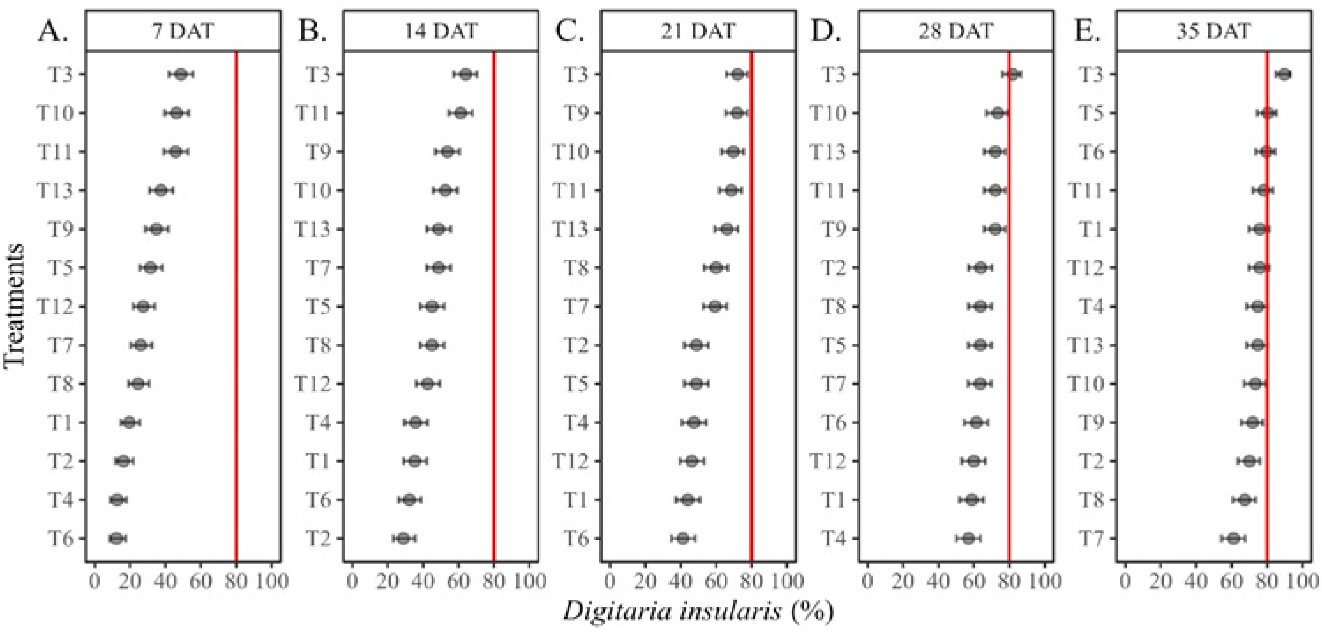
For the control of *D. insularis* over the evaluation periods after the first application. Stability in the control was observed between 28 and 35 DAT for T8 (dicamba + glyphosate + haloxyfop-p-methyl) and T9 (triclopyr + glyphosate + haloxyfop-p-methyl), whereas T7 (2,4-D + glyphosate + haloxyfop-p-methyl) decreased in this range (Figure 5). The T3 treatment (fluroxypyr/clethodim + glyphosate) reached 81% control at 26 DAT, with the first value exceeding 80%. The greatest control acceleration was observed at T6 (diclosulam/halauxifen-methyl + glyphosate), with a 64% gain between 7 and 35 DAT. In contrast, T10 (atrazine/mesotrione + glyphosate + p-methyl haloxyfop) showed the lowest acceleration, from 47% at 7 DAT to 78% at 35 DAT.

Control of *D. insularis* has proven to be challenging due to the advanced stage of plant development and water restriction during pre-sowing desiccation. In the context of mixed infestation with *Conyza* spp., broadleaf herbicides antagonized graminicides, significantly reducing control effectiveness. The combination of fluroxypyr + clethodim was the first to achieve more than 80% control of *D. insularis* at 28 DAT, without signs of antagonism, indicating that this combination is an efficient option for ACCase inhibitors. In addition, the use of diclosulam/halauxifen-methyl combined with haloxyfop-p-methyl was also effective without antagonistic effects and is a viable alternative for management (Agrofit, 2024).

