

Selectivity and efficacy of pre-emergence herbicides applied with or without glufosinate in soybean

Seletividade e eficácia de herbicidas pré-emergentes aplicados com ou sem glufosinato em soja

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ABSTRACT - The use of pre-emergence herbicides in soybean has increased in recent years, mainly to control weed species that are tolerant or resistant to glyphosate. This study aimed to evaluate the phytotoxicity and weed control provided by pre-emergence herbicides applied alone or in combination with glufosinate-ammonium. Field experiments were conducted using a randomized block design with four replications. Treatments included weed-free and weedy controls, the pre-emergence herbicides pyrazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, sulfentrazone+imazethapyr, and S-metolachlor+fomesafen; and the same herbicides combined with glufosinate-ammonium. Herbicide phytotoxicity and control of *Euphorbia heterophylla*, *Raphanus raphanistrum*, and *Urochloa plantaginea* were assessed from 7 to 42 days after treatment (DAT). At 21 DAT, soybean physiological variables were measured, and at harvest, yield components were determined. All herbicide treatments were selective for the soybean cultivar Brasmax Vênus CE, as the initial phytotoxicity symptoms disappeared during crop development and did not reduce grain yield. Pyrazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, sulfentrazone+imazethapyr, and S-metolachlor+fomesafen, applied alone or in combination with post-emergence glufosinate-ammonium, improved weed control. Although diuron+sulfentrazone and S-metolachlor+fomesafen combined with glufosinate-ammonium negatively affected some soybean physiological traits, these effects did not compromise grain yield. Pyrazosulfuron-ethyl+flumioxazin, imazethapyr+flumioxazin, sulfentrazone+imazethapyr, pyrazosulfuron-ethyl+flumioxazin+glufosinate-ammonium, diuron+sulfentrazone+glufosinate-ammonium, sulfentrazone+imazethapyr+glufosinate-ammonium, and S-metolachlor+fomesafen+glufosinate-ammonium resulted in the best soybean yield components, with grain yields exceeding that of the weed-free control. The absence of weed control resulted in grain yield losses greater than 90%.

Keywords: *Euphorbia heterophylla*. *Glycine max*. *Raphanus raphanistrum*. *Urochloa plantaginea*. Tank herbicide mixtures.

RESUMO - O uso de herbicidas pré-emergentes em soja tem aumentado nos últimos anos, principalmente para o controle de espécies de plantas daninhas tolerantes ou resistentes ao glyphosate. Este estudo objetivou avaliar a fitotoxicidade e o controle de plantas daninhas por herbicidas pré-emergentes, aplicados isoladamente ou em associação com amônio-glufosinato. Foram conduzidos experimentos a campo em delineamento de blocos casualizados, com quatro repetições. Os tratamentos incluíram as testemunhas capinada e infestada; os herbicidas pré-emergentes pirazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, sulfentrazone+imazethapyr e S-metolachlor+fomesafen; e os mesmos herbicidas associados ao amônio-glufosinato. A fitotoxicidade dos herbicidas e o controle de *Euphorbia heterophylla*, *Raphanus raphanistrum* e *Urochloa plantaginea* foram avaliados dos 7 aos 42 dias após a aplicação dos tratamentos (DAT). Aos 21 DAT, foram aferidas as variáveis fisiológicas da soja e na colheita avaliou-se os componentes do rendimento de grãos. Todos os tratamentos herbicidas foram seletivos à cultivar de soja Brasmax Vênus CE, uma vez que os sintomas iniciais de fitotoxicidade desapareceram com o desenvolvimento da cultura e não reduziram a produtividade. Pirazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, sulfentrazone+imazethapyr e S-metolachlor+fomesafen, aplicados isoladamente ou em associação com amônio-glufosinato em pós-emergência, melhoraram o controle das plantas daninhas. Embora diuron+sulfentrazone e S-metolachlor+fomesafen associados ao amônio-glufosinato tenham afetado negativamente algumas características fisiológicas da soja, esses efeitos não comprometeram a produtividade. Pirazosulfuron-ethyl+flumioxazin, imazethapyr+flumioxazin, sulfentrazone+imazethapyr, pirazosulfuron-ethyl+flumioxazin+amônio-glufosinato, diuron+sulfentrazone+amônio-glufosinato, sulfentrazone+imazethapyr+amônio-glufosinato e S-metolachlor+fomesafen+amônio-glufosinato resultaram nos melhores componentes do rendimento de grãos, com produtividade superior à testemunha capinada. A ausência de controle de plantas daninhas resultou em perdas de produtividade de grãos superiores a 90%.

Palavras-chave: *Euphorbia heterophylla*. *Glycine max*. *Raphanus raphanistrum*. *Urochloa plantaginea*. Misturas de herbicidas em tanque.

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INTRODUCTION

Brazil is one of the world's largest soybean producers, with a cultivated area of 45.77 million hectares in the 2024/25 growing season and an average yield of 3.2 t ha⁻¹, which remains below the crop's yield potential under high-input production systems (CONAB, 2026). Among the factors limiting soybean productivity, weed interference is one of the most important, causing significant reductions in grain yield and production efficiency (KUMAR et al., 2024).

Weeds compete with soybean for water, light, nutrients, and space, in addition to serving as hosts for pests and diseases and releasing allelopathic compounds that may impair crop growth and development (GALON et al., 2022a). The intensity of weed interference depends on weed species, infestation level, crop management practices, cultivar, and environmental conditions (KUMAR et al., 2024). Soybean is particularly sensitive to weed competition

between 14 and 42 days after emergence, during which inadequate weed management may result in substantial yield losses (GALON et al., 2022a; KUMAR et al., 2024).

Chemical control remains the main strategy for weed management because of its effectiveness and operational practicality (ARSENIJEVIC et al., 2025). For many years, glyphosate-resistant Roundup Ready® (RR) soybean cultivars enabled efficient weed control. However, the repeated use of glyphosate without adequate herbicide rotation favored the evolution of resistant weed populations, reducing the long-term sustainability of this technology (ADEGAS et al., 2022). To broaden weed management options, new herbicide-resistant soybean technologies have been introduced, including Enlist™, which is tolerant to 2,4-D choline, glyphosate, and glufosinate-ammonium, and LibertyLink®, which is tolerant to glufosinate-ammonium. These technologies allow greater flexibility and diversification of post-emergence weed management programs (ALBRECHT et al., 2018; FOLES et al., 2023). Nevertheless, reports of weed populations with reduced susceptibility or resistance to glufosinate and other herbicides highlight the need to preserve the effectiveness of these technologies through integrated weed management strategies (GAZOLA et al., 2021; FOLES et al., 2023).

In this context, the use of pre-emergence herbicides has increased considerably because residual herbicides provide early-season weed control, reduce weed emergence, decrease selection pressure on post-emergence herbicides, and contribute to delaying the evolution of herbicide-resistant weed populations (SANTIN et al., 2019; DALAZEN et al., 2020). Consequently, combining pre-emergence herbicides with effective post-emergence programs has become an important strategy for sustainable weed management in soybean.

Despite their agronomic benefits, pre-emergence herbicides may cause crop injury depending on the active ingredient, environmental conditions, and soybean cultivar. Such injury may affect physiological processes, including photosynthesis, and, under unfavorable conditions, compromise crop development and grain yield (GAZOLA et al., 2021). Therefore, evaluating the selectivity of herbicide programs combining pre- and post-emergence applications is

essential to ensure effective weed control without impairing crop performance.

We hypothesized that combining pre-emergence herbicides with post-emergence glufosinate-ammonium would improve weed control without compromising soybean selectivity, physiological performance, or grain yield. Therefore, this study evaluated the selectivity and efficacy of pre-emergence herbicides applied alone or in combination with post-emergence glufosinate-ammonium in the soybean cultivar Brasmex Vênus CE, focusing on weed control, crop tolerance, physiological responses, and grain yield.

MATERIAL AND METHODS

Study area

Two field experiments were conducted in the experimental area of the Federal University of Fronteira Sul (UFFS), Erechim Campus, Rio Grande do Sul, Brazil (27°43'31" S, 52°17'40" W, 650 m altitude), during the 2022/23 and 2023/24 growing seasons. In both seasons, the experiments were conducted to evaluate the phytotoxicity and efficacy of pre-emergence herbicides in Enlist® soybean, applied alone or in combination with post-emergence glufosinate-ammonium. The experiments were conducted over two consecutive growing seasons to assess the consistency of treatment performance under different environmental conditions.

The soil at the experimental site is classified as a Typic Hapludox (Red Latosol). Soil acidity correction and fertilization were performed according to soil physicochemical analysis and technical recommendations for soybean. The soil chemical and physical properties were as follows: pH in water = 5.6; organic matter (OM) = 3.2%; P = 9.7 mg dm⁻³; K = 134.4 mg dm⁻³; Al³⁺ = 0.0 cmolc dm⁻³; Ca²⁺ = 6.7 cmolc dm⁻³; Mg²⁺ = 3.1 cmolc dm⁻³; effective cation exchange capacity (CEC) = 10.1 cmolc dm⁻³; CEC at pH 7 = 14.6 cmolc dm⁻³; H+Al = 4.5 cmolc dm⁻³; base saturation = 69%; clay = 65%; silt = 23%; sand = 12%. Precipitation (mm) and mean air temperature (°C) during the experimental periods are shown in Figure 1.

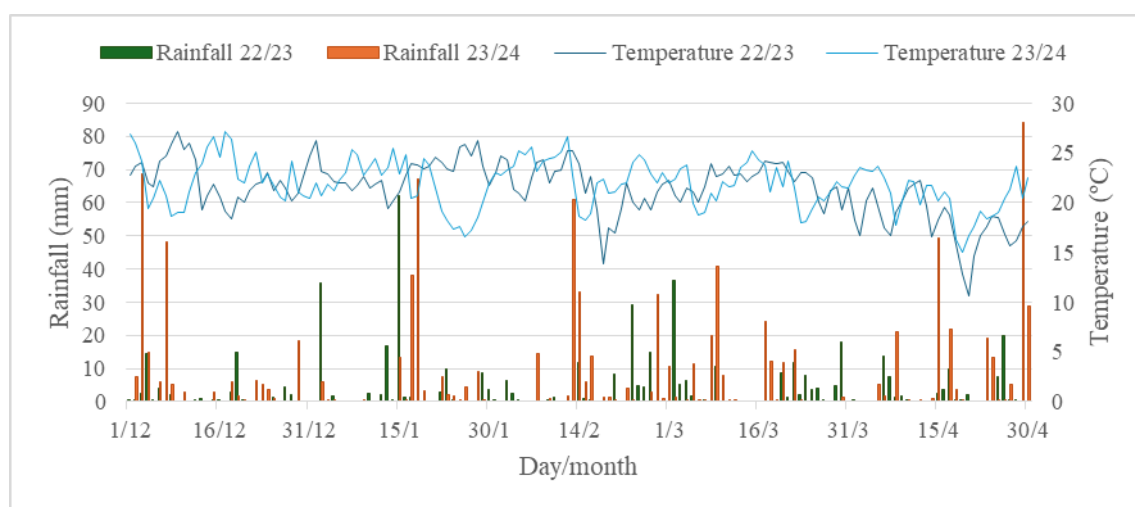


Figure 1. Precipitation (mm) and mean air temperature (°C) during the experimental periods from December 2022 to April 2023 and from December 2023 to April 2024.

In both growing seasons, soil cover before soybean sowing consisted of a mixture of black oat (*Avena strigosa*), common vetch (*Vicia sativa*), and radish (*Raphanus sativus*), producing 5.5 and 6.0 t ha⁻¹ of dry biomass in 2022/23 and 2023/24, respectively. The cover crops were desiccated 15 days before soybean sowing with glyphosate+saflufenacil (1440+49 g ha⁻¹) plus mineral oil (0.5% v/v).

Experimental design

The experiments were arranged in a randomized complete block design with four replications, totaling 13 treatments. Each experimental plot measured 3 × 5 m (15 m²) and consisted of six soybean rows spaced 0.5 m apart. The useful plot area (6 m²) consisted of the four central rows, excluding one row on each side and 1 m from each end of the plot.

Soybean sowing and fertilization

Soybean was sown on December 5, 2022, and December 1, 2023, using a seed-and-fertilizer drill. In both growing seasons, the cultivar Brasmax Vênus CE (Enlist™ technology) was used. The sowing density was 15.7 seeds m⁻², corresponding to approximately 314,000

seeds ha⁻¹. Basal fertilization consisted of 380 kg ha⁻¹ of the 05-20-20 (N-P-K) fertilizer in 2022/23 and 300 kg ha⁻¹ of 05-30-15 in 2023/24.

Treatments and weed species evaluated

The treatments are shown in Table 1, including the active ingredient (a.i.) rates and application timings. Herbicides were applied using a precision CO₂-pressurized backpack sprayer, equipped with four DG 110.02 flat-fan nozzles, calibrated to deliver a spray volume of 150 L ha⁻¹ at 210 kPa and a walking speed of 3.6 km h⁻¹.

Pre-emergence herbicides were applied immediately after sowing (plant-and-spray), whereas post-emergence glufosinate-ammonium was applied when soybean plants reached the V3–V4 growth stages. At the time of the post-emergence application, weed densities were 16, 17, and 63 plants m⁻² for *Euphorbia heterophylla* (wild poinsettia), *Raphanus raphanistrum* (wild radish), and *Urochloa plantaginea* (alexandergrass), respectively. At application, *E. heterophylla* and *R. raphanistrum* were at the 3–5- and 3–4-leaf stages, respectively, whereas *U. plantaginea* had 1–3 tillers. Hand weeding was performed as needed to maintain the weed-free control throughout the experimental period.

Table 1. Herbicide treatments, active ingredients (a.i.) rates, and application timings during the 2022/23 and 2023/24 soybean growing seasons.

Treatment ¹	Rate (g a.i. ha ⁻¹)	Application timing
Weed-free control	---	---
Weedy control	---	---
[Pyrazosulfuron-ethyl+flumioxazin]	120+80	Pre
[Diuron+sulfentrazone]	490+245	Pre
[Imazethapyr+flumioxazin]	127+60	Pre
[Sulfentrazone+imazethapyr]	360+96	Pre
[S-metolachlor+fomesafen]	1036+240	Pre
Glufosinate-ammonium	600	Post
[Pyrazosulfuron-ethyl+flumioxazin]+glufosinate-ammonium	120+80+600	Pre/Post
[Diuron+sulfentrazone]+glufosinate-ammonium	490+245+600	Pre/Post
[Imazethapyr+flumioxazin]+glufosinate-ammonium	127+60+600	Pre/Post
[Sulfentrazone+imazethapyr]+glufosinate-ammonium	360+96+600	Pre/Post
[S-metolachlor+fomesafen]+glufosinate-ammonium	1036+240+600	Pre/Post

¹Herbicides listed in square brackets [] were applied at soybean pre-emergence. Pre = pre-emergence application; Post = post-emergence application.

Variables evaluated

Soybean phytotoxicity and weed control were visually assessed at 7, 14, 21, 28, 35, and 42 days after treatment (DAT). Ratings were assigned using a 0–100% scale, where 0% represented no visible crop injury or no weed control and 100% represented complete crop death or complete weed control, respectively.

At 21 DAT following glufosinate-ammonium application, soybean gas exchange was evaluated by measuring internal CO₂ concentration (C_i, μmol mol⁻¹), stomatal conductance (g_s, mol m⁻² s⁻¹), net photosynthetic rate (A, μmol m⁻² s⁻¹), and transpiration rate (E, mol H₂O m⁻² s⁻¹).

Water use efficiency (WUE, mol CO₂ mol H₂O⁻¹) and instantaneous carboxylation efficiency (CE, mol CO₂ m⁻² s⁻¹) were calculated as A/E and A/C_i, respectively. Measurements were performed on the last fully expanded trifoliate leaf of five plants per experimental plot using a portable infrared gas analyzer (IRGA; ADC LCA PRO, Analytical Development Co. Ltd., Hoddesdon, UK). Measurements were taken under natural light between 7:00 and 11:00 h on clear days.

Before harvest, 10 plants per plot were randomly collected from the useful plot area, placed in bags, and transported to the Laboratory of Sustainable Management of Agricultural Systems (MASSA/UFFS) for determination of the number of pods per plant and grains per plant.

After manual harvesting and threshing of the 6 m² useful plot area, thousand-grain weight (g) and grain yield (kg ha⁻¹) were determined. Thousand-grain weight was estimated from eight subsamples of 100 grains each, which were weighed on an analytical balance. Grain yield was adjusted to a moisture content of 13% and expressed as kg ha⁻¹.

Statistical analysis

The experiments were conducted over two consecutive growing seasons (2022/23 and 2023/24) using the same experimental design, treatments, and procedures. Data were tested for normality using the Shapiro–Wilk test and for homogeneity of variances using Hartley’s test. After verification of the assumptions for analysis of variance, data were subjected to combined analysis of variance across growing seasons. When significant effects were detected by the F-test, treatment means were grouped using the Scott–Knott test at $p \leq 0.05$. Statistical analyses were performed using Sisvar software, version 5.6.

RESULTS AND DISCUSSION

Herbicide selectivity in soybean

The results indicate that glufosinate-ammonium

applied alone or in combination with pyrazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, sulfentrazone+imazethapyr, and S-metolachlor+fomesafen caused the highest levels of soybean phytotoxicity from 7 to 35 DAT. However, phytotoxicity remained below 13% up to 14 DAT, decreased to less than 5% by 35 DAT, and reached 0% at 42 DAT (Table 2). Therefore, although these treatments caused greater phytotoxicity than the other herbicide treatments, injury levels were still considered low. According to Carvalho et al. (2022), herbicide phytotoxicity ranging from 10 to 20% of visible leaf injury in soybean is considered low and generally does not affect grain yield. Soybean cultivars may differ in their tolerance to herbicides, depending on the genetic characteristics of the tested materials, soil chemical and physical properties, environmental conditions, and the products and rates used (SANTIN et al., 2019; ARSENIJEVIC et al., 2025).

According to Arsenijevic et al. (2025), glufosinate-ammonium applied either alone or in combination with other herbicides may cause phytotoxicity in soybean, particularly under high temperatures and intense solar radiation, which can enhance the herbicide effects on the crop. The same authors reported that, although soybean exhibited up to 20% phytotoxicity, plants recovered without reductions in grain yield, which is consistent with the findings of the present study.

Table 2. Phytotoxicity (%) of the soybean cultivar Brasmax Vênus CE, as affected by herbicide treatments during the 2022/23 and 2023/24 growing seasons.

Treatment ¹	Phytotoxicity (%)					
	7 DAT ²	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT
Weed-free control	0.00 d ³	0.00 d	0.00 c	0.00 c	0.00 b	0.00 ^{ns}
Weedy control	0.00 d	0.00 d	0.00 c	0.00 c	0.00 b	0.00
[Pyrazosulfuron-ethyl+flumioxazin]	10.67 b	6.25 c	2.50 b	0.00 c	0.00 b	0.00
[Diuron+sulfentrazone]	11.00 b	7.00 c	2.50 b	2.50 b	1.88 a	0.00
[Imazethapyr+flumioxazin]	10.17 b	7.00 c	2.50 b	2.50 b	0.62 b	0.00
[Sulfentrazone+imazethapyr]	11.83 a	7.50 c	4.50 b	2.50 b	1.25 b	0.00
[S-metolachlor+fomesafen]	7.67 c	5.75 c	2.50 b	0.00 c	0.00 b	0.00
Glufosinate-ammonium	10.77 b	9.50 b	8.62 a	6.38 a	4.38 a	0.00
[Pyrazosulfuron+flumioxazin]+glufosinate	11.50 a	10.00 b	7.25 a	5.00 a	3.12 a	0.00
[Diuron+sulfentrazone]+glufosinate	12.00 a	12.50 a	10.00 a	5.75 a	3.50 a	0.00
[Imazethapyr+flumioxazin]+glufosinate	11.00 b	11.25 a	7.00 a	2.50 b	0.00 b	0.00
[Sulfentrazone+imazethapyr]+glufosinate	12.50 a	11.25 a	7.50 a	5.75 a	2.50 a	0.00
[S-metolachlor+fomesafen]+glufosinate	11.00 b	10.00 b	7.50 a	5.00 a	3.50 a	0.00
CV (%)	14.60	26.49	50.75	71.69	138.12	0.00
Total mean	9.24	7.54	4.80	2.91	1.60	0.00
P _{treatments}	0.000	0.000	0.000	0.000	0.000	0.000
P _{years}	0.060	0.070	0.065	0.064	0.080	0.000

¹Herbicides listed in square brackets [] were applied at soybean pre-emergence. ²DAT, days after treatment application. ³Means followed by the same lowercase letter within a column do not differ according to the Scott–Knott test ($p < 0.05$).

S-metolachlor+fomesafen caused the lowest phytotoxicity symptoms from 7 to 35 DAT, with values similar to those of the weed-free and weedy controls from 28 DAT onward, when no injury was observed (Table 2). Cardoso et al. (2024) reported that S-metolachlor caused slight phytotoxicity early in the soybean cycle, with no symptoms observed at 34 DAT, partially corroborating the present results. Soil pH, texture, organic matter content,

herbicide rate, and herbicide physicochemical properties may affect herbicide sorption in the soil and consequently influence the extent of crop phytotoxicity (FREITAS et al., 2014).

The other treatments (pyrazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, and sulfentrazone+imazethapyr) caused greater phytotoxicity than S-metolachlor+fomesafen

only at 7 DAT, although injury remained below 12%. Symptoms decreased over time and reached 0% by 42 DAT (Table 2), indicating that soybean plants recovered from herbicide injury. Dalazen et al. (2020) reported that sulfentrazone at the recommended rate caused mild injury symptoms in soybean, not exceeding 10% under normal rainfall conditions in clay soils. Galon et al. (2022b) observed phytotoxicity below 13% following the application of diuron+sulfentrazone and imazethapyr+flumioxazin in soybean. Cardoso et al. (2024) also reported minor injury symptoms with pyrazosulfuron-ethyl+flumioxazin and diuron+sulfentrazone, which disappeared by 34 DAT. Thus, the present results are consistent with previous findings for these herbicides.

Compared with pre-emergence herbicides (pyrazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, sulfentrazone+imazethapyr, and S-metolachlor+fomesafen) applied alone, their combination with glufosinate-ammonium increased phytotoxicity by an average of 41.58% across evaluations from 7 to 42 DAT (Table 2). This increase was likely due to the additional phytotoxicity caused by glufosinate-ammonium, which resulted in an average injury of 7.93% when applied alone, compared with 4.42% and 7.55% for pre-emergence herbicides applied alone or combined with glufosinate-ammonium, respectively. Oliveira et al. (2024) reported that glufosinate-ammonium caused slight phytotoxicity in soybean but did not significantly affect grain yield. Such injuries are considered mild and have minimal effects on soybean grain yield (CARVALHO et al., 2022).

By 42 DAT, no herbicide treatment caused visible phytotoxicity in soybean, and all treatments were similar to the controls (Table 2). Over time, crop injury decreased from

an average 9.24% at 7 DAT to 0% at 42 DAT. This reduction may be related to herbicide degradation and movement through the soil profile, as well as rainfall during soybean growth, which may have reduced herbicide activity (Figure 1). Dalazen et al. (2020) similarly reported lower phytotoxicity in years with higher precipitation due to reduced herbicide availability in the soil, consistent with the present findings.

Weed control efficacy

Imazethapyr+flumioxazin, glufosinate-ammonium, and combinations of pre- and post-emergence herbicides, including pyrazosulfuron-ethyl+flumioxazin+glufosinate-ammonium, diuron+sulfentrazone+glufosinate-ammonium, imazethapyr+flumioxazin+glufosinate-ammonium, sulfentrazone+imazethapyr+glufosinate-ammonium, and S-metolachlor+fomesafen+glufosinate-ammonium, provided the highest control of wild poinsettia (*Euphorbia heterophylla*) from 7 to 42 DAT (Table 3). Glufosinate-ammonium was effective both alone and in combination with other herbicides. Pre-emergence herbicides such as flumioxazin and sulfentrazone have shown high efficacy in controlling wild poinsettia (GAZOLA et al., 2021). Imazethapyr may be ineffective against resistant biotypes (PEREIRA et al., 2022), whereas S-metolachlor can reduce the plant's lipophilic layer, enhancing the efficacy of post-emergence applications (FILES et al., 2025). Considering that the wild poinsettia biotype evaluated in this study was not resistant to glufosinate-ammonium, weed control exceeded 95% when this herbicide was applied either alone or in combination with other herbicides, particularly when weeds were at early growth stage. This level of control is considered excellent.

Table 3. Control (%) of wild poinsettia (*Euphorbia heterophylla* L.) in the soybean cultivar Brasmax Vênus CE, as affected by herbicide treatments during the 2022/23 and 2023/24 growing seasons.

Treatment ¹	Control of wild poinsettia (%)					
	7 DAT ²	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT
Weed-free control	100.0 a ³	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a
Weedy control	0.00 e	0.00 e	0.00 e	0.00 d	0.00 d	0.00 e
[Pyrazosulfuron-ethyl+flumioxazin]	90.00 c	92.50 b	92.08 c	85.00 b	81.25 b	77.50 b
[Diuron+sulfentrazone]	60.00 d	48.75 d	0.00 e	0.00 d	0.00 d	0.00 e
[Imazethapyr+flumioxazin]	97.00 b	100.00 a	95.00 b	95.00 a	96.25 a	96.25 a
[Sulfentrazone+imazethapyr]	90.00 c	90.00 c	88.33 d	82.50 b	81.25 b	65.00 c
[S-metolachlor+fomesafen]	89.08 c	92.50 b	91.33 c	45.00 c	38.75 c	45.00 d
Glufosinate-ammonium	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a
[Pyrazosulfuron+flumioxazin]+glufosinate	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a
[Diuron+sulfentrazone]+glufosinate	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a
[Imazethapyr+flumioxazin]+glufosinate	100.00 a	100.00 a	100.00 a	100.00 a	98.75 a	98.75 a
[Sulfentrazone+imazethapyr]+glufosinate	100.00 a	100.00 a	100.00 a	100.00 a	98.75 a	98.75 a
[S-metolachlor+fomesafen]+glufosinate	100.00 a	100.00 a	100.00 a	95.00 a	95.00 a	95.00 a
CV (%)	1.85	1.97	2.23	17.72	5.90	8.10
Total mean	86.62	86.44	82.06	77.12	76.15	75.10
P _{treatments}	0.000	0.000	0.000	0.000	0.000	0.000
P _{years}	0.997	0.997	0.997	0.997	0.997	0.870

¹Herbicides listed in square brackets [] were applied at soybean pre-emergence. ²DAT, days after treatment application. ³Means followed by the same lowercase letter within a column do not differ according to the Scott-Knott test (p < 0.05).

