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Sensitivity of soybean cultivars to the herbicide metribuzin

Sensibilidade de cultivares de soja ao herbicida metribuzin

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Highlights

There is variability in the sensitivity of soybean cultivars to metribuzin.
Increasing the dose of metribuzin causes greater damage to the soybean crop.
M 5917 IPRO, M 6130 I2X, M 6301 I2X, and NS 5252 I2X were more tolerant.

Abstract

Weed resistance to herbicides, especially glyphosate, has made their management difficult in soybean crops. One alternative is the use of pre-emergent herbicides. However, even when recommended for the crop, selectivity depends on several factors, including the soybean cultivar. In this sense, the objective of this work was to evaluate the sensitivity of different soybean cultivars to the herbicide metribuzin. The experiment was conducted in a greenhouse in a completely randomized design with four replications, in a 19 x 3 factorial arrangement. Factor A consisted of 19 soybean cultivars. Factor B consisted of three doses of metribuzin; zero, 480 g a.i. ha^{-1}, and 960 g a.i. ha^{-1}. The variables evaluated were: phytotoxicity, quantum efficiency of PSII (Fv/Fm), effective efficiency of PSII (YII), relative electron transport rate (rETR), plant height, and shoot dry mass (SDM). Data were subjected to analysis of variance (ANOVA) ($p < 0.05$) and means were compared using the Scott-Knott test ($p < 0.05$). A significant interaction was observed between the factors soybean cultivar and metribuzin dose. The herbicide metribuzin caused negative alterations in the physiological and growth characteristics of the plants, demonstrating the phytotoxicity of the herbicide in some soybean cultivars, especially at the highest dose evaluated. The cultivars M 5917, M 6130 I2X, M 6301 I2X, and NS 5252 I2X showed greater tolerance to metribuzin.
Key words: Selectivity. *Glycine max.* Integrated weed management. Resistance.

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Resumo

A resistência de plantas daninhas a herbicidas, especialmente ao glifosato, tem dificultado seu manejo em lavouras de soja. Uma alternativa é o uso de herbicidas pré-emergentes. No entanto, mesmo quando recomendados para a cultura, a seletividade depende de diversos fatores, incluindo a cultivar de soja. Nesse sentido, o objetivo deste trabalho foi avaliar a sensibilidade de diferentes cultivares de soja ao herbicida metribuzin. O experimento foi conduzido em casa de vegetação, em delineamento inteiramente casualizado com quatro repetições, em esquema fatorial 19 x 3. O fator A consistiu em 19 cultivares de soja. O fator B consistiu em três doses de metribuzin: zero, 480 g i.a. ha^{-1} e 960 g i.a. ha^{-1}. As variáveis avaliadas foram: fitotoxicidade, eficiência quântica do FSII (Fv/Fm), eficiência efetiva do FSII (YII), taxa relativa de transporte de elétrons (rETR), altura da planta e massa seca da parte aérea (MSPA). Os dados foram submetidos à análise de variância (ANOVA) ($p < 0,05$) e as médias foram comparadas pelo teste de Scott-Knott ($p < 0,05$). Observou-se interação significativa entre os fatores cultivar de soja e dose de metribuzin. O herbicida metribuzin causou alterações negativas nas características fisiológicas e de crescimento das plantas, demonstrando a fitotoxicidade do herbicida em algumas cultivares de soja, especialmente na maior dose avaliada. As cultivares M 5917, M 6130 I2X, M 6301 I2X e NS 5252 I2X apresentaram maior tolerância ao metribuzin.
Palavras-chave: Seletividade. *Glycine max*. Manejo integrado de plantas daninhas. Resistência.

Introduction

Soybean (*Glycine max* (L.) Merrill) cultivation is one of the most socioeconomically important crops for Brazil, being among the most exported and nationally produced commodities. In the 2024/2025 harvest, soybean production reached approximately 171.38 million tons, in an estimated cultivated area of 47.35 million hectares, confirming Brazil as the world's largest producer of this oilseed (Companhia Nacional de Abastecimento [CONAB], 2025).

Despite being a widely cultivated crop, several challenges compromise soybean production capacity, ranging from cultivar selection to phytosanitary management. The phytosanitary challenges that limit crop productivity include the presence of weed plants, which interfere with cultivation and can cause losses of up to 70% in productivity if no control method is used (López-Ovejero et al., 2016; Vitorino et al., 2017).

Currently, to mitigate the impacts of weeds, their control is mainly based on the application of herbicides, with glyphosate being the most widely used herbicide in the world due to its efficiency in controlling emerged plants with a broad spectrum of action, as well as its selectivity in genetically modified soybean cultivars (Roundup Ready - RR) (Heap & Duke, 2018). However, the excessive use of glyphosate has caused selection pressure on weeds, leading to the selection of resistant biotypes. According to the international database of herbicide-resistant weeds, there are 62 species resistant to this herbicide worldwide, with 12 cases recorded nationally (Heap, 2026). To prevent and manage these resistant weeds, the implementation of integrated weed management (IWM) is recommended.

Measures such as crop rotation, the use of cover crops, reduction in the seed bank, and rotation and mixing of herbicides with different mechanisms of action, in order to discourage the selection and spread of resistance, among other measures, are strongly recommended (Beckie & Harker, 2017).