On the other hand, treatments involving 2,4-D, dicamba, and triclopyr with haloxyfop demonstrated significant antagonism, reducing the control of *D. insularis*. 2,4-D, in particular, can induce the action of cytochrome P450, increasing the degradation of graminicides and limiting their efficacy (Polito et al., 2021). Short intervals between applications, such as in the case of haloxyfop followed by glufosinate with an interval of only 10 days, also reduced the efficacy, especially under dry soil conditions (Lopes et al., 2021). Soil moisture is a crucial factor for the uptake of ACCase inhibitors, and clethodim is more effective in moist soils, although it maintains some control under drought conditions.

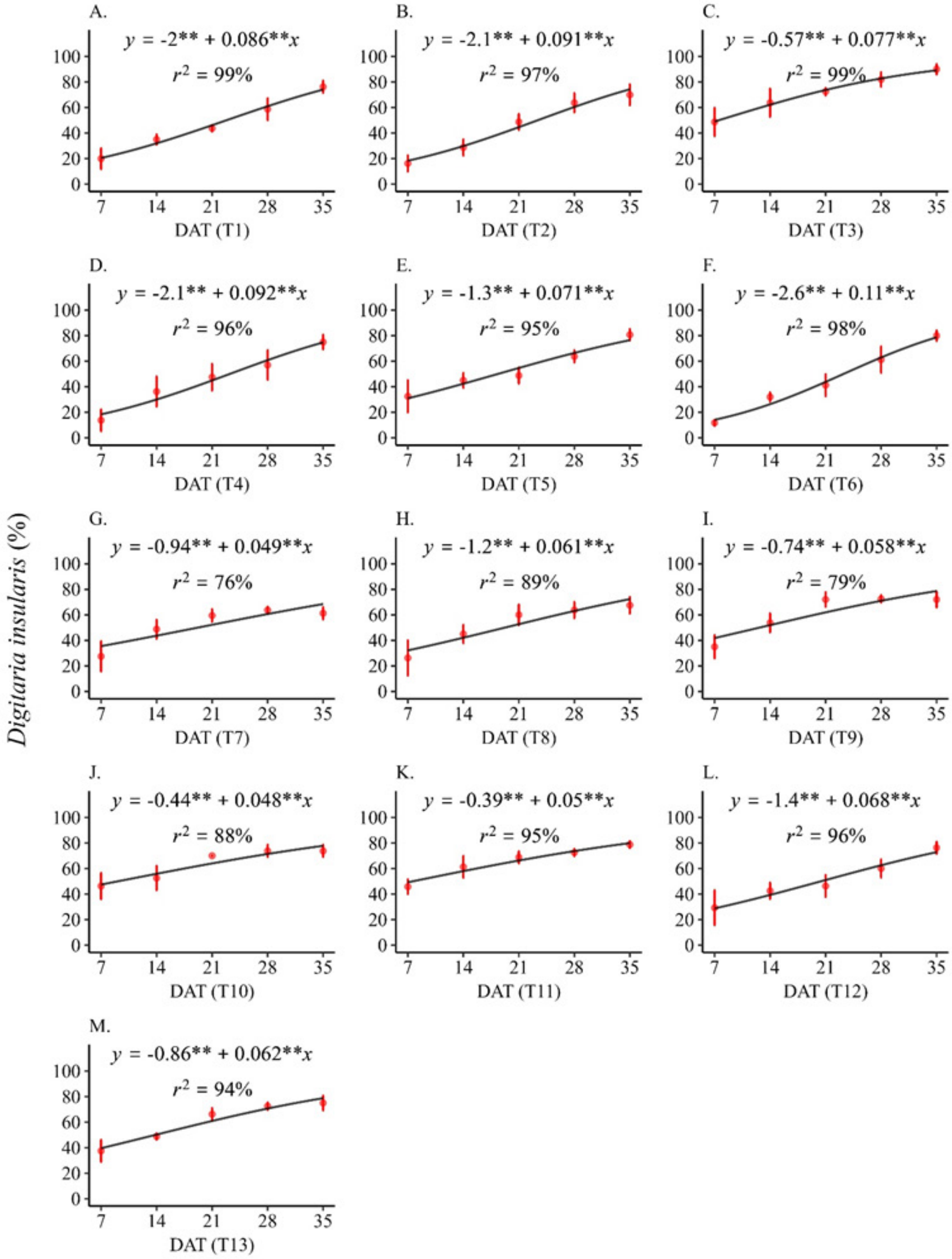
Therefore, greater spacing between applications and the use of alternative combinations are recommended to optimize control and avoid resistance in *D. insularis*. Studies suggest that minimum intervals of 6 days between 2,4-D and ACCase inhibitors and 30-45 days for dicamba in non-tolerant soybeans may prevent antagonism and promote better control (Barros et al., 2021; Cassol et al., 2024).

Considering the simultaneous control of *D. insularis* and



*T1 – 2,4-D (1,000 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1}); T2 – Dicamba (480 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T3 – Fluroxypyr (300 g ai ha^{-1}) + Clethodym (210 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T4 – Triclopyr (720 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T5 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T6 – Diclosulam (20.3 g ai ha^{-1}) + Halauxifen-methyl (3.86 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T7 – 2,4-D (1,000 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T8 – Dicamba (480 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T9 – Triclopyr (720 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T10 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T11 – Diclosulam (20.3 g ai ha^{-1}) + Halauxifen-methyl (3.86 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T12 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + 2,4-D (1,000 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T13 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + 2,4-D (1,000 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T14 – Control. Error bars represent standard deviation (±SD)

Figure 4. Percentages of D. insularis in response to different herbicide treatments at 7, 14, 2, 28 and 35 days after application



*T1 – 2,4-D (1,000 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1}); T2 – Dicamba (480 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1}); T3 – Fluroxypyr (300 g ai ha^{-1}) + Clethodym (210 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1}); T4 – Triclopyr (720 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1}); T5 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1}); T6 – Diclosulam (20.3 g ai ha^{-1}) + Halauxifen-methyl (3.86 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1});T7 – 2,4-D (1,000 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1});T8 – Dicamba (480 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1}); T9 – Triclopyr (720 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1}); T10 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1}); T11 – Diclosulam (20.3 g ai ha^{-1}) + Halauxifen-methyl (3.86 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1}); T12 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + 2,4-D (1,000 g ai ha^{-1}) followed by Haloxyfop (150 g ai ha^{-1}) and Ammonium glufosinate (400 g ai ha^{-1}); T13 – Atrazine (500 g ai ha^{-1}) + Mesotrione (50 g ai ha^{-1}) + 2,4-D (1,000 g ai ha^{-1}) + Haloxyfop-p-methyl (150 g ai ha^{-1}) followed by Ammonium glufosinate (400 g ai ha^{-1}); T14 – Control. ** – Significant at $p \leq 0.01$ by the t-test. Vertical bars represent the standard deviation (SD)

Figure 5. Beta regression analysis with logit link function (1/{1 + exp[-y]}) for the control of D. insularis as a function of days after the first application (DAT) in each treatment

Conyza spp., and to provide a practical recommendation, this study concluded that the herbicide halauxifen + diclosulam, both in association with and in sequential application with haloxyfop-p-methyl, was effective in managing both species, even under water restriction scenarios. Such efficacy is particularly relevant for late-season crops in southern Mato Grosso do Sul, where poor rainfall has become a limiting factor for weed control, in addition to shortening the period available for pre-sowing soybean desiccation.

The combination of halauxifen and diclosulam stands out not only for its efficiency under adverse conditions but also for its flexibility of application, as it requires a relatively short withdrawal period of only 14 days between application and sowing. This allows producers to adjust management according to agronomic needs and climatic variables, reducing the risk of phytotoxicity and optimizing the crop cycle.

Conclusions

The auxinic herbicides 2,4-D, dicamba, and triclopyr exhibited antagonism with haloxyfop-p-methyl when controlling *D. insularis* at advanced phenological stages (BBCH 60–69), thereby reducing grass control efficacy.

Halauxifen-methyl/diclosulam and atrazine/mesotrione showed compatibility with haloxyfop-p-methyl, providing effective control (> 80%) of *D. insularis* (BBCH 60–69) in either tank-mix or sequential treatments. Atrazine requires a 30-day pre-plant interval, whereas sequential applications including glufosinate require only seven days.

For the management of *Conyza* spp. (BBCH 50–59), only 2,4-D + glyphosate and fluroxypyr + clethodim + glyphosate resulted in sub-optimal control (< 80%), whereas all other combinations provided effective suppression (> 80%).

Contribution of authors: L. O. Marques, R. P. P. N. Borges, P. A. V. Salmazo, G. P. da Silva, D. M. Barros, F. C. Munaro, and C. Haruo contributed to the research and methodology, data acquisition and analysis, and drafting the original manuscript. P. V. da Silva, B. F. Schedenffeldt, E. Silva de Medeiros, M. Mauad, C. C. Bicalho, R. C. Dias, and P. A. Monquero contributed to the study's conceptualization, methodology, data analysis, and manuscript writing.

Data Availability Statement: The authors declare that there are no data underlying the text.

Conflict of Interest: The authors declare no conflict of interest.

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