The post-emergence application of glufosinate-ammonium, either alone or following pre-emergence herbicides, improved control compared with pre-emergence herbicides applied alone (Table 3). Glufosinate-ammonium enhanced the control of wild poinsettia plants that emerged after being partially affected by pre-emergence herbicides. Pre-emergence herbicides are recommended in several crops for managing resistant or tolerant weeds because they allow crop establishment under reduced weed interference and decrease reliance on post-emergence applications. Camargo et al. (2019) reported effective wild poinsettia control with glufosinate-ammonium, supporting the findings of the present study.

Imazethapyr+flumioxazin was the only pre-emergence treatment that provided more than 95% wild poinsettia control throughout the evaluation period without post-emergence glufosinate-ammonium (Table 3), suggesting that the evaluated biotype was susceptible to ALS- and/or PROTOX-inhibiting herbicides. Silva et al. (2020) similarly reported 95% wild poinsettia control with flumioxazin, which is consistent with the present findings.

Diuron+sulfentrazone provided the lowest wild poinsettia control among the tested herbicides, with control equivalent to the weedy treatment from 21 DAT onward (Table 3). During both experimental years, 200–340 mm of rainfall occurred within the first 60 days after pre-emergence herbicide application (Figure 1), which may have promoted herbicide leaching. The high clay content (~65%) of the soil may also have affected herbicide availability through sorption to soil colloids. Consequently, weed control efficacy declined

markedly, from 60% at the first assessment to 0% at the third assessment. This response may be associated with the emergence of new weed cohorts, recovery of initially affected plants, or reduced residual herbicide activity due to environmental conditions and/or soil characteristics. Matos et al. (2020) reported that 80–120 mm of rainfall could leach more than 60% of sulfentrazone applied with diuron.

Pyrazosulfuron-ethyl+flumioxazin, sulfentrazone+imazethapyr, and S-metolachlor+fomesafen provided intermediate control, with efficacy above 88% until 21 DAT (Table 3). In Brazil, herbicides must achieve at least 80% control to be considered effective (VELINI et al., 1995). Pyrazosulfuron-ethyl+flumioxazin and sulfentrazone+imazethapyr met this threshold until 35 DAT, whereas S-metolachlor+fomesafen did so until 21 DAT. Soil properties such as pH, clay content, cation exchange capacity, and organic matter may influence herbicide availability by increasing adsorption to soil colloids and reducing the amount of active ingredient in the soil solution (COSTA et al., 2023).

The application of imazethapyr+flumioxazin+glufosinate-ammonium, sulfentrazone+imazethapyr+glufosinate-ammonium, and S-metolachlor+fomesafen+glufosinate-ammonium provided the highest wild radish control, with values similar to those of the weed-free plots from 7 to 42 DAT (Table 4). Other treatments, including pyrazosulfuron-ethyl+flumioxazin, imazethapyr+flumioxazin, sulfentrazone+imazethapyr, pyrazosulfuron+flumioxazin+glufosinate, and diuron+sulfentrazone+glufosinate-ammonium, provided intermediate levels of control (Table 4).

Table 4. Control (%) of wild radish (*Raphanus raphanistrum* L.) in the soybean cultivar Brasmax Vênus CE, as affected by herbicide treatments during the 2022/23 and 2023/24 growing seasons.

Treatment ¹	Control of wild radish (%)					
	7 DAT ²	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT
Weed-free control	100.00a ³	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a
Weedy control	0.00 d	0.00 e	0.00 e	0.00 d	0.00 e	0.00 d
[Pyrazosulfuron-ethyl+flumioxazin]	94.17 a	87.50 b	83.75 b	83.75 b	94.50 a	94.50 a
[Diuron+sulfentrazone]	28.12 c	20.00 d	10.00 d	10.00 d	0.00 e	0.00 d
[Imazethapyr+flumioxazin]	98.25 a	94.67 a	91.67 b	91.88 a	91.25 b	100.00 a
[Sulfentrazone+imazethapyr]	97.42 a	94.08 a	86.71 b	90.00 a	86.25 b	86.25 b
[S-metolachlor+fomesafen]	82.50 b	70.00 c	68.33 c	65.00 c	66.25 c	57.50 c
Glufosinate-ammonium	86.88 b	88.88 b	88.75 b	79.38 b	55.00 d	55.00 c
[Pyrazosulfuron+flumioxazin]+glufosinate	93.79 a	95.12 a	90.00 b	83.54 b	85.00 b	97.50 a
[Diuron+sulfentrazone]+glufosinate	77.50 b	94.00 a	89.75 b	81.25 b	85.00 b	96.25 a
[Imazethapyr+flumioxazin]+glufosinate	98.25 a	99.75 a	98.75 a	98.75 a	97.50 a	98.75 a
[Sulfentrazone+imazethapyr]+glufosinate	97.50 a	100.00 a	97.00 a	97.50 a	97.50 a	100.00 a
[S-metolachlor+fomesafen]+glufosinate	91.25 a	95.50 a	93.54 a	90.83 a	90.00 b	100.00 a
CV (%)	14.81	9.95	10.78	13.98	12.57	6.33
Total mean	80.43	79.96	76.79	74.76	72.94	75.83
P _{treatments}	0.000	0.000	0.000	0.000	0.000	0.000
P _{years}	0.070	0.065	0.078	0.079	0.064	0.997

¹Herbicides listed in square brackets [] were applied at soybean pre-emergence. ²DAT, days after treatment application. ³Means followed by the same lowercase letter within a column do not differ according to the Scott-Knott test ($p < 0.05$).

Flumioxazin primarily controls broadleaf weeds by inhibiting PROTOX, leading to membrane damage under light exposure (NOVAIS et al., 2022). When combined with other pre-emergence herbicides and followed by glufosinate-ammonium, the synergistic effects of these herbicides may enhance weed control. Oliveira et al. (2017) reported more than 90% control of dicotyledonous weeds using combinations such as S-metolachlor+imazethapyr, fomesafen+imazethapyr, flumioxazin+imazethapyr, and flumioxazin+metribuzin at 40 and 60 DAT.

In general, pre-emergence herbicides followed by glufosinate-ammonium provided greater wild radish control throughout the evaluation period (7–42 DAT) than pre-emergence herbicides applied alone (Table 4). This response can be attributed to the complementary application timings and distinct modes of action of the herbicides. Glufosinate-ammonium is a contact herbicide applied post-emergence that controls wild radish plants already emerged at the time of application, whereas pre-emergence herbicides suppress the

emergence of new weed cohorts. As a result, weed infestation remains lower for a longer period, improving control throughout the evaluation period. Similar results were reported by Camargo et al. (2019), who observed improved wild poinsettia control using herbicide combinations.

Glufosinate-ammonium, pyrazosulfuron-ethyl+flumioxazin+glufosinate-ammonium, diuron+sulfentrazone+glufosinate-ammonium, sulfentrazone+imazethapyr+glufosinate-ammonium, and S-metolachlor+fomesafen+glufosinate-ammonium were among the treatments that provided the highest alexandergrass control from 7 to 42 DAT (Table 5). The post-emergence application contributed to more effective weed control because pre-emergence herbicides suppressed alexandergrass emergence, whereas glufosinate-ammonium controlled plants that had already emerged. Similarly, Santin et al. (2019) reported effective alexandergrass control with pre-emergence diuron+sulfentrazone followed by post-emergence glufosinate-ammonium.

Table 5. Control (%) of alexandergrass (*Urochloa plantaginea* L.) in the soybean cultivar Brasmax Vênus CE, as affected by herbicide treatments during the 2022/23 and 2023/24 growing seasons.

Treatments ¹	Control of alexandergrass (%)					
	7 DAT ²	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT
Weed-free control	100.00 a ³	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a
Weedy control	0.00 e	0.00 e	0.00 e	0.00 h	0.00 f	0.00 f
[Pyrazosulfuron-ethyl+flumioxazin]	87.83 c	81.12 c	75.42 c	70.00 f	47.50 e	50.00 e
[Diuron+sulfentrazone]	89.54 c	80.00 c	82.36 b	73.33 e	65.62 d	0.00 f
[Imazethapyr+flumioxazin]	89.29 c	82.50 c	80.83 b	70.00 f	60.62 d	80.00 c
[Sulfentrazone+imazethapyr]	92.42 b	87.92 b	84.58 b	72.50 e	78.12 c	73.75 d
[S-metolachlor+fomesafen]	75.21 d	62.25 d	64.17 d	40.00 g	45.00 e	0.00 f
[Glufosinate-ammonium]	88.12 c	92.50 b	100.00 a	95.21 c	90.62 b	98.75 a
[Pyrazosulfuron+flumioxazin]+glufosinate	93.25 b	96.25 a	96.25 a	91.66 d	90.62 b	97.50 a
[Diuron+sulfentrazone]+glufosinate	93.25 b	99.50 a	98.38 a	97.50 b	95.00 b	96.25 a
[Imazethapyr+flumioxazin]+glufosinate	94.67 b	96.17 a	94.67 a	100.00 a	93.12 b	93.75 b
[Sulfentrazone+imazethapyr]+glufosinate	95.00 b	100.00 a	98.75 a	100.00 a	98.75 a	97.50 a
[S-metolachlor+fomesafen]+glufosinate	86.25 c	95.75 a	97.25 a	90.00 d	90.62 b	92.50 b
CV (%)	5.73	6.27	7.07	2.38	10.63	6.24
Total mean	83.45	82.61	82.51	76.94	73.51	67.69
P _{treatments}	0.000	0.000	0.000	0.000	0.000	0.000
P _{years}	0.065	0.077	0.068	0.087	0.297	0.997

¹Herbicides listed in square brackets [] were applied at soybean pre-emergence. ²DAT, days after treatment application. ³Means followed by the same lowercase letter within a column do not differ according to the Scott-Knott test ($p < 0.05$).

The application of pyrazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, and sulfentrazone+imazethapyr provided alexandergrass control ranging from 80% to 93% up to 14 DAT. Thereafter, weed control efficacy generally decreased (Table 5). These herbicides provided good initial alexandergrass control because of their residual activity; however, control declined as herbicide activity decreased over time. Several studies have reported the need for complementary post-emergence herbicide applications following pre-emergence treatments to improve control of the weed community (BRUNHARO; CHRISTOFFOLETI; NICOLAI, 2014; SANTIN et al., 2019).

Oliveira et al. (2017) observed more than 80% control of narrow-leaved weeds following applications of S-metolachlor+imazethapyr, fomesafen+imazethapyr, flumioxazin+imazethapyr, flumioxazin+metribuzin, S-metolachlor, and flumioxazin, partially corroborating the present results.

At 42 DAT, diuron+sulfentrazone and S-metolachlor+fomesafen provided alexandergrass control equivalent to the weedy control, representing the poorest performance among the tested herbicide treatments (Table 5). According to Inoue et al. (2014), diuron can be leached through the 0–10 cm soil layer in clay soils under high rainfall

conditions (80–100 mm). This is consistent with the conditions of the present study, in which approximately 200–340 mm of rainfall occurred within 60 DAT after pre-emergence herbicide application during the first and second growing seasons, respectively (Figure 1). This rainfall may have promoted herbicide leaching, while the high clay content of the experimental soil (65%) may also have increased herbicide adsorption to soil colloids, reducing availability in the soil solution for plant uptake.

Across the six evaluations, glufosinate-ammonium increased alexandergrass, wild poinsettia, and wild radish control by an average of 28.81%, 29.35%, and 19.00%, respectively, when applied following the pre-emergence herbicides pyrazosulfuron-ethyl+flumioxazin, diuron+sulfentrazone, imazethapyr+flumioxazin, sulfentrazone+imazethapyr, and S-metolachlor+fomesafen (Tables 3, 4, and 5). These results indicate that pre-emergence herbicides followed by post-emergence glufosinate-ammonium represent an effective strategy for improving weed control. According to Brunharo, Christoffoleti, and Nicolai (2014), integrating pre- and post-emergence herbicides can result in more effective weed control in both perennial and annual crops. This highlights the importance of post-emergence application, as treatments including glufosinate-ammonium generally provided high levels of control of wild poinsettia, wild radish,

and alexandergrass above 80% from 14 to 42 DAT (Tables 3, 4, and 5). Furthermore, given the increasing occurrence of glyphosate-resistant weeds, glufosinate-ammonium represents an alternative herbicide for the management of susceptible weed populations (BRUNHARO; CHRISTOFFOLETI; NICOLAI, 2014; ARSENIJEVIC et al., 2025).

Effect of herbicides on soybean physiological parameters

Regarding the physiological variables (C_i , g_s , A , E , CE , and WUE), treatments containing diuron+sulfentrazone and S-metolachlor+fomesafen, particularly when associated with glufosinate-ammonium, generally showed lower physiological performance (Table 6). The reduced photosynthetic activity observed with diuron+sulfentrazone can be explained by the mode of action of diuron, a photosystem II inhibitor that disrupts electron transport and consequently reduces carbon assimilation (TROPALDI et al., 2015). In addition, sulfentrazone inhibits protoporphyrinogen oxidase (PROTOX), causing oxidative damage that can impair chlorophyll synthesis and photosynthetic efficiency (TORRES et al., 2012). These mechanisms likely contributed to the lower photosynthetic rate and carboxylation efficiency observed in these treatments.

Table 6. Internal CO_2 concentration (C_i , $\mu\text{mol mol}^{-1}$), stomatal conductance (g_s , $\text{mol m}^{-2} \text{s}^{-1}$), net photosynthetic rate (A , $\mu\text{mol m}^{-2} \text{s}^{-1}$), transpiration rate (E , $\text{mol m}^{-2} \text{s}^{-1}$), carboxylation efficiency (CE , $\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$), and water use efficiency (WUE , $\text{mol CO}_2 \text{ mol H}_2\text{O}^{-1}$) of the soybean cultivar Brasmax Vênus CE, as affected by herbicide treatments during the 2022/23 and 2023/24 growing seasons.

Treatments ¹	Physiological variables					
	C_i	g_s	A	E	CE	WUE
Weed-free control	303.38 c ²	0.44 c	14.80 b	3.62 a	0.049 c	4.10 b
Weedy control	296.88 c	0.36 d	15.00 b	3.07 b	0.051 b	5.04 a
[Pyrazosulfuron-ethyl+flumioxazin]	300.50 c	0.49 b	15.66 a	3.39 a	0.052 b	4.63 b
[Diuron+sulfentrazone]	320.62 a	0.48 b	13.32 c	3.39 a	0.042 d	3.96 b
[Imazethapyr+flumioxazin]	301.38 c	0.39 d	14.36 b	3.28 a	0.048 c	4.41 b
[Sulfentrazone+imazethapyr]	297.88 c	0.42 c	15.10 b	3.57 a	0.051 b	4.24 b
[S-metolachlor+fomesafen]	308.75 b	0.55 a	16.18 a	3.42 a	0.052 b	4.97 a
Glufosinate-ammonium	290.75 d	0.46 c	16.85 a	2.98 b	0.058 a	5.74 a
[Pyrazosulfuron+flumioxazin]+glufosinate	303.12 c	0.52 b	15.53 a	3.04 b	0.051 b	5.20 a
[Diuron+sulfentrazone]+glufosinate	298.12 c	0.46 c	14.94 b	2.89 b	0.050 b	5.20 a
[Imazethapyr+flumioxazin]+glufosinate	303.62 c	0.56 a	15.51 a	3.48 a	0.051 b	4.46 b
[Sulfentrazone+imazethapyr]+glufosinate	299.00 c	0.47 c	15.74 a	3.15 b	0.053 b	5.04 a
[S-metolachlor+fomesafen]+glufosinate	291.50 d	0.44 c	13.86 c	3.16 b	0.047 c	4.35 b
CV (%)	2.93	13.73	8.76	8.91	9.20	12.31
Total mean	301.19	0.46	15.14	3.26	0.05	4.72
$P_{\text{treatments}}$	0.000	0.000	0.000	0.001	0.000	0.000
P_{years}	0.075	0.067	0.068	0.077	0.069	0.082

¹Herbicides listed in square brackets [] were applied at soybean pre-emergence. ²Means followed by the same letters within a column do not differ according to the Scott-Knott test at $p < 0.05$.

In contrast, soybean plants treated with glufosinate-ammonium alone showed a lower internal CO_2 concentration (C_i) associated with a higher photosynthetic rate (A), carboxylation efficiency (CE), and water-use efficiency

(WUE). The simultaneous reduction in C_i and increase in A suggests greater CO_2 consumption by the photosynthetic apparatus rather than biochemical limitation, indicating that CO_2 entering the leaf was rapidly assimilated during carbon

fixation (RONCHI et al., 2006). Consequently, the lower C_i may reflect greater photosynthetic demand for CO_2 , which is consistent with the higher CE values observed. Greater photosynthetic activity was also associated with higher water-use efficiency because more carbon was assimilated per unit of water lost through transpiration (RONCHI et al., 2006).

Conversely, the combination of S-metolachlor+fomesafen with glufosinate-ammonium reduced the photosynthetic rate despite the lower C_i , indicating that the decrease in internal CO_2 concentration in this treatment was not associated with enhanced carbon assimilation but rather with herbicide-induced physiological stress. Nevertheless, these physiological changes did not negatively affect soybean grain yield, supporting the selectivity of the herbicide program under the conditions of the present study.

Effect of herbicides on major soybean grain yield components

The results indicate that imazethapyr+flumioxazin, sulfentrazone+imazethapyr, pyrazosulfuron-ethyl+flumioxazin+glufosinate-ammonium, diuron+sulfentrazone+glufosinate-ammonium, sulfentrazone+imazethapyr+glufosinate-ammonium, and S-metolachlor+fomesafen+glufosinate-ammonium provided high performance for the evaluated grain yield components (NP, NGP, and GY) (Table 7). The phytotoxicity caused by pre-emergence herbicides and glufosinate-ammonium did not compromise grain yield, corroborating the observations of Santin et al. (2019). In addition to soybean recovery from herbicide injury, these

treatments provided high levels of control of wild poinsettia, wild radish, and alexandergrass. This response indicates reduced competition between these weed species and the crop, allowing greater expression of soybean yield components. Similar results were reported by Arsenijevic et al. (2025), who evaluated glufosinate-ammonium in combination with other herbicides applied either pre- or post-emergence. Those authors also reported that soybean plants recovered from herbicide injury over time and that herbicide combinations improved weed control, resulting in greater soybean grain yield. No significant differences were observed among treatments for thousand-grain weight (TGW), indicating that the herbicide treatments did not impair grain filling. Similarly, Alencar et al. (2022) found no significant effects of chlorimuron, cloransulam, fomesafen, and glyphosate on soybean thousand-grain weight.

The weedy control, S-metolachlor+fomesafen, and glufosinate-ammonium showed lower performance for NP, NGP, and grain yield (Table 7). Other treatments showed intermediate performance, reflecting differences in weed interference and herbicide efficacy. In the weedy control, weeds remained uncontrolled; S-metolachlor+fomesafen showed reduced efficacy after 28 DAT, and glufosinate-ammonium effectively controlled wild poinsettia and alexandergrass but provided lower control of wild radish at later evaluations. Moreover, without pre-emergence herbicides, soybean emerged under weed interference until the V3–V4 stages, which may have reduced crop yield potential (CARVALHO et al., 2022).

Table 7. Number of pods (NP), grains per plant (NGP), thousand-grain weight (TGW, g), and grain yield (GY, kg ha⁻¹) of the soybean cultivar Brasmax Vênus CE, as affected by herbicide treatments during the 2022/23 and 2023/24 growing seasons.

Treatments ¹	Grain yield components			
	NP	NGP	TGW	GY
Weed-free control	52.32 b ²	108.28 b	147.31 a	3206.98 a
Weedy control	46.82 c	104.90 b	154.63 a	262.15 c
[Pyrazosulfuron-ethyl+flumioxazin]	55.15 b	105.86 b	148.65 a	2077.24 b
[Diuron+sulfentrazone]	58.10 a	118.99 a	143.35 a	1677.88 b
[Imazethapyr+flumioxazin]	58.54 a	108.91 b	147.58 a	2914.43 a
[Sulfentrazone+imazethapyr]	52.30 b	109.51 b	144.46 a	2788.74 a
[S-metolachlor+fomesafen]	30.55 d	61.52 c	142.48 a	1671.59 b
Glufosinate-ammonium	48.39 c	108.15 b	141.61 a	2625.68 b
[Pyrazosulfuron+flumioxazin]+glufosinate	52.90 b	118.09 a	144.57 a	3161.28 a
[Diuron+sulfentrazone]+glufosinate	48.59 b	111.01 b	142.58 a	3062.25 a
[Imazethapyr+flumioxazin]+glufosinate	64.86 a	118.36 a	145.99 a	2915.06 a
[Sulfentrazone+imazethapyr]+glufosinate	63.95 a	125.32 a	145.86 a	3302.39 a
[S-metolachlor+fomesafen]+glufosinate	57.92 a	126.10 a	143.04 a	3432.26 a
CV (%)	15.39	12.81	4.84	18.52
Total mean	53.11	109.62	145.55	2545.99
P _{treatment}	0.000	0.000	0.037	0.000
P _{years}	0.065	0.069	0.071	0.080

¹Herbicides listed in square brackets [] were applied at soybean pre-emergence. ²Means followed by the same letter within a column do not differ according to the Scott-Knott test at $p < 0.05$.

The application of imazethapyr + flumioxazin, sulfentrazone + imazethapyr, pyrazosulfuron-ethyl + flumioxazin + glufosinate-ammonium, diuron + sulfentrazone + glufosinate-ammonium, imazethapyr + flumioxazin + glufosinate-ammonium, sulfentrazone + imazethapyr + glufosinate-ammonium, and S-metolachlor + fomesafen + glufosinate-ammonium resulted in the highest soybean grain yields, which did not differ from the weed-free control (Table 7). This response was likely associated with the selectivity of these herbicide programs to soybean combined with their high efficacy in controlling wild poinsettia, wild radish, and alexandergrass, thereby minimizing competition between the crop and weeds for environmental resources. According to Arsenijevic et al. (2025), when herbicides are selective to soybean and provide effective weed control under favorable environmental conditions, high grain yields can be achieved.

The lack of weed control (weedy) resulted in a grain yield loss of more than 90% compared with the average of the herbicide treatments and the weed-free control (Table 7), highlighting the importance of effective weed management through chemical or mechanical methods. Although mechanical control is labor-intensive and costly, herbicide selection should ensure both high weed-control efficacy and crop selectivity. As previously discussed, the marked yield reduction in the weedy control can be attributed to infestation by wild poinsettia, wild radish, and alexandergrass, which compete with soybean for essential resources such as water, light, nutrients, and space and may also release allelopathic compounds that interfere with crop growth and development. Similar findings have been reported in studies evaluating herbicide efficacy in soybean, in which effective weed management was associated with improved crop performance and grain yield (ALBRECHT et al., 2018; ARSENIJEVIC et al., 2025; CARDOSO et al., 2024; FILES et al., 2025).

The application of the pre-emergence herbicides pyrazosulfuron-ethyl + flumioxazin, diuron + sulfentrazone, imazethapyr + flumioxazin, sulfentrazone + imazethapyr, and S-metolachlor + fomesafen followed by post-emergence glufosinate-ammonium increased soybean grain yield by approximately 30%, corresponding to 949 kg ha⁻¹, compared with the respective pre-emergence treatments applied alone (Table 7). In contrast, glufosinate-ammonium applied alone, without a pre-emergence herbicide, resulted in a grain yield approximately 17% (549 kg ha⁻¹) lower than that of the weed-free control. These results demonstrate the importance of including pre-emergence herbicides in soybean weed management programs to complement post-emergence weed control with glufosinate-ammonium.

Several studies have reported that the use of a single herbicide may not provide adequate control of multiple weed species, whereas herbicide combinations or sequential programs can improve weed control through complementary modes of actions and application timings, resulting in greater crop productivity (BRUNHARO; CHRISTOFFOLETI; NICOLAI, 2014; ADEGAS et al., 2022). As previously discussed, in the absence of pre-emergence herbicides, soybean seedlings emerge under weed interference and compete with weeds until post-emergence herbicide application at the V3-V4 growth stages. This early competition may affect crop development and the subsequent establishment of yield components, particularly pod formation, which occurs approximately 35 to 60 days after emergence. Consequently, weed interference during early

soybean development may reduce the crop's yield potential (CARVALHO et al., 2022), as also observed in the present study.

Overall, the results demonstrate that the use of pre-emergence herbicides followed by post-emergence glufosinate-ammonium provides more effective weed control and represents an important strategy for managing herbicide-resistant or herbicide-tolerant weed species, particularly those resistant to glyphosate. Furthermore, this management strategy may contribute to greater economic returns by improving soybean grain yield.

CONCLUSIONS

All herbicide programs evaluated were selective to the soybean cultivar Brasmax Vénus CE. Initial phytotoxicity symptoms progressively decreased during crop development, and no visible injury was observed at 42 days after treatment (DAT), without compromising grain yield.

The integration of pre-emergence herbicides with post-emergence glufosinate-ammonium improved the control of *Euphorbia heterophylla*, *Raphanus raphanistrum*, and *Urochloa plantaginea*, representing an effective strategy for soybean weed management. Among the pre-emergence treatments evaluated, imazethapyr + flumioxazin provided consistently high control of wild poinsettia and wild radish under the conditions of this study.

Several pre-emergence herbicide programs, particularly when followed by post-emergence glufosinate-ammonium, maintained soybean grain yield at levels equivalent to those obtained in the weed-free control, whereas the absence of weed control resulted in grain yield losses greater than 90%.

The consistency of these responses across two growing seasons indicates that integrating pre-emergence herbicides with post-emergence glufosinate-ammonium is an effective weed management strategy that provides effective weed control while maintaining soybean selectivity and grain yield under the environmental conditions evaluated.

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