In this sense, the use of residual herbicides, applied pre-emergence to weeds, presents itself as an integrated management alternative, not only to minimize new cases of resistance, but also for efficient control, especially in the initial stage of soybean development (Busi et al., 2020). Consequently, producers have been using pre-emergent herbicides in soybean cultivation to reduce the infestation level of difficult-to-control weeds, providing a tool to assist in managing areas with a history of resistance (Mueller et al., 2014). Recently, some molecules used in the past have also been regaining market share, such as metribuzin (a photosystem II inhibitor - PSII). Metribuzin is a selective, highly effective, and broad-spectrum herbicide against broadleaf weeds, and is also effective against some narrow-leaf weeds (Shaner, 2014).

However, even if a given active ingredient is considered selective for a crop, it can still promote alterations in the plant's physiology and morphology, with responses such as reduced photosynthesis, phytotoxicity, and decreased height, leaf area, and shoot dry matter mass (Song et al., 2007). Some herbicides can reduce crop yield potential without showing visual effects, while others cause greater damage, although the crop may recover fully (Ferreira et al., 2005).

According to Silva et al. (2009), the selectivity of herbicides will always be relative, depending on the spectrum of action, stage of plant development, climatic conditions, soil type, dose, and application method, among others. Another relevant factor is the cultivar used. According to Velini et al. (2000), for an herbicide to be considered selective and definitively and indiscriminately recommended for a particular crop, it must demonstrate selectivity to the most common cultivars of that crop. However, modern cultivars have mostly not been treated with the herbicide metribuzin, as since the introduction and widespread adoption of RR technology, there has been a considerable reduction in the use of other active ingredients in soybean cultivation, including during the breeding and selection process of new cultivars.

Due to a lack of detailed information on the behavior of soybean cultivars in response to pre-emergent herbicides, the objective of the current study was to evaluate the tolerance of soybean cultivars to doses of the herbicide metribuzin applied pre-emergence.

Material and Methods

Experimental design and treatments

The experiment was conducted in a greenhouse at the Center for Agricultural Sciences of the State University of Londrina (UEL). It was carried out in a completely randomized design (CRD), arranged in a 19x3 factorial scheme, with four replications. The first factor (A) was composed of 19 soybean cultivars recommended for cultivation in the state of Paraná, namely: BMX Lança IPRO; BMX Lótus IPRO; BMX Fibra IPRO; BMX Nexus I2X; BMX Compacta IPRO; BMX Fúria CE; M 6601 I2X; BMX 66E; BMX Coliseu I2X; DM 64I63 IPRO, GH 2459 I2X; M 5917 IPRO; M 5921 I2X; M 6130 I2X; M 6301 I2X; NS 5252 I2X; NS 5922 IPRO; NS 7524 IPRO; TMG 2360 IPRO. The second factor (B) evaluated was based on three doses of the herbicide metribuzin (Sencor® 480, 480 g a.i. L^{-1}, Bayer S.A.), with the following doses: 0 (control), 480 g a.i. ha^{-1}, and 960 g a.i. ha^{-1}. These are equivalent to doses of 1.0 and 2.0 L of the commercial product (C.P.) ha^{-1}. The dose of metribuzin recommended by the manufacturer varies from 360 to 480 g a.i. ha^{-1}, depending on the soil characteristics and weeds present in the area (Sistema de Agrotóxicos Fitossanitário [AGROFIT], 2025).

Experimental setup and treatment application

The experimental units consisted of pots with a volume of 1 dm^3, filled with Oxisol collected at FAZESC, UEL-PR. The soil in the experimental area is classified as a dystrophic Red Oxisol, composed of 12% sand, 36% silt, and 52% clay; pH ($CaCl_2$) 4.8; 20,100 g dm^{-3} of organic matter and 8.8 cmolc dm^{-3} of cation exchange capacity.

Ten soybean seeds of the respective cultivar were sown at a depth of 3 cm in each pot. After sowing, the pots were irrigated to bring the soil moisture close to field capacity. Herbicide treatments were applied the day after sowing. Spraying was carried out using a carbon dioxide (CO_2) pressurized backpack sprayer equipped with a boom with two XR 110.02 fan-type nozzles, a working pressure of 30 psi, and a spray volume equivalent to 150 L ha^{-1}.

After the treatments were applied, a 10 mm irrigation was carried out with a sprinkler. Throughout the experiment, irrigation was performed periodically, maintaining soil moisture at close to field capacity.

Evaluations

Phytotoxicity

The damage caused by the herbicide in soybean crops was evaluated seven, 14, and 21 days after plant emergence (DAE). For this evaluation, the zero to 100% scale proposed by Frans et al. (1986) was used (Table 1), where zero means absence of symptoms and 100 corresponds to total plant death. The control assessments were performed by two evaluators, with each treatment being compared to the respective control (without herbicide application) of the cultivar.

Table 1
Visual scale for assessing herbicide phytotoxicity in crops

Injury (%)	Main categories	Detailed description of the injury
0	No effect	No injury
10	Mild effect	Mild discoloration or atrophy
20		Some discoloration or atrophy
30		More pronounced but not lasting injury
40	Moderate effect	Moderate injury, usually with recovery
50		More lasting injury, doubtful recovery
60		Lasting injury, no recovery
70	Severe effect	Severe injury, reduced stand
80		Crop nearly destroyed
90		Rarely any plants remaining
100	Total effect	Complete destruction of the culture

Source: Frans et al. (1986).

Physiological assessments

Physiological analyses were performed on soybean plants seven, 14, and 21 DAE. An OS1p fluorometer (Opti-Sciences, Hudson, USA) was used for this purpose. The analyses were performed on two leaflets from two randomly selected plants in each experimental unit. The maximum quantum efficiency of PSII (Fv/Fm) was evaluated in leaves adapted to darkness for 30 minutes. The effective efficiency of photosystem II (YII) was also evaluated by adapting the leaves to PAR (Photosynthetically Active Radiation), i.e., the portion of the photosynthetically active light spectrum, 500 and 1000 μmol m^{-2} s^{-1}, for 30 seconds each. The values for the relative electron transport rate (rETR) were calculated from rETR = YII x PAR x 0.5 x 0.84 (Baker, 2008). Measurements of physiological variables were performed between 7:00 and 9:00 in the morning.

Biometric analyses

At 21 DAE, the shoot length (height) of each plant was evaluated using a millimeter ruler. The shoot dry mass (SDM) of the plants was also determined. For this purpose, the plants were cut at ground level and placed in paper bags, separated by experimental unit. The samples were then kept in an oven at 65°C for 72 hours and subsequently weighed on a precision scale.

Data analysis

The data were subjected to exploratory analyses, where the homoscedasticity of variances was tested using Bartlett's test ($p>0.05$) and the normality of residuals was tested using the Shapiro-Wilk test ($p>0.05$), in order to satisfy the assumptions of analysis of variance (ANOVA). Subsequently, an ANOVA was performed ($p < 0.05$) and the means were compared using the Scott-Knott test at a 5% probability level, using packages from the RStudio statistical software.

Results and Discussion

Phytotoxicity of metribuzin in soybean plants

For the phytotoxicity variable, an interaction was observed between the doses of the herbicide applied and the soybean cultivars (Table 2), indicating that the phytotoxicity of the herbicide metribuzin depends on the dose and the cultivar. At 7 DAE, the cultivars that were most tolerant to metribuzin at the recommended dose (480 g a.i. ha^{-1}) were BMX Lança IPRO, BMX Lótus IPRO, M 6601 I2X, BMX 66E, M 6130 I2X, M 6301 I2X, and NS 5252 I2X, with values below 50%. At the highest dose evaluated (960 g a.i. ha^{-1}), the phytotoxicity index of the plants increased, exceeding 70% in some genotypes, such as the cultivars BMX Fúria CE and GH 2459 I2X.

Table 2
Percentage of phytotoxicity in soybean cultivars at seven, 14, and 21 DAE subjected to different doses of the herbicide metribuzin

Cultivar	Phytotoxicity (%) of soybean cultivars								
	7 DAE			14 DAE			21 DAE		
	Metribuzin dose (g a.i. ha^{-1})								
	0	480	960	0	480	960	0	480	960
BMX Lança IPRO	0.0 aB	43.8 cA	55.0 bA	0.0 aC	61.2 cB	96.2 aA	0.0 aC	47.5 bB	92.5 aA
BMX Lótus IPRO	0.0 aB	41.2 cA	53.8 bA	0.0 aC	76.2 bB	97.5 aA	0.0 aC	65.0 aB	97.5 aA
BMX Fibra IPRO	0.0 aB	60.0 bA	61.2 aA	0.0 aC	71.2 bB	97.5 aA	0.0 aC	62.5 aB	93.8 aA
BMX Nexus I2X	0.0 aB	58.8 bA	61.2 aA	0.0 aC	86.2 aB	100.0 aA	0.0 aC	75.0 aB	100.0 aA
BMX Compacta IPRO	0.0 aB	55.0 bA	60.0 aA	0.0 aB	88.8 aA	75.0 bA	0.0 aC	62.5 aB	96.2 aA
BMX Fúria CE	0.0 aB	62.5 bA	71.2 aA	0.0 aC	83.8 aB	98.8 aA	0.0 aC	57.5 bB	97.5 aA
M 6601 I2X	0.0 aB	43.8 cA	47.5 bA	0.0 aC	60.0 cB	85.0 bA	0.0 aC	52.5 bB	73.8 cA
BMX 66E	0.0 aC	46.2 cB	65.0 aA	0.0 aC	61.2 cB	85.0 bA	0.0 aC	65.0 aB	93.8 aA
BMX Coliseu I2X	0.0 aC	36.2 cB	52.5 bA	0.0 aC	51.2 cB	68.8 cA	0.0 aC	63.8 aB	82.5 bA
DM 64I63 IPRO	0.0 aB	55.0 bA	50.0 bA	0.0 aB	71.2 bA	73.8 cA	0.0 aC	70.0 aB	82.5 bA
GH 2459 I2X	0.0 aB	75.0 aA	70.0 aA	0.0 aC	80.0 aB	96.2 aA	0.0 aC	70.0 aB	81.2 bA
M 5917 IPRO	0.0 aC	40.0 cB	58.8 aA	0.0 aC	57.5 cB	92.5 aA	0.0 aC	45.0 bB	88.8 aA
M 5921 I2X	0.0 aB	60.0 bA	67.5 aA	0.0 aC	81.2 aB	91.2 aA	0.0 aB	67.5 aA	63.8 dA
M 6130 I2X	0.0 aC	31.2 cB	47.5 bA	0.0 aC	57.5 cB	76.2 cA	0.0 aC	50.0 bB	63.8 dA
M 6301 I2X	0.0 aB	50.0 cA	57.5 aA	0.0 aC	65.0 cB	92.5 aA	0.0 aC	52.5 bB	71.2 cA
NS 5252 I2X	0.0 aB	42.5 cA	42.5 bA	0.0 aB	62.5 cA	71.2 cA	0.0 aC	52.5 bB	82.5 bA
NS 5922 IPRO	0.0 aB	55.0 bA	40.0 bA	0.0 aB	77.5 bA	77.5 cA	0.0 aC	72.5 aB	90.0 aA
NS 7524 IPRO	0.0 aB	70.0 aA	57.5 aA	0.0 aB	73.8 bA	82.5 bA	0.0 aC	71.2 aB	92.5 aA
TMG 2360 IPRO	0.0 aB	55.0 bA	65.0 aA	0.0 aC	77.5 bB	92.5 aA	0.0 aC	47.5 bB	95.0 aA
Mean	0.00	51.64	57.04	0.00	70.71	86.83	0.00	60.52	86.26

Means followed by the same lowercase letter in the column and uppercase letters in the row do not differ from each other by the Scott-Knott test ($p < 0.05$).

In the evaluation at 14 DAE, the average values of phytotoxicity levels increased for both doses evaluated, but at a higher level with the higher dose (Table 2). However, as in previous evaluations, variations were observed between genotypes, resulting from the observed interaction. Genotypes such as M 6130 I2X and BMX Coliseu I2X showed lower levels of phytotoxicity, although considered to be moderate levels (40 to 60%) (Table 1). On the other hand, cultivars such as BMX Nexus I2X and BMX Compacta IPRO showed a severe effect, even at the lowest dose evaluated.

At 21 DAE, the average phytotoxicity of the cultivars compared to the previous evaluation was reduced at the dose of 480 g a.i. ha^{-1} (Table 2), indicating recovery of the plants of some cultivars. The cultivars BMX Lança IPRO and TMG 2360 IRPO were the least affected at this evaluation date considering the lowest dose of metribuzin evaluated, although they did not differ from other genotypes. However, others presented high levels of phytotoxicity, such as BMX Nexus I2X, DM 64I63 IPRO, GH 2459 I2X, NS 5922 IPRO, and NS 7524 IPRO.

Physiological analyses

Maximum (Fv/Fm) and effective (YII) quantum efficiency of PSII and relative electron transport rate (rETR)

The physiological characteristics (Fv/Fm, YII, and rETR), also showed an interaction between the herbicide dose and soybean cultivar factors (Tables 3, 4, and 5). This means that these variables demonstrated responses dependent on the herbicide dose applied and the cultivars tested. Thus, it is noticeable that some cultivars have a greater capacity for physiological tolerance to metribuzin. In the Fv/Fm evaluation carried out at 7 DAE (Table 3), all cultivars differed from their respective control, suggesting that they were affected by the application of metribuzin. The Fv/Fm values were significantly reduced, indicating the phytotoxic effect of the herbicide on the photosynthetic activity of the plants soon after emergence. This reduction in Fv/Fm at 7 DAE was observed for both doses evaluated. The mean Fv/Fm value among the cultivars at the zero dose was 0.800, a value considered normal for plants that do not show damage to the photosynthetic apparatus (Baker, 2008). On the other hand, for doses of 480 and 960 g a.i. ha^{-1}, the values were reduced to 0.181 and 0.169, respectively (Table 3).

Table 3
Maximum quantum efficiency of PSII (Fv/Fm) of soybean cultivars at seven, 14 and 21 DAE subjected to different doses of the herbicide metribuzin

Cultivar	Maximum quantum efficiency of PSII (Fv/Fm)								
	7 DAE			14 DAE			21 DAE		
	Metribuzin dose (g a.i. ha^{-1})								
	0	480	960	0	480	960	0	480	960
BMX Lança IPRO	0.816 aA	0.155 aB	0.093 bB	0.829 aA	0.827 aA	0.398 aB	0.792 aA	0.777 aA	0.377 cB
BMX Lótus IPRO	0.822 aA	0.171 aB	0.082 bB	0.826 aA	0.715 aA	0.281 bB	0.790 aA	0.763 aA	0.113 dB
BMX Fibra IPRO	0.812 aA	0.191 aB	0.101 bB	0.820 aA	0.800 aA	0.158 cB	0.778 aA	0.761 aA	0.339 cB
BMX Nexus I2X	0.822 aA	0.076 aB	0.076 bB	0.820 aA	0.795 aA	0.000 cB	0.775 aA	0.712 aA	0.000 dB
BMX Compacta IPRO	0.797 aA	0.171 aB	0.091 bB	0.821 aA	0.736 aA	0.207 bB	0.796 aA	0.722 aA	0.309 cB
BMX Fúria CE	0.830 aA	0.199 aB	0.052 bB	0.829 aA	0.828 aA	0.000 cB	0.741 aA	0.794 aA	0.359 cB
M 6601 I2X	0.809 aA	0.152 aB	0.059 bB	0.815 aA	0.763 aA	0.541 aB	0.805 aA	0.781 aA	0.532 bB
BMX 66E	0.813 aA	0.166 aB	0.145 bB	0.808 aA	0.805 aA	0.456 aB	0.776 aA	0.769 aA	0.543 bA
BMX Coliseu I2X	0.804 aA	0.212 aB	0.182 bB	0.813 aA	0.764 aA	0.538 aB	0.773 aA	0.793 aA	0.408 cB
DM 64I63 IPRO	0.811 aA	0.082 aC	0.525 aB	0.798 aA	0.804 aA	0.477 aB	0.792 aA	0.731 aA	0.544 bA
GH 2459 I2X	0.816 aA	0.128 aB	0.203 bB	0.828 aA	0.615 aA	0.372 bB	0.811 aA	0.776 aA	0.531 bB
M 5917 IPRO	0.813 aA	0.372 aB	0.083 bC	0.825 aA	0.816 aA	0.603 aB	0.816 aA	0.784 aA	0.762 aA
M 5921 I2X	0.795 aA	0.212 aB	0.083 bB	0.829 aA	0.775 aA	0.558 aB	0.809 aA	0.792 aA	0.528 bB
M 6130 I2X	0.808 aA	0.262 aB	0.231 bB	0.817 aA	0.786 aA	0.689 aA	0.787 aA	0.759 aA	0.775 aA
M 6301 I2X	0.807 aA	0.131 aB	0.081 bB	0.824 aA	0.820 aA	0.796 aA	0.781 aA	0.789 aA	0.747 aA
NS 5252 I2X	0.602 aA	0.192 aB	0.543 aA	0.796 aA	0.801 aA	0.330 bB	0.745 aA	0.716 aA	0.491 bA
NS 5922 IPRO	0.806 aA	0.097 aB	0.165 bB	0.820 aA	0.616 aA	0.126 cB	0.796 aA	0.478 bB	0.350 cB
NS 7524 IPRO	0.813 aA	0.175 aB	0.281 bB	0.808 aA	0.816 aA	0.600 aB	0.782 aA	0.752 aA	0.362 cB
TMG 2360 IPRO	0.811 aA	0.280 aB	0.133 bB	0.824 aA	0.824 aA	0.620 aA	0.812 aA	0.775 aA	0.416 bB
Mean	0.800	0.181	0.169	0.818	0.774	0.408	0.787	0.749	0.447

Means followed by the same lowercase letter in the column and uppercase letters in the row do not differ from each other by the Scott-Knott test ($p < 0.05$).

In the evaluation carried out at 14 DAE, it was possible to observe the recovery of photosynthetic activity in plants when the lowest dose of metribuzin was applied (Table 3), such that no cultivar that received the dose of 480 g a.i. ha^{-1} differed from its respective control. However, at a dose of 960 g a.i. ha^{-1}, some cultivars showed a significant reduction in Fv/Fm, notably BMX Fibra IPRO, BMX Nexus I2X, BMX Fúria CE, and NS 5922 IPRO. At 21 DAE, at the recommended dose of metribuzin (480 g a.i. ha^{-1}), a significant reduction in Fv/Fm was observed only for the cultivar NS 5922 IPRO (Table 3). However, at the highest dose evaluated (960 g a.i. ha^{-1}), a reduction in this parameter was observed for most of the cultivars evaluated. The cultivars M 5917 IPRO, M 6130 I2X, and M 6301 I2X were more tolerant, differing from the others. On average, increasing the dose of metribuzin from 480 to 960 g a.i. ha^{-1} led to reductions of 47% and 41% in Fv/Fm at 14 and 21 DAE, respectively.

The effective efficiency of PSII (YII) was also significantly affected in response to metribuzin application, with variation between doses and soybean cultivars (Table 4). At 7 DAE, all evaluated cultivars showed a significant reduction in this variable at both doses (480 and 960 g a.i. ha^{-1}) compared to untreated plants of the same cultivar. At a dose of 480 g a.i. ha^{-1}, the most tolerant cultivars were BMX Fibra IPRO, DM 64I63 IPRO, M 6139 I2X, and TMG 2360 IPRO, differing from the other cultivars evaluated. At a dose of 960 g a.i. ha^{-1}, only the DM 64I63 IPRO cultivar differed from the others, although its YII value was lower than its control without application.

Table 4
Effective efficiency of PSII (YII) of soybean cultivars at seven, 14, and 21 DAE subjected to different doses of the herbicide metribuzin

Cultivar	Effective efficiency (YII)								
	7 DAE			14 DAE			21 DAE		
	Metribuzin dose (g a.i. ha^{-1})								
	0	480	960	0	480	960	0	480	960
BMX Lança IPRO	0.685 aA	0.043 bB	0.000 cB	0.679 aA	0.610 aA	0.357 aA	0.755 aA	0.740 aA	0.359 cB
BMX Lótus IPRO	0.702 aA	0.060 bB	0.006 cB	0.671 aA	0.470 aA	0.365 aA	0.753 aA	0.726 aA	0.107 dB
BMX Fibra IPRO	0.685 aA	0.306 aB	0.020 cC	0.600 aA	0.332 bA	0.362 aA	0.741 aA	0.725 aA	0.323 cB
BMX Nexus I2X	0.653 aA	0.006 bB	0.007 cB	0.728 aA	0.586 aA	0.000 bB	0.738 aA	0.678 aA	0.000 dB
BMX Compacta IPRO	0.693 aA	0.020 bB	0.015 cB	0.630 aA	0.581 aA	0.162 bB	0.758 aA	0.688 aA	0.294 cB
BMX Fúria CE	0.699 aA	0.048 bB	0.009 cB	0.732 aA	0.715 aA	0.000 bB	0.706 aA	0.756 aA	0.342 cB
M 6601 I2X	0.691 aA	0.043 bB	0.019 cB	0.652 aA	0.471 bA	0.524 aA	0.766 aA	0.744 aA	0.506 bB
BMX 66E	0.704 aA	0.168 aB	0.003 cB	0.641 aA	0.240 bB	0.556 aA	0.739 aA	0.732 aA	0.517 bA
BMX Coliseu I2X	0.657 aA	0.083 bB	0.007 cB	0.689 aA	0.328 bB	0.644 aA	0.736 aA	0.755 aA	0.388 cB
DM 64I63 IPRO	0.685 aA	0.183 aC	0.467 aB	0.670 aA	0.366 bB	0.692 aA	0.754 aA	0.696 aA	0.518 bA
GH 2459 I2X	0.673 aA	0.000 bB	0.153 cB	0.703 aA	0.367 bA	0.531 aA	0.773 aA	0.739 aA	0.505 bB
M 5917 IPRO	0.664 aA	0.196 aB	0.001 cB	0.636 aA	0.319 bB	0.605 aA	0.777 aA	0.746 aA	0.726 aA
M 5921 I2X	0.657 aA	0.112 bB	0.015 cB	0.607 aA	0.613 aA	0.524 aA	0.770 aA	0.754 aA	0.502 bB
M 6130 I2X	0.655 aA	0.252 aB	0.000 cC	0.477 aA	0.560 aA	0.547 aA	0.750 aA	0.723 aA	0.738 aA
M 6301 I2X	0.710 aA	0.003 bB	0.001 cB	0.674 aA	0.581 aA	0.689 aA	0.744 aA	0.752 aA	0.711 aA
NS 5252 I2X	0.681 aA	0.000 bC	0.307 bB	0.696 aA	0.622 aA	0.273 bB	0.710 aA	0.681 aA	0.468 bA
NS 5922 IPRO	0.695 aA	0.000 bB	0.010 cB	0.714 aA	0.347 bB	0.167 bB	0.758 aA	0.455 bB	0.333 cB
NS 7524 IPRO	0.661 aA	0.000 bB	0.048 cB	0.690 aA	0.645 aA	0.197 bB	0.745 aA	0.716 aA	0.344 cB
TMG 2360 IPRO	0.639 aA	0.168 aB	0.013 cB	0.672 aA	0.305 bB	0.613 aA	0.774 aA	0.738 aA	0.396 bB
Mean	0.678	0.089	0.0579	0.661	0.477	0.411	0.741	0.713	0.425

Means followed by the same lowercase letter in the column and uppercase letters in the row do not differ from each other by the Scott-Knott test ($p < 0.05$).

In the evaluation at 14 DAE, in general, the plants showed recovery in YII, even if partial, in most cultivars for both doses of metribuzin. Even so, some highlights should be mentioned, such as the total reduction in YII for the cultivars BMX Nexus I2X and BMX Fúria CE when the higher dose of metribuzin was applied. On the other hand, the M 5921 I2X, M 6130 I2X, and M 6301 I2X cultivars were the positive highlights, showing excellent tolerance to metribuzin at both doses evaluated. Finally, at 21 DAE, with the exception of the NS 5922 IPRO cultivar, the other cultivars did not differ from each other and did not show a reduction in YII with the application of 480 g a.i. ha^{-1}. At a dose of 960 a.i. ha^{-1}, only the cultivars M 5917 IPRO, M 6130 I2X, and M 6301 I2X differed from the others, showing a significant reduction in YII.

Like the other physiological variables, the relative electron transport rate (rETR) was also affected by the application of metribuzin, with a significant interaction between the doses and cultivars evaluated (Table 5). At 7 DAE, all cultivars showed a reduction in rETR with the application of metribuzin at both doses. At the dose of 480 g a.i. ha^{-1}, only the cultivars BMX Fibra IPRO, DM 64I63 IPRO, and M 6130 I2X differed from the others, with the smallest reductions in rETR. At 14 and 21 DAE, recovery in rETR was observed in most of the evaluated cultivars, mainly at the recommended dose and at 21 DAE. At 21 DAE, only the NS 5922 IPRO cultivar differed from the others, with a lower rETR value at the recommended dose, and this cultivar was also the only one that differed from its control without application.

Table 5
Relative electron transport rate (rETR) of soybean cultivars at seven, 14, and 21 DAE subjected to different doses of the herbicide metribuzin

Cultivar	Relative rate of electron transport (rETR)								
	7 DAE			14 DAE			21 DAE		
	Metribuzin dose (g a.i. ha^{-1})								
	0	480	960	0	480	960	0	480	960
BMX Lança IPRO	24.4 aA	1.50 bB	0.00 cB	24.18 aA	21.73 aA	12.72 aA	26.90 aA	26.38 aA	12.77 cB
BMX Lótus IPRO	25.0 aA	2.12 bB	0.20 cB	23.93 aA	16.75 aA	12.98 aA	26.80 aA	25.88 aA	3.82 dB
BMX Fibra IPRO	24.42 aA	10.90 aB	0.70 cC	21.35 aA	11.83 bA	12.90 aA	26.40 aA	25.88 aA	11.48 cB
BMX Nexus I2X	23.30 aA	0.20 bB	0.25 cB	25.95 aA	20.88 aA	0.00 bB	26.32 aA	25.12 aA	0.00 dB
BMX Compacta IPRO	24.67 aA	0.70 bB	0.50 cB	22.43 aA	20.68 aA	5.75 bB	26.98 aA	24.52 aA	10.48 cB
BMX Fúria CE	24.92 aA	1.70 bB	0.27 cB	26.05 aA	25.45 aA	0.00 bB	25.15 aA	26.98 aA	12.20 cB
M 6601 I2X	24.62 aA	1.52 bB	0.67 cB	23.22 aA	16.77 bA	18.68 aA	27.32 aA	26.50 aA	18.05 bB
BMX 66E	25.10 aA	5.95 aB	0.10 cB	22.85 aA	8.55 bB	19.80 aA	26.32 aA	26.10 aA	18.45 bA
BMX Coliseu I2X	23.40 aA	2.92 bB	0.22 cB	24.55 aA	11.65 bB	22.93 aA	26.20 aA	26.93 aA	13.82 cB
DM 64I63 IPRO	24.42 aA	6.50 aC	16.65 aB	23.88 aA	13.00 bB	24.68 aA	26.90 aA	24.77 aA	18.45 bA
GH 2459 I2X	24.00 aA	0.00 bB	5.45 cB	25.05 aA	13.07 bA	18.93 aA	27.55 aA	26.32 aA	18.00 bB
M 5917 IPRO	23.65 aA	6.95 aB	0.05 cB	22.68 aA	11.32 bB	21.55 aA	27.68 aA	26.60 aA	25.65 aA
M 5921 I2X	23.42 aA	3.97 bB	0.52 cB	21.60 aA	21.82 aA	18.67 aA	27.45 aA	26.88 aA	18.88 bB
M 6130 I2X	23.35 aA	8.97 aB	0.00 cC	16.97 aA	19.93 aA	19.48 aA	26.73 aA	25.75 aA	26.25 aA
M 6301 I2X	25.32 aA	0.10 bB	0.02 cB	24.00 aA	20.65 aA	24.52 aA	26.50 aA	26.77 aA	25.30 aA
NS 5252 I2X	24.25 aA	0.00 bC	10.92 bB	24.80 aA	22.15 aA	9.68 bB	25.30 aA	24.25 aA	16.65 bA
NS 5922 IPRO	24.77 aA	0.00 bB	0.35 cB	25.45 aA	12.32 bB	5.90 bB	27.02 aA	16.23 bB	11.85 cB
NS 7524 IPRO	23.55 aA	0.00 bB	1.72 cB	24.57 aA	22.98 aA	7.00 bB	26.50 aA	25.52 aA	12.25 cB
TMG 2360 IPRO	22.75 aA	6.00 aB	0.42 cB	23.93 aA	10.85 bB	21.85 aA	27.57 aA	26.32 aA	14.10 bB
Mean	24.17	3.16	2.05	23.55	16.97	14.63	26.72	25.46	15.18

Means followed by the same lowercase letter in the column and uppercase letters in the row do not differ from each other by the Scott-Knott test ($p < 0.05$).

Biometric analyses

Evaluation of the height of the soybean cultivars demonstrated the occurrence of an interaction between the factors evaluated (Table 6). That is, the dose of metribuzin affected the soybean cultivars differently. At a dose of 480 g a.i. ha^{-1}, the cultivars BMX Lótus IPRO, M 6601 I2X, BMX Coliseu I2X, DM 64I63 IPRO, M 6130 I2X, NS 5252 I2X, and TMG 2360 IPRO were the least affected, with the highest plant height values. At a dose of 960 g a.i. ha^{-1}, the cultivars with the greatest height were DM 64I63 IPRO, M 5921 I2X, M 6130 I2X, and NS 5252 I2X. On the other hand, the cultivars BMX Fibra IPRO, BMX Nexus I2X, BMX Compacta IPRO, and BMX Fúria CE were severely affected by the higher dose of metribuzin, resulting in reduced plant height. On average across cultivars, the dose of 960 g a.i. ha^{-1} caused a 54% reduction in plant height compared to the control, while at the recommended dose the reduction was approximately 24%.

Table 6
Height of soybean cultivars 21 DAE subjected to different doses of the herbicide metribuzin

Cultivar	Plant height (cm) at 21 DAE		
	Metribuzin dose (g a.i. ha^{-1})		
	0	480	960
BMX Lança IPRO	19.00 aA	14.62 bA	7.50 bB
BMX Lótus IPRO	20.00 aA	19.75 aA	8.50 bB
BMX Fibra IPRO	16.38 aA	14.12 bA	4.75 cB
BMX Nexus I2X	18.73 aA	12.25 bB	0.00 cC
BMX Compacta IPRO	17.62 aA	9.12 bB	4.62 cB
BMX Fúria CE	21.50 aA	12.50 bB	3.62 cC
M 6601 I2X	20.50 aA	15.75 aA	10.00 aB
BMX 66E	22.25 aA	13.12 bB	7.62 bC
BMX Coliseu I2X	20.00 aA	17.25 aA	11.88 aB
DM 64I63 IPRO	18.88 aA	16.62 aA	13.50 aA
GH 2459 I2X	17.25 aA	11.62 bB	6.38 bC
M 5917 IPRO	20.00 aA	14.62 bB	11.75 aB
M 5921 I2X	18.88 aA	14.12 bA	13.62 aA
M 6130 I2X	21.00 aA	16.38 aB	13.50 aB
M 6301 I2X	19.88 aA	14.25 bB	15.12 aB
NS 5252 I2X	18.25 aA	19.38 aA	13.25 aB
NS 5922 IPRO	17.88 aA	11.62 bB	8.62 bB
NS 7524 IPRO	19.75 aA	14.62 bB	8.25 bC
TMG 2360 IPRO	17.00 aA	16.62 aA	5.00 cB
Mean	19.20	14.65	8.81

Means followed by the same lowercase letter in the column and uppercase letters in the row do not differ from each other by the Scott-Knott test ($p < 0.05$).

For the shoot dry mass variable, no significant interactions were observed between the evaluated factors (Figure 1). However, a significant difference was observed between the soybean cultivars and the metribuzin doses. The cultivars BMX Lótus IPRO, BMX Fibra IPRO, BMX Nexus I2X, BMX Compacta IPRO, BMX Fúria CE, NS 5922 IPRO, and NS 7524 IPRO showed a significant reduction in dry mass accumulation, differing from the other cultivars (Figure 1A). Regarding the metribuzin dose, plants treated with 480 g a.i. ha^{-1} experienced an approximately 70% reduction in dry mass accumulation. The higher dose of 960 g a.i. ha^{-1} resulted in an approximately 85% reduction in shoot dry mass accumulation (Figure 1B).

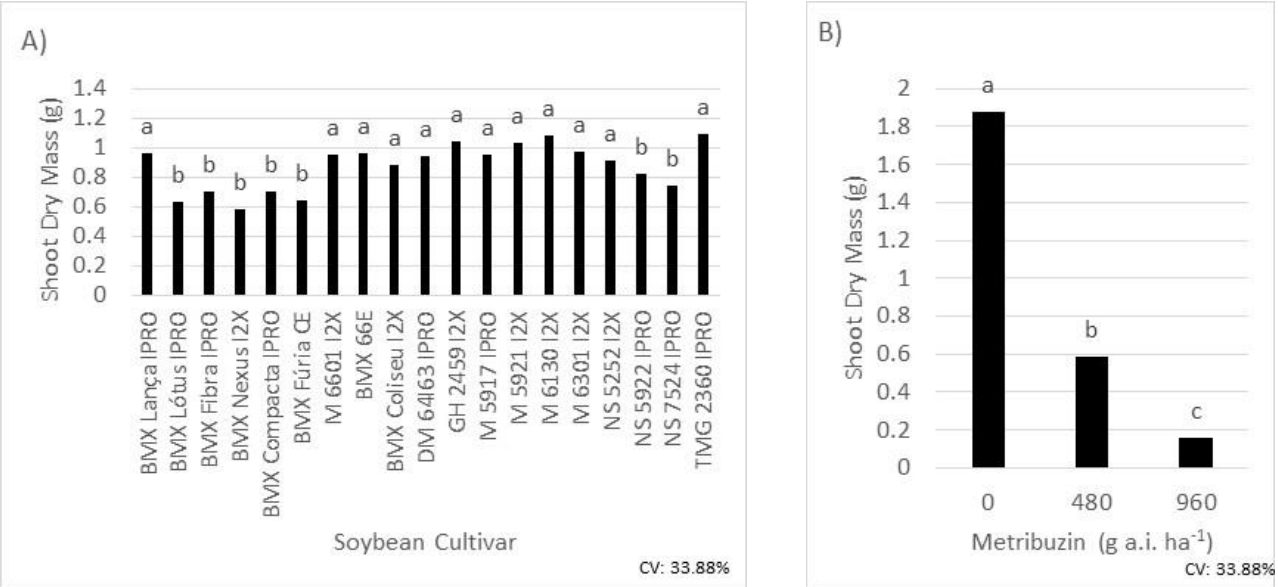

Figure 1. Shoot dry mass of the plants at 21 DAE in response to the soybean cultivar (A) and metribuzin dose (B).
Means followed by the same letter do not differ from each other by the Scott-Knott test ($p < 0.05$).

The current study evaluated the sensitivity of soybean cultivars to the herbicide metribuzin applied pre-emergence. The results confirm the initial hypotheses: that there is variability in the sensitivity of soybean cultivars to metribuzin; and that increasing the dose can lead to increased injury in treated plants, depending on the cultivar. The selectivity of pre-emergent herbicides depends on several factors, and this study was able to demonstrate the importance of the genetic aspect. Older studies, conducted in the 1970s and 1980s with soybean cultivars no longer grown in Brazil, also showed variations in responses to metribuzin doses. Among the dozens of studies conducted during that period, Velloso and Fleck (1980) observed that the application of 490 g a.i. ha^{-1} of metribuzin resulted in variations in the accumulation of dry matter in soybean cultivars, mainly when the application was carried out with incorporation into the soil.

Barrentine et al. (1982) also reported important differences in the sensitivity of three soybean cultivars to metribuzin, in both field studies and under controlled conditions. According to the authors, the C50 values were three times higher in the Tracy-M and Centennial cultivars compared to the Tracy cultivar, which was extremely sensitive to metribuzin, even though it is a parent of the Tracy-M cultivar. Similarly, Barrentine et al. (1976) evaluated 45 soybean cultivars for metribuzin tolerance and concluded that damage varied according to the cultivar, with effects ranging from mild to severe.

Variations in genotype responses to the herbicide metribuzin have also been observed in other crops, such as wheat (Kleemann & Gill, 2007), rice (Marsh & Al-Khatib, 2023), sweet potato (Santos et al., 2018), and potato (Correia & Carvalho, 2018). These studies were developed more recently compared to those developed for soybean cultivation, due to the reduced use of pre-emergent herbicides since the release of glyphosate-tolerant soybean cultivars in Brazil in 2005 (Adegas et al., 2022). However, with the renewed use of pre-emergent herbicides in Brazil, aimed at managing resistance and preventing new outbreaks, studies on pre-emergent herbicides are once again becoming a necessity.

Variations were observed among cultivars in phytotoxicity, physiological parameters (Fv/Fm, YII, and rETR) and biometric parameters (plant height and shoot dry mass). Metribuzin is an herbicide that acts in pre-emergence and early post-emergence to control weeds. This herbicide inhibits electron transport in PSII by displacing plastoquinone Qb in the D1 protein (Cobb & Reade, 2010). This results in the accumulation of electrons in PSII, which, upon reacting with O_2 molecules in the presence of light, form reactive oxygen species (ROS). ROS are harmful to cell membranes, leading to lipid peroxidation and cellular leakage, with consequent death of sensitive treated plants (Hess, 2000).

Soybean crops tolerate metribuzin in pre-emergence application, with registration for use at doses between 360 and 480 g a.i. ha^{-1} (AGROFIT, 2025). However, even so, this herbicide can affect plant growth, as well as the photosynthetic activity of plants. In the present work, some cultