ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.27, n.8, p.600-609, 2023
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n8p600-609

Selectivity of post-emergence herbicides in soybean and their efficacy on the control of *Conyza* spp.[1]

Seletividade de herbicidas pós-emergentes na cultura da soja e sua eficácia no controle de *Conyza* spp.

Paulo V. da Silva[2], Elias S. de Medeiros[2], Bruna Schedenffeldt[3*], Marlon A. Vendruscolo[2], Daniel Zamignam[2], Pedro A. V. Salmazo[2], Roque de C. Dias[4], Munir Mauad[2], Carolina C. Bicalho[5] & Patricia A. Monquero[3]

[1] Research developed at Universidade Federal da Grande Dourados, Dourados, MS, Brazil
[2] Universidade Federal da Grande Dourados, Dourados, MS, Brazil
[3] Universidade Federal de São Carlos, Araras, SP, Brazil
[4] Universidade Federal do Triângulo Mineiro, Iturama, MG, Brazil
[5] Universidade Estadual do Mato Grosso do Sul, Dourados, MS, Brazil

HIGHLIGHTS:

The advanced phenological stage of Conyza *spp. may affect the effectiveness of post-emergence herbicides on soybean.*
Flumetsulam causes phytotoxicity in soybean.
Diversification of the chemical control strategy for Conyza *spp.*

ABSTRACT: The management of *Conyza* spp. is becoming increasingly challenging in soybean, especially post-emergence; therefore, it must be linked to the effectiveness of control with selectivity. This study aimed to evaluate the phytotoxic effects on soybean and the control of *Conyza* spp. at an advanced phenological stage through different post-emergence herbicides registered for soybean. The experimental design was randomized blocks with plots divided in time with 4 replications, consisting of 14 treatments: cloransulam at three different doses (30, 35, and 40 g a.i. ha^{-1}); fomesafen (250 g a.i. ha^{-1}); imazethapyr (100 g a.i. ha^{-1}); chlorimuron in three different doses (15, 18, and 20 g a.i. ha^{-1}); flumetsulam (108 g a.i. ha^{-1}); lactofen (180 g a.i. ha^{-1}); bentazon (720 g a.i. ha^{-1}); and flumiclorac (60 g a.i. ha^{-1}). All were associated with glyphosate (1080 g a.i. ha^{-1}), in addition to two controls, one weeded and the other without. Visual assessments of phytotoxicity in the soybean crop and weed control were performed at 7, 14, 21, 28, and 35 days after treatment (DAT). Bentazon stood out among all treatments, showing adequate selectivity in soybean, in addition to effective weed control at 14 DAT. No dose of cloransulam or chlorimuron herbicide was effective in controlling *Conyza* spp. The phenological stage of *Conyza* spp. and water availability impacted weed control of post-emergence herbicides and selectivity in soybean.

Key words: phytotoxic, chlorimuron, flumetsulam, advanced phenological stage

RESUMO: O manejo de *Conyza* spp., se torna cada vez mais desafiador em soja, principalmente na pós-emergência, logo, deve-se atrelar eficácia de controle com seletividade. Este trabalho teve como objetivo avaliar os efeitos fitotóxicos na cultura da soja e o controle de *Conyza* spp. em estágio fenológico avançado, através de diferentes herbicidas registrados em pós-emergência para a cultura da soja. O delineamento experimental foi o de blocos ao acaso com parcelas subdivididas no tempo com 4 repetições, sendo composto por 14 tratamentos: cloransulam em três diferentes doses (30, 35 e 40 g.i.a.ha^{-1}); fomesafen (250 g i.a. ha^{-1}); imazethapyr (100 g i.a. ha^{-1}); chlorimuron em três diferentes doses (15,18 e 20 g i.a. ha^{-1});flumetsulam (108 g i.a. ha^{-1}); lactofen (180 g i.a. ha^{-1}); bentazon (720 g i.a. ha^{-1}) e flumiclorac (60 i.a. ha^{-1}). Todos foram associados com o glifosato (1080 g i.a. ha^{-1}), além de duas testemunhas,uma capinada e outra sem. Foram realizadas avaliações visuais de fitotoxicidade na cultura da soja e de controle na planta daninha nos 7, 14, 21, 28 e 35 dias após tratamento (DAT). O bentazon se destacou entre todos os tratamentos, apresentando adequada seletividade na soja, além de efetivo controle de plantas daninhas aos 14 DAT. Nenhuma dose dos herbicidas cloransulam e chlorimuron foram eficazes no controle de *Conyza* spp. O estádio fenológico de *Conyza* spp. e a disponibilidade hídrica impacta o controle de plantas daninhas em herbicidas de pós-emergência e seletividade em soja.

Palavras-chave: fitotoxicidade, chlorimuron, flumetsulam, estádio fenológico avançado

• Ref. 269389 – Received 08 Nov, 2022
* Corresponding author - E-mail: bfschedenffeldt@gmail.com
• Accepted 26 Mar, 2023 • Published 03 Apr, 2023
Editors: Geovani Soares de Lima & Hans Raj Gheyi

This is an open-access article distributed under the Creative Commons Attribution 4.0 International License.

Introduction

In Brazil, soybean has become one of the main agricultural commodities, and currently, the country is the largest producer in the world (Barbosa et al., 2021). Soybean production for the 2021/22 season may reach a total of 269.3 million tons, representing an increase of 13.8 million tons compared to the previous season (CONAB, 2022).

The achievement of these high yield indices in soybean is explained by technological investments during cultivation (Carvalho et al., 2022). However, plants of the genus *Conyza* are a current problem, causing great losses in final grain yield (Santos et al., 2014) due to their highly competitive capacity and seed production, reaching more than 800,000 seeds per plant (Kaspary et al., 2017). In addition, these weeds are difficult to control because there has been an increase in the selection pressure for *Conyza* spp. resistant to different herbicides (Pinho et al., 2019; Queiroz et al., 2020; Queiroz et al., 2022).

There are recent reports of *Conyza* spp. biotypes with multiple resistance to the herbicides glyphosate, chlorimuron, paraquat, and 2,4-D in the south of the state of Mato Grosso do Sul (Albrecht et al., 2021). Resistance further limits post-emergence herbicide options for the management of *Conyza* spp. in soybean production, which already has few options for selective and registered herbicides (Albrecht et al., 2020).

Thus, it is necessary to conduct research that provides information on herbicides registered for soybean and with potential control of *Conyza* spp. Therefore, the objective of this study was to evaluate the phytotoxic effects on soybean crops and the control of *Conyza* spp. in the advanced phenological stage through different registered post-emergence herbicides for soybean.

Material and Methods

The experiment was conducted from October 25, 2020, to February 25, 2021, in the field at the Experimental Farm of Agricultural Sciences (FAECA) of the Federal University of Grande Dourados (UFGD), located in the municipality of Dourados in the state of Mato Grosso do Sul (22° 14' 12.3" S, 54° 59' 53.2" W; altitude of 408 m). The region presents, according to the Köppen climate classification, a Cwa climate model (humid mesothermal, hot summers, and dry winters) and has an average annual rainfall of 1405.7 mm, which is higher in the summer with a drier winter and an average annual temperature of 22.6°C.

The experimental units consisted of 3 × 5 m plots, with six rows of soybean in each experimental unit. Soil samples were taken from the experimental area before the installation of the experiment with an Oxisol soil (United States, 2014) that corresponds to a Latossolo Vermelho Distroférrico in the Brazilian soil classification system (EMBRAPA, 2018), whose chemical and physical characteristics were determined according to methodologies recommended by Teixeira et al. (2017) and are presented in Table 1.

The experimental design consisted of randomized blocks with four replicates, 12 herbicide treatments, and weedy check and hand-weeded control plots for a total of 14 treatments. The doses of commercial products are shown in Table 2.

There was no conventional soil preparation in the experimental area aiming to maintain the natural infestation of the weeds present in the area. Before sowing, the soybean seeds were treated with fungicide and insecticide Standak Top, BASF - pyraclostrobin (5 g a.i. ha^{-1}) + methyl thiophanate (45 g a.i. ha^{-1}) + fipronil (50 g a.i. ha^{-1}) - for 100 kg of soybean seeds. The soybean variety used was M6210 IPRO, which was mechanically sown at a spacing of 0.45 m between rows and 14 seeds per linear meter, with a final population of approximately 310,000 plants per hectare. Fertilization was performed in the sowing line with NPK fertilizer formulated at 08-20-20.

Before soybean maturation, a population survey of *Conyza* spp. was conducted using the inventory square methodology,

Table 1. Chemical and physical soil analysis performed at the experimental farm, September 2020, Dourados, MS

pH	OM	P	K	Ca	Mg	Al	H + Al	SB	S	Arg	Silt	Sand
$CaCl_2$	(g dm^{-3})	(mg dm^{-3})	(mmol$_c$ dm^{-3})						(%)	(g kg^{-1})		
6.3	33.1	35.2	5.0	72.0	31.5	0.0	30.8	108.5	77.9	644	203	152

Source: Agro TecSolo Agronomic Analysis and Consultancy (2022)

Table 2. Application of different post-emergence herbicide treatments and their respective doses for the control of *Conyza* spp. in soybean

Treatments	Herbicides	Trade name	Rate (g a.i. ha^{-1})	Adjuvant* (mL L^{-1})
T1	Witness without weeding	------	------	------
T2	Weeded witness	------	------	------
T3	Cloransulam + Glyphosate	Pacto + Glizmax Prime	30 +1080	2
T4	Fomesafen + Glyphosate	Flex + Glizmax Prime	250 +1080	2
T5	Imazethapyr + Glyphosate	Zethapyr + Glizmax Prime	100 +1080	2
T6	Chlorimuron + Glyphosate	Classic + Glizmax Prime	15 +1080	0.5
T7	Flumetsulam + Glyphosate	Scorpion + Glizmax Prime	108 +1080	5
T8	Lactofen + Glyphosate	Dribble + Glizmax Prime	180 +1080	5
T9	Bentazon + Glyphosate	Basagran 480 + Glizmax Prime	720 +1080	2
T10	Flumiclorac + Glyphosate	Radiant + Glizmax Prime	60 +1080	5
T11	Cloransulam + Glyphosate	Pacto + Glizmax Prime	35 +1080	2
T12	Cloransulam + Glyphosate	Pacto + Glizmax Prime	40 +1080	2
T13	Chlorimuron + Glyphosate	Classic + Glizmax Prime	18 +1080	0.5
T14	Chlorimuron + Glyphosate	Classic + Glizmax Prime	20 +1080	0.5

* Joint Oil

which consisted of randomly placing a 1 m² on the chosen area. A density of 71 plants m^{-2} with a height greater than 10 cm was obtained. According to the BBCH classification scale, the plants were in phenological stage (23/30) (Hess et al., 1997).

After crop emergence, other pest management was performed to ensure the full development of the soybean crop, aiming to control ants, *Euschistus herois* (Fabricius, 1798 - Hemiptera: Pentatomidae) and snails, *Bemisia tabaci* (Gennadius, 1889 - Hemiptera: Aleyrodidae), and the preventive application of the fungicide Approach Prima (Du Pont) composed of the strobilurin peakxystrobin, an external quinone inhibitor in complex III (FRAC Group C3), and a triazole. These applications were performed manually using an electric backpack sprayer with a six-point bar and 0.50 m spacing between nozzles.

For herbicide applications, a CO_2 pressurized sprayer calibrated to deliver 160 L ha^{-1} at three bars equipped with TTI 110.02 nozzles was used for application 0.5 m above the plant canopy. The application occurred between the V3 and V4 soybean growth stages on November 22, 2020. The environmental conditions at the time of application in relation to humidity, temperature, and wind speed were 75%, 25°C, and 2 km h^{-1}, respectively.

The rainfall conditions and average maximum and minimum temperatures for the duration of the experiment for the Dourados, MS region, are shown in Figure 1. This information was collected from the climate station Embrapa Agropecuária Oeste (Dourados, MS), located about 20 km from the experiment site (22° 16' 31" S, 54° 49' 06" W, 408 m).

Desiccation of soybean with glufosinate (400 g a.i. ha^{-1}) and flumioxazin (22.5 g a.i. ha^{-1}) was performed on February 25, 2021, when the plants were at phenological stage R7.3.

Visual evaluations of weed control and soybean phytotoxicity were performed at 7, 14, 21, 28, and 35 days after treatment (DAT). For control and phytotoxicity, the visual scale of ALAM (1974) was followed, which assigns a score of 0% for the absence of symptoms caused by the herbicide and 100% for the death of the weed. For the characterization of the phytotoxicity symptom, 0% was the absence of damage, and 80-100% means total plant destruction (plant death).

After the end of the evaluation period, the experimental units were manually and individually harvested, and the three central rows were selected, thus discarding 0.5 m from the ends of the experimental units to avoid errors and to standardize the harvest, allowing the estimation of the total grain weight corresponding to each plot, moisture content, and 100 grain mass determination.

Moisture evaluation was performed using individual samples of grains from each plot, in which the grains of each plot were subjected to an industrial moisture meter model AL-102 ECOR. Regarding the evaluation of the mass of 1000 grains, some samples from each plot were individually subjected to a grain counter. NV-C/01, obtaining 1000 soybeans in each plot. After counting, weighing was performed on an analytical scale to obtain the corresponding mass.

Statistical analyses of soybean phytotoxicity (%) and *Conyza* spp. control (%) using two generalized additive models of location, scale, and shape (GAMLSS) with inflated beta family and Log and Logit link functions were used for the mean and variance, respectively. To verify the effects of block, treatment, DAT, and the interaction (treatment × DAT), the F statistic was applied. For comparison between the treatment levels, we used the marginal means estimated with adjustments made using the Tukey test. Regression analysis via GAMLSS was used to analyze the response variable as a function of the DAT. For the hypothesis tests, a 0.05 significance level was considered.

For deviance analysis of total weight, weight (1000 grains), and productivity (kg ha^{-1}), linear models with normal distributions were used, and for moisture content, the

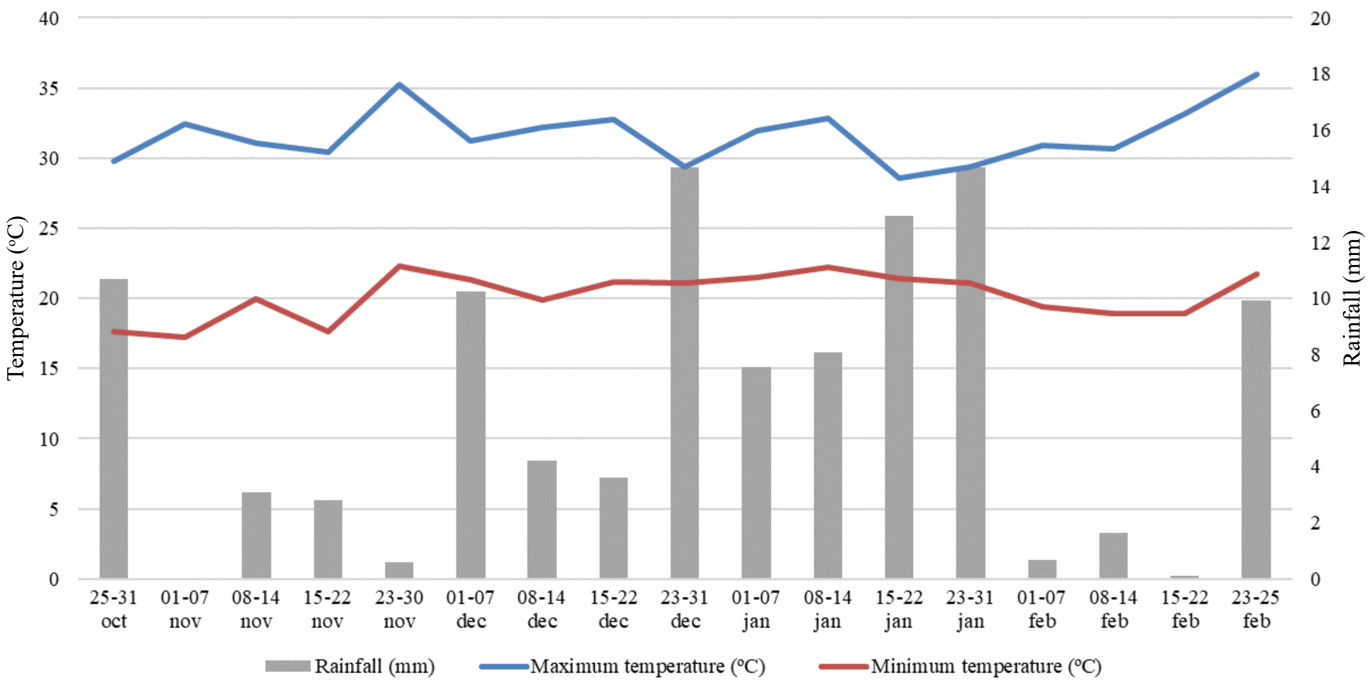


Figure 1. Rainfall index and mean average maximum and minimum temperatures experiment. Dourados, MS, 2020-2021

GAMLSS model with beta distribution was used. To verify the effects of the blocks and treatments, the F test was applied. A Tukey test was used to compare the treatment levels. All statistical analyses were performed using R software (R Core Team, 2021). To construct the GAMLSS models, the gamlss library was used (Rigby & Stasinopoulos, 2005).

Results and Discussion

There was a significant effect of the treatment × DAT interaction for soybean phytotoxicity (%) (F = 5.425, p ≤ 0.01) and for the control of *Conyza* spp. (%) (F = 9.194, p ≤ 0.01).

Figure 2 shows the results of the multiple comparison test in relation to the treatment breakdown within each DAT when evaluated for soybean phytotoxicity (%). Thus, we observed how each herbicide behaved over the days evaluated between Gl 3 and 13.

At 7 DAT, treatments flumiclorac + glyphosate (60 + 1080 g a.i. ha^{-1}) and lactofen + glyphosate (180 + 1080 g a.i. ha^{-1}) showed the highest phytotoxic effects in soybean, with percentages greater than 50% (Figure 2). These treatments were statistically equal to flumetsulam + glyphosate (108 + 1080 g a.i. ha^{-1}) and fomesafen + glyphosate (250 + 1080 g a.i. ha^{-1}), which presented percentages greater than 40%.

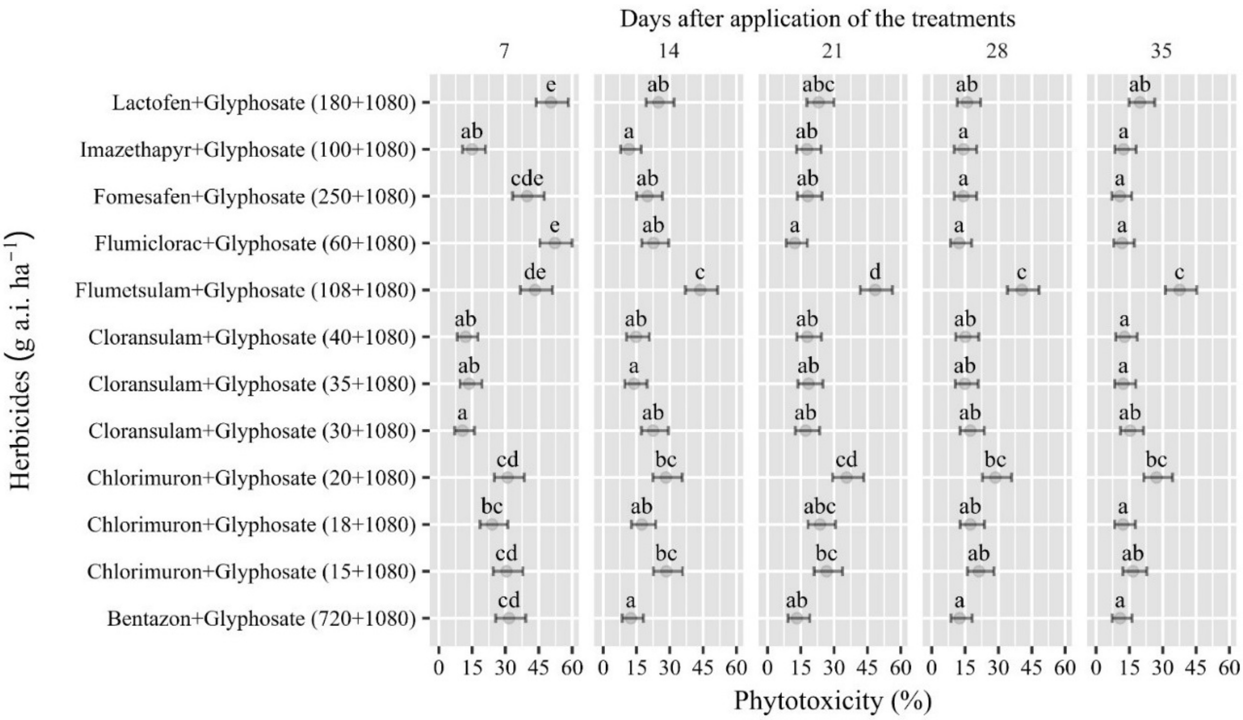
Thus, the PPO-inhibiting herbicides (fomesafen, lactofen, and flumiclorac) and flumetsulam (ALS) resulted in the highest soybean phytotoxicity at 7 DAT. The lowest dose of cloransulam + glyphosate (30 + 1080 g a.i. ha^{-1}) resulted in the lowest soybean phytotoxicity, less than 20%, and it was not statistically different from either the other treatments with higher doses of cloransulam or imazethapyr + glyphosate (100 + 1080 g a.i. ha^{-1}). At 7 DAT, in general, all herbicide treatments had phytotoxicity greater than 30%, except for treatments with cloransulam and imazethapyr, which had phytotoxicity less than 20%.

At 35 DAT, most treatments did not differ from each other, with phytotoxicity percentages lower than 20%. The exceptions were the treatments flumetsulam + glyphosate (108 + 1080 g a.i. ha^{-1}) and the highest dose of chlorimuron + glyphosate (20 + 1080 g a.i. ha^{-1}), which did not differ from each other and resulted in phytotoxicity of 48 and 30%, respectively (Figure 2). Flumetsulam cannot be considered a potential product in soybean post-emergence due to the high phytotoxic damage in the crop.

The selectivity of flumetsulam varies as a function of its absorption and translocation time. At higher doses, larger amounts of the herbicide can be absorbed, overloading the metabolic processes that flumetsulam can act on in plants. In addition, adverse conditions, such as temperature and water deficit, tend to increase and/or prolong the symptoms of phytotoxicity in plants (Dranca et al., 2018), as observed throughout this experiment (Figure 1).

For *Conyza* spp. control, there was no significant difference between most of the treatments at 7 DAT, with control percentages lower than 60% (Figure 3). The exception was bentazon + glyphosate (720 + 1080 g a.i. ha^{-1}) in which the control was close to 80% in the first evaluation. This behavior remained in the evaluation at 14 DAT; however, there was no significant difference in relation to the treatments of chlorimuron + glyphosate (18 + 1080 g a.i. ha^{-1}) and flumetsulam + glyphosate (108 + 1080 g a.i. ha^{-1}) which showed control between 45 and 70%.

Flumetsulam + glyphosate (108 + 1080 g a.i. ha^{-1}) showed effective control of *Conyza* spp. post-emergence in soybean at 35 DAT. However, this treatment was not statistically different from treatments cloransulam + glyphosate (35 +



Treatment followed by the same letter do not differ significantly (p > 0.05 by Tukey test

Figure 2. Analysis of the treatment unfolding within each days after treatment (DAT) when evaluating the percentages of soybean

1080 g a.i. ha^{-1}), cloransulam + glyphosate (40 + 1080 g a.i. ha^{-1}), and chlorimuron + glyphosate (18 + 1080 g a.i. ha^{-1}) (Figure 3). The ineffectiveness of the other treatments (flumiclorac, imazethapyr, and fomesafen) can be explained by the advanced phenological stage of *Conyza* spp., with heights greater than 10 cm hindering effective management.

Schneider et al. (2021) emphasized that the developmental stage of *Conyza* spp. is directly related to herbicide susceptibility; thus, herbicide application in the early stages of development is essential for successful control. Therefore, in advanced stages, with the increase and accumulation of dry matter, plants acquire a greater ability to survive and recover from the effects of herbicides (Zimmer et al., 2018). The herbicide susceptibility of *Conyza* spp. is conditional on plant height plants smaller than 10 cm are more susceptible to herbicide treatments, and plants taller than 20 cm are less susceptible to herbicide treatments (Silva et al., 2021).

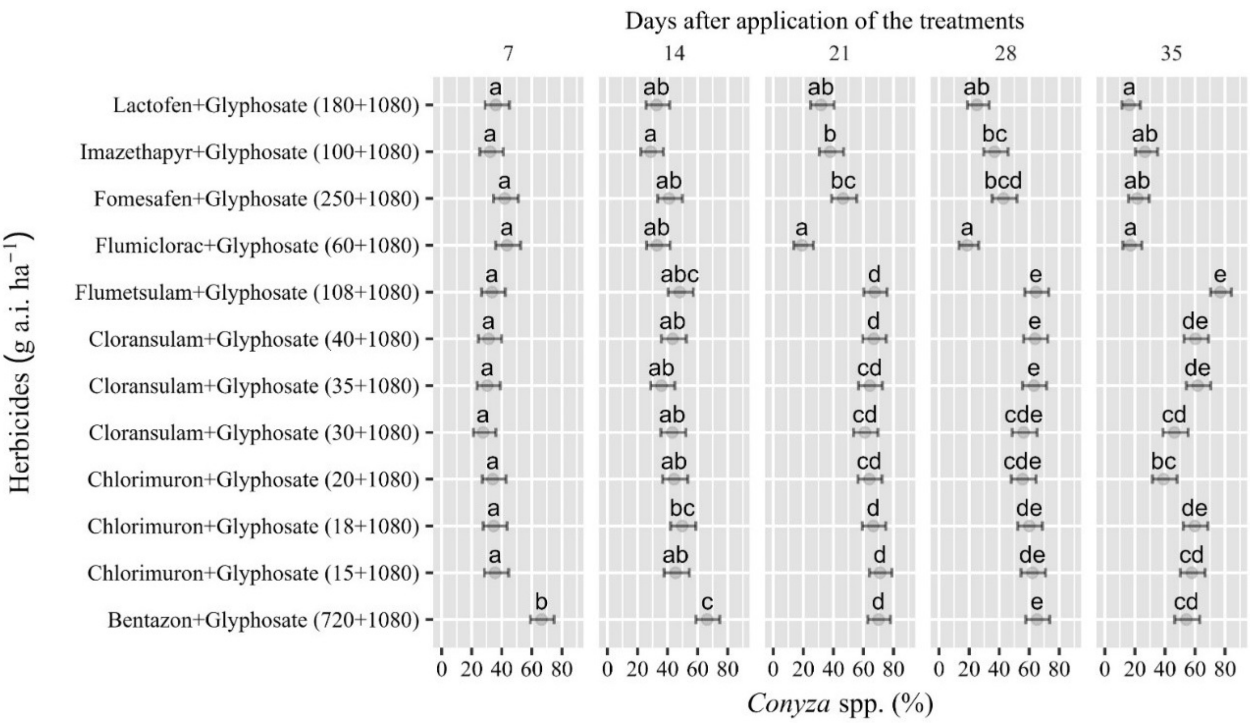
Another relevant aspect is that at 7 DAT, no treatment showed effective weed control, and all treatments had less than 60% control. However, at 14 DAT, the herbicide bentazon showed almost 80% control of *Conyza* spp., even in plants taller than 15 cm, but the control subsequently decreased due to the vegetative development of *Conyza* spp. plants and the production and expansion of new leaves, as it is a contact product that inhibits PSII.

This describes a potential new tool for *Conyza* spp. management in soybean production, as it showed adequate selectivity in soybean and effective control at 14 DAT, even under water stress conditions and high temperatures. If bentazon is used in *Conyza* spp. smaller than 10 cm and/or combined with other herbicides, greater control longevity, such as the absence of regrowth and mitigation of phytotoxic effects in soybean, may be observed. Bentazon has been used for several decades, and the possibility of post-emergence use in soybean should also be considered in pre-sowing desiccation, either in sequential applications and/or combinations with other herbicides, such as auxin mimics and/or ALS inhibitors.

Dykun et al. (2020) evaluated the control efficacy and selectivity of treatments containing bentazon post-emergence in soybean and found that bentazon alone resulted in 88% biomass loss for *Amaranthus retroflexus*, 92% for *Chenopodium album*, 70% for *Setaria glauca*, and 52% for *Echinochloa crus-galli*. In addition, the authors observed a synergistic effect for weed control in the combination of bentazon with imazamox. Treatments with bentazon did not result in the deterioration of soybean quality and increased productivity due to the greater effectiveness of weed control.

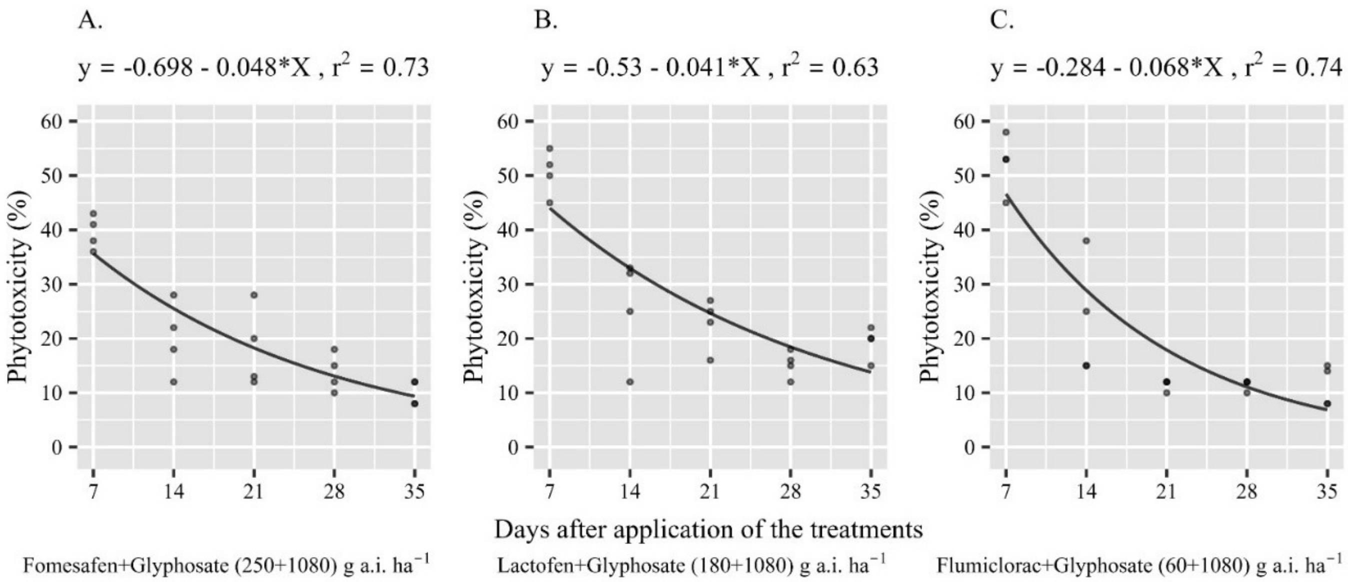
The regression analyses for soybean phytotoxicity, considering DAT as an explanatory variable, indicated a significant effect of DAT when evaluating soybean phytotoxicity in treatments fomesafen + glyphosate (250+1080 g a.i. ha^{-1}; R^2 = 72%; Figure 4A), lactofen + glyphosate (180+1080 g a.i. ha^{-1}; R^2 = 63%; Figure 4B), and flumiclorac + glyphosate (60+1080 g a.i. ha^{-1}; R^2 = 74%; Figure 4C).

The treatments chlorimuron + glyphosate (15+1080 g a.i. ha^{-1}; $y = -0.996 - 0.02 * X$; R^2 = 34%), bentazon + glyphosate (720+1080 g a.i. ha^{-1}; $y = -1.116 - 0.039 * X$; R^2 = 54%), and chlorimuron + glyphosate (18+1080 g a.i. ha^{-1}; $y = -1.316 - 0.018 * X$; R^2 = 32%) were significant but showed R^2 values less than 0.60 and therefore are not shown. Regarding the phytotoxicity of the significant treatments, there was a reduction in phytotoxicity levels over time. Among the curves, the greatest reduction in phytotoxicity was observed in the treatment flumiclorac + glyphosate (60+1080 g a.i. ha^{-1}), in which control was obtained close to 47% at 7 DAT and 7% at



Treatments followed by the same letter do not differ significantly (p > 0.05) by Tukey test

Figure 3. Analysis of the treatment breakdown within each day after treatment (DAT) when evaluating the percentages of *Conyza* spp.



* Significant at p ≤ 0.05 by t test

Figure 4. Analysis of soybean phytotoxicity (%) as a function of days after treatment (DAT) in different herbicides had a significant effect in the regression ($R^2 > 0.6$). The equation shown in each figure corresponds to the log link function

35 DAT. For treatment that included the herbicide bentazon, a PSII inhibitor, the highest phytotoxic damage levels also occurred in the first evaluations, being reduced and becoming less expressive at 35 DAT (close to 8%).

At 7 DAT, chlorimuron + glyphosate (18+1080 g a.i. ha^{-1}) showed a soybean phytotoxicity that was not very significant, and at 35 DAT, the mitigation of the effects was not very significant, with close to a 5% reduction in phytotoxicity. The low soybean phytotoxicity in all ALS-inhibitor herbicides is explained by differential herbicide metabolism. Soybean can rapidly metabolize imazethapyr into nontoxic metabolites, rapidly convert chlorimuron into inactive compounds, and detoxify cloransulam through rapid detoxification (Qu et al., 2021).

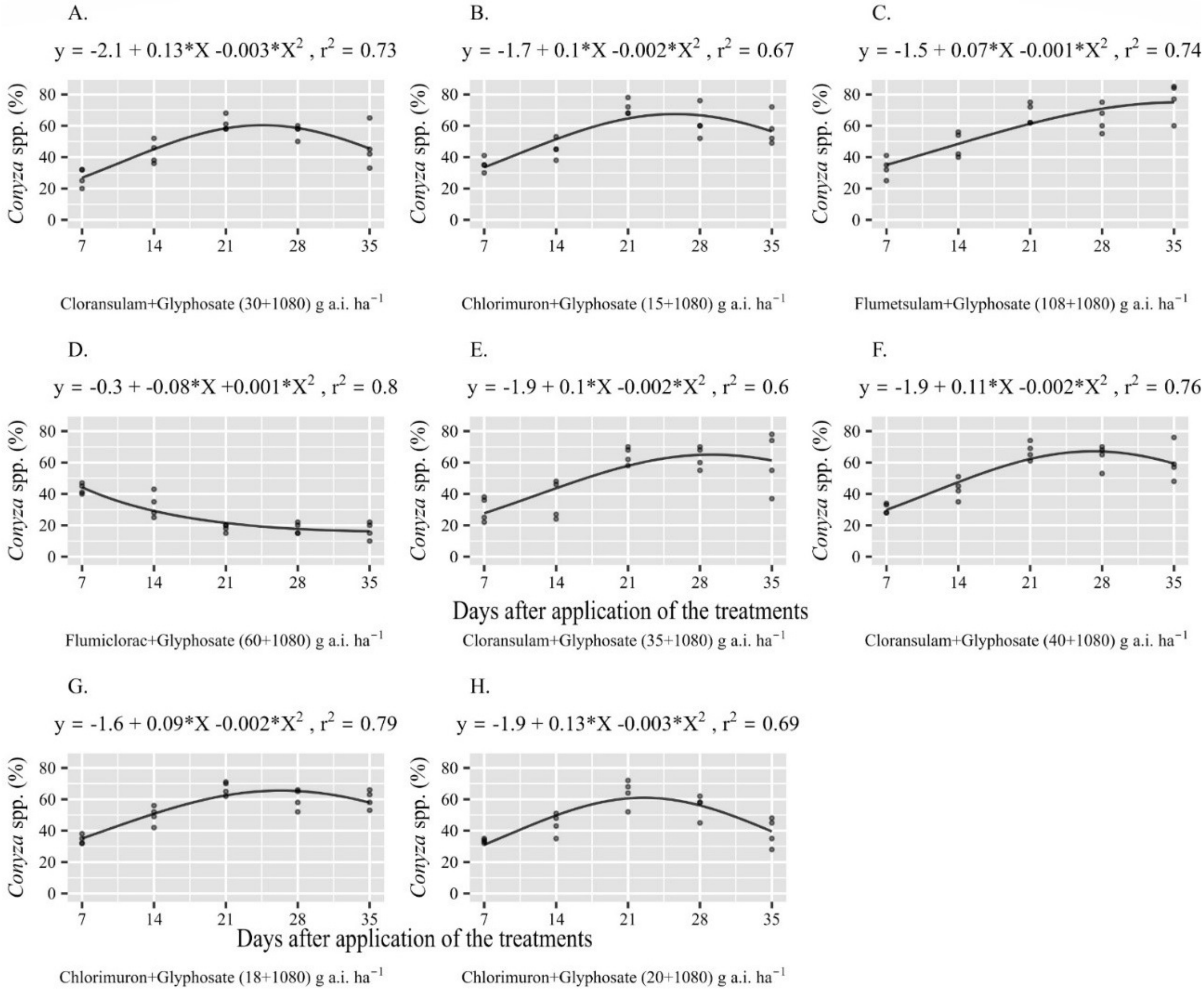
The PPO-inhibitor herbicides (fomesafen, lactofen, and flumiclorac) had high levels of phytotoxicity in the first evaluations, especially at 7 DAT (Figure 4). After 14 DAT, phytotoxicity injury began to decrease, and by 35 DAT, they reached the lowest levels. The exception was flumetsulam, which at 35 DAT, still had high phytotoxicity, with scores close to 50% compared to other PPO inhibitors.

For *Conyza* spp. control, treatments cloransulam + glyphosate (35+1080 g a.i. ha^{-1}; R^2 = 73%; Figure 5A), chlorimuron + glyphosate (15+1080 g a.i. ha^{-1}; R^2 = 67%; Figure 5B), flumetsulam + glyphosate (108+1080 g a.i. ha^{-1}; R^2 = 74%; Figure 5C), bentazon + glyphosate (720+1080 g a.i. ha^{-1}; $y = -0.55 - 0.024 * X - 0.001 * X^2$; R^2 = 58%), flumiclorac + glyphosate (60+1080 g a.i. ha^{-1}; R^2 = 80%; Figure 5D), cloransulam + glyphosate (35+1080 g a.i. ha^{-1}; R^2 = 60%; Figure 5E), cloransulam + glyphosate (40+1080 g a.i. ha^{-1}; R^2 = 76%; Figure 5F), chlorimuron + glyphosate (18+1080 g a.i. ha^{-1}; R^2 = 79%; Figure 5G), and chlorimuron + glyphosate (20+1080 g a.i. ha^{-1}; R^2 = 69%; Figure 5H) were significant as a function of DATs.

Treatment flumetsulam + glyphosate (108+1080 g a.i. ha^{-1}) was the only treatment where weed control did not reach a maximum at 35 DAT and continued to increase, being the only herbicide combination with a control greater than 75%. For the herbicide bentazon, a PSII inhibitor, the highest control of *Conyza* spp. was between 14 and 21 DAT, which was much faster than the other treatments. With the exception of flumetsulam, no herbicide established a control greater than 80%.

The ALS-inhibiting herbicides cloransulam and chlorimuron at all doses had a similar response. Because they are systemic herbicides, the highest control was observed near 28 DAT, indicating a delay for these systemic products to show symptoms and higher weed control. Herbicides associated with glyphosate are commonly used for *Conyza* spp. control in Brazil, often resulting in effective control of plants with heights up to 10 cm. Therefore, treatments with cloransulam and chlorimuron did not result in a control greater than 80%; this behavior can be explained by applications in the wrong phenological stage (plants higher than 15 cm). Bressanin et al. (2014) demonstrated excellent *Conyza* spp. control with glyphosate + chlorimuron in plants with 4–6 pairs of leaves, while Santos et al. (2014) found lower sensitivity of *Conyza sumatrensis* biotypes to chlorimuron in vegetative stages above six leaves (> 10 cm), explained by reduced herbicide absorption due to factors related to external leaf anatomy, such as the presence of trichomes.

In addition to the size of the plants, immediately following herbicide treatment application, the area where the experiment was conducted underwent severe water restriction (Figure 1). Herbicide efficacy is also affected by environmental factors that influence the physiological characteristics of weed growth (Alizade et al., 2020). Water restriction, which influences leaf anatomy, resulting in changes in leaf thickness and a decrease in the number of stomata, negatively impacts herbicide absorption and, consequently, its control efficacy. In addition to the morphological aspects, the water deficit also reduces herbicide translocation in the plant, both before and after herbicide application. For satisfactory weed control, post-



* Significant at p ≤ 0.05 by t test

Figure 5. Analysis of *Conyza* spp. (%) as a function of days after treatment (DAT) in different herbicides had a significant effect on the regression ($R^2 > 0.6$). The equation shown in each figure corresponds to the log link function

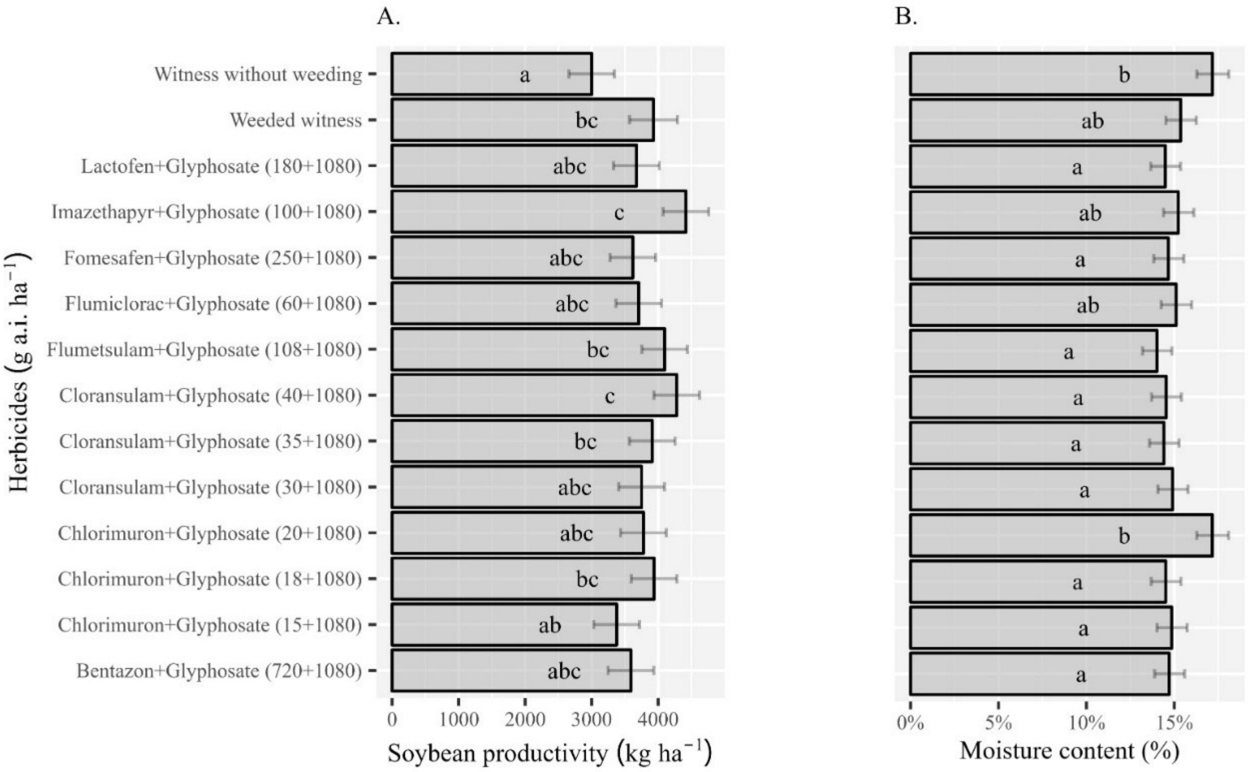
emergence herbicides need to be absorbed and translocated to the site of action so that maximum efficacy is reached, which occurs when weeds have favorable physiological conditions to absorb and translocate the herbicide (Lopes et al., 2021). However, if the weed is stressed at the time of application, it influences the translocation of the herbicide.

However, under conditions with no water restriction and in plants up to 10 cm in height, the herbicides cloransulam and chlorimuron present satisfactory control. Blainski et al. (2015) observed an optimal behavior of ALS-inhibiting herbicides at 42 DAT when using cloransulam at 35 and 40 g ha^{-1} with controls of 87.0 and 90.7% in plants of *Conyza* spp. with 5 to 10 cm in height. The cloransulam treatment was not statistically different from chlorimuron treatment (85.7%), and neither herbicide affected the soybean crop. In this study, ALS-inhibiting herbicides showed low phytotoxic effects on soybean crops.

Although there was no significant treatment for soybean total weight (1000 grains; data not shown), productivity (kg ha^{-1}) (F = 9.00, $p \leq 0.01$) and moisture content (%) (F = 4.27, $p \leq 0.01$) changed among treatments (Figure 6). For soybean productivity, treatment controls without weeding had the lowest mean (3.000 kg ha^{-1}) and were statistically different ($p \leq 0.05$) from the weeded control, imazethapyr + glyphosate (100+1080 g a.i. ha^{-1}), flumetsulam + glyphosate (108+1080 g a.i. ha^{-1}), cloransulam + glyphosate (35+1080 g a.i. ha^{-1}), cloransulam + glyphosate (40+1080 g a.i. ha^{-1}), and chlorimuron + glyphosate (18+1080 g a.i. ha^{-1}) (Figure 6A).

The weeded control, cloransulam + glyphosate (30+1080 g a.i. ha^{-1}), fomesafem + glyphosate (250+1080 g a.i. ha^{-1}), imazethapyr + glyphosate (100+1080 g a.i. ha^{-1}), flumetsulam + glyphosate (108+1080 g a.i. ha^{-1}), lactofen + glyphosate (180+1080 g a.i. ha^{-1}), bentazon + glyphosate (720+1080 g a.i. ha^{-1}), flumiclorac + glyphosate (60+1080 g a.i. ha^{-1}), cloransulam + glyphosate (35+1080 g a.i. ha^{-1}), cloransulam + glyphosate (40+1080 g a.i. ha^{-1}), and chlorimuron + glyphosate (18+1080 g a.i. ha^{-1}) did not differ and showed the highest productivity, which means that the weeded control and the application of these herbicide treatments resulted in a high soybean yield (Figure 6A).

Treatments imazethapyr + glyphosate (100+1080 g a.i. ha^{-1}) and chlorimuron + glyphosate (15+1080 g a.i. ha^{-1})



Treatments followed by the same letter do not differ significantly ($p > 0.05$) by Tukey test

Figure 6. Analysis of the behavior of each treatment level when evaluating productivity (A) and moisture content (B) in soybean. Vertical bars represent the standard error of the mean estimate

did not differ from each other in relation to the statistical analysis and had the highest yield. For soybean moisture content, there was no statistical difference between the control without weeding and chlorimuron + glyphosate (20+1080 g a.i. ha^{-1}), and both showed the highest moisture content, with percentages higher than 16% (Figure 6B). The other treatments had a moisture content closer to 15% (Figure 6B).

In this study, the lack of control resulted in a significant loss of productivity, as the control without weeding resulted in the lowest averages. In contrast, all herbicide treatments, even if the control was not effective and/or culminated in high phytotoxicity, had better productivity than the control without weeding, showing that the adoption of chemical weed management was essential for greater productivity. The area where the experiment was conducted had a high infestation of *Conyza* spp. Thus, the critical period of weed control had already started with a high weed density; for this reason, some treatments with herbicides had higher mean productivity than the weeded control. Therefore, the establishment of soybean in competition with weeds impacts productivity culture.

The ALS-inhibiting herbicide treatments had the highest yields, indicating higher productivity than the control without weeding, and were statistically similar to the weeded control. In general, these active ingredients are rapidly metabolized by soybean. The highest chlorimuron dose resulted in a higher moisture content, high phytotoxicity in soybean, and low *Conyza* spp. control, which is explained by the physiological stress caused by post-emergence application combined with competition with *Conyza* spp., resulting in a delay in the vegetative development of soybean, influencing grain maturation, and delaying the crop desiccation for harvest.

The adverse climatic conditions after the application of post-emergence herbicides (water restriction and high temperature) resulted in stress for the vegetative development of soybean, as the need for water savings leads to decreased photosynthesis and internal translocation in the plant (Lopes et al., 2021), resulting in a lower photosynthetic rate, lower stomatal conductance, and lower herbicide absorption and translocation. These physiological changes in the plant caused changes in secondary metabolism and in the hormone levels of plants, which are often routes of formation for important compounds in the development and survival of soybean (Rockenbach et al., 2018). Alencar et al. (2022), evaluating the selectivity of the herbicides chlorimuron, cloransulam, and fomesafen, observed high phytotoxicity at high temperatures and water deficit; however, the authors reported that these greater phytotoxic effects were mitigated, especially after the occurrence of rainfall over time, without a loss in productivity.

Finally, the weed phenological stage and the climatic conditions impact the control efficacy of post-emergence herbicides and selectivity in soybean, causing ineffective control of *Conyza* spp. and/or high soybean phytotoxicity even for products often used post-emergence. Therefore, the recommendations for herbicide application in this modality should be considered only in seasons with greater water availability and early vegetative development of *Conyza* spp., aiming at weed control percentages greater than 80% and the mitigation of phytotoxic effects on soybean.

Conclusions

1. Bentazon stood out among all treatments, showing adequate selectivity in soybean, in addition to effective weed control at 14 DAT, even under adverse weather conditions, such as water stress and high temperatures.

2. Although the herbicides cloransulam and chlorimuron showed no phytotoxicity and the highest soybean yields, none of the doses tested were effective in controlling *Conyza* spp.

3. The phenological stage of *Conyza* spp. and water availability impact weed control by post-emergence herbicides and selectivity in soybean.

Literature Cited

AGROTECSOLO – Análises agronômicas e consultoria. Available on: <http://www.agrotecsolo.com.br/>. Accessed on: Jul. 2022.

ALAM - Asociation Latino americana de Malezas. Recomendaciones sobre unificación de los sistemas de evaluación em ensayos de control de malezas. ALAM, v.1, p.35-38, 1974.

Albrecht, A. J. P.; Albrecht, L. P.; Rodrigues Alves, S. N.; Silva, A. F. M.; Silva, W. D. O.; Lorenzetti, J. B.; Barroso, A. A. M. Pre-sowing application of combinations of burndown and preemergent herbicides for *Conyza* spp. control in soybean. Agronomía Colombiana, v.39, p.121-128, 2021. https://doi.org/10.15446/agron.colomb.v39n1.89545

Albrecht, A. J. P.; Pereira, V. G. C.; Souza, C. N. Z. D.; Zobiole, L. H. S.; Albrecht, L. P.; Adegas, F. S. Multiple resistance of *Conyza sumatrensis* to three mechanisms of action of herbicides. Acta Scientiarum. Agronomy, v.42, p.1-9, 2020. https://doi.org/10.4025/actasciagron.v42i1.42485

Alencar, E. S.; Geist. M. L.; Pereira, J. P. M.; Schedenffeldt, B. F.; Nunes, F. A.; Silva, P. V. da; Dupas, E.; Mauad, M.; Monquero, P. A.; Medeiros, E. S. Seletividade de herbicidas pós-emergentes isolados ou associados a fertilizante foliar na cultura da soja. Revista de Ciências Agroveterinárias, v.21, p.1-16, 2022. https://doi.org/10.5965/223811712142022384

Alizade, S.; Keshtkar, E.; Mokhtasi-Bidgoli, A.; Sasanfar, H.; Streibig, J. C. Effect of water deficit stress on benzoylprop-ethyl performance and physiological traits of winter wild oat (*Avena sterilis subsp. ludoviciana*). Crop Protection, v.137, p.105-292, 2020. https://doi.org/10.1016/j.cropro.2020.105292

Barbosa, E. J. A.; Galle, V.; Coronel, D. A. Variable costs in soybean culture: The evolution of a property in northwestern Rio Grande do Sul. Inform Gepec, v.25, p.85-106, 2021. https://doi.org/10.48075/igepec.v25i2.26485

Blainski, E.; Maciel, C. D. G.; Zobiole, L. H. S.; Rubin, R. D. S.; Silva, A. A. P.; Karpinski, A. K.; Helvig, E.O. Cloransulam-methyl efficiency in post-emergence control of *Conyza bonariensis* in RRTM soybeans crops. Revista Brasileira de Herbicidas, v.14, p.235-242, 2015.

Bressanin, F. N.; Jayme Neto, N.; Martins, J. F.; Martins, J. V. F.; Alves, P. L. D. C. A. Controle de biótipos resistentes de *Conyza bonariensis* com glyphosate + clorimuron-etílico em função do estádio de desenvolvimento. Revista Brasileira de Herbicidas, v.14, p.68-72, 2014. https://doi.org/10.7824/rbh.v13i1.208

Carvalho, S. J. P.; Magalhães, T. B.; Ovejero, R. F. L.; Palhano, M. G. Fitotoxicidade de subdoses do herbicida dicamba quando aplicado em pré-emergência da cultura da soja não-tolerante. Revista de Ciências Agroveterinárias, v.21, p.85-92, 2022. https://doi.org/10.5965/223811712122022085

CONAB - Companhia Nacional de Abastecimento. Produção de grãos da safra 2020/21 segue como maior da história: 268,9 milhões de toneladas, 2022. Avaiable on: <https://www.conab.gov.br/ultimas-noticias/3691-producao-degraos-da-safra-2020-21-segue-como-maior-da-historia-268-9milhoes-detoneladas>. Accessed on: Jul. 2022.

Dranca, A. C.; Helvig, E. O.; Goes Maciel, C. D. de; Carbonari, C. A.; Velini, E. D. Associations of herbicides with fertilizer and plant grown regulator on soybean. Applied Research & Agrotechnology, v.11, p.69-80, 2018. https://doi.org/10.5935/PAeT.V11.N3.07

Dykun, A.; Zherebko, V.; Dykun, M. The effectiveness of herbicides in soybean cultivation. Žemės ūkio mokslai, v.27, p.115-124, 2020. https://doi.org/10.6001/zemesukiomokslai.v27i3.4341

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Sistema brasileiro de classificação de solos, 5.ed. Rio de Janeiro: Embrapa, 2018, 356p.

Hess, M; Barralis, G.; Bleiholder, H.; Buhrs, L.; Eggers, T.; Hack, H.; Stauss, R. Use of the extended BBCH scale - general for the descriptions of the growth stages of mono- and dicotyledonous weed species. Weed Research, v.37, p.433-441, 1997.

Kaspary, T. E.; Lamego, F. P.; Cutti, L.; Aguiar, A. C. D. M.; Rigon, C. A. G.; Basso, C. J. Growth, phenology, and seed viability between glyphosate-resistant and glyphosate-susceptible hairy fleabane. Bragantia, v.76, p.92-101, 2017. https://doi.org/10.1590/1678-4499.542

Lopes, A. F.; Junior, J. H.; Gimenez, G. S.; De Oliveira, G. M.; Dalazen, G. Controle de capim-amargoso com herbicidas graminicidas após diferentes períodos de restrição hídrica. Weed Control Journal, v.20, p.1-8, 2021. https://doi.org/10.7824/wcj.2021;20:00756

Pinho, C. F.; Leal, J. F. L.; Souza, A. dos S.; Oliveira, G. F. P. B. de; Oliveira, C. de; Langaro, A. C.; Machado, A. F. L.; Christoffoleti, P. J.; Zobiole, L. H. S. First evidence of multiple resistance of Sumatran Fleabane (*Conyza sumatrensis* (Retz.) E. Walker) to five- mode-of-action herbicides. Australian Journal of Crop Science, v.13, p.1688-1697, 2019.

Qu, R.; He, B.; Yang, J.; Lin, H.; Yang, W.; Wu, Q.; Yang, G. Where are the new herbicides? Pest Management Science, v.77, p.2620–2625, 2021. https://doi.org/10.1002/ps.6285

Queiroz, A. R. S.; Delatorre, C.; Markus, C.; Lucio, F.; Angonese, P.; Merotto, A. Rapid necrosis II: physiological and molecular analysis of 2,4-D resistance in Sumatran fleabane (*Conyza sumatrensis*). Weed Science, v.70, p.36-45, 2022. https://doi.org/10.1017/wsc.2021.71

Queiroz, A. R. S.; Delatorre, C.; Lucio, F.; Rossi, C.; Zobiole, L.; Merotto, Rapid necrosis: a novel plant resistance mechanism to 2,4-D. Weed Science, v.68, p.6-18, 2020. https://doi.org/ 10.1017/wsc.2019.65

R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2021. Avaiable on: <https://www.R-project.org/> Accessed on: Jul. 2022.

Rigby, R. A.; Stasinopoulos, D. M. Generalized additive models for location, scale and shape (with discussion). Journal of the Royal Statistical Society: Series C (Applied Statistics), v.54, p.507-554, 2005.

Rockenbach, A. P.; Rizzardi, M. A.; Nunes, A. L.; Bianchi, M. A.; Caverzan, A.; Schneider, T. Interferência entre plantas daninhas e a cultura: alterações no metabolismo secundário. Revista Brasileira de Herbicidas, v.17, p.59-70, 2018. https://doi.org/10.7824/rbh.v17i1.527

Santos, F. M.; Vargas, L.; Christoffoleti, P. J.; Agostinetto, D.; Martin, T. N.; Ruchel, Q.; Fernando, J. A. Estádio de desenvolvimento e superfície foliar reduzem a eficiência de *chlorimuronethyl* e glifosato em *Conyza sumatrensis*. Planta Daninha, v.32, p.361-375, 2014. https://doi.org/10.1590/S0100-83582014000200014

Silva, P. V.; Oliveira, M. V. B. de; Barros, D. M.; Molina, D. Z.; Carvalho, R. D. de; Monquero, P. A.; Inácio, E. M. Estratégias de controle de *Conyza* spp. em pré-plantio da soja: Aplicações únicas ou sequenciais? Research, Society and Development, v.10, p.1-9, 2021. https://doi.org/10.33448/rsd-v10i8.16995

Schneider, T.; Camera, J. N.; Koefender, J.; Rizzardi, M. A.; Bianchi, M. A.; Rockenbach, A. P. Herbicide performance in the control of *Conyza* spp. where three plant heights. Bioscience Journal, v.37, p.1981-3163, 2021. https://doi.org/10.14393/BJ-v37n0a2021-53718

Teixeira, P. C.; Donagemma, G. K.; Fontana, A.; Teixeira, W. G. (org.) Manual de métodos de análise de solo. 3.ed. Brasília: Embrapa, 2017. 573p.

United States. Soil Survey Staff. Keys to soil taxonomy. 12 ed. Lincoln: USDA NRCS. 2014. Available on: <http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/>. Accessed on: Feb. 2023.

Zimmer, M.; Young, B. G.; Johnson, W. G. Herbicide programs utilizing halauxifen-methyl for glyphosate-resistant horseweed (*Conyza canadensis*) control in soybean. Weed Technology, v.32, p.659-664, 2018. https://doi.org/10.1017/wet.2018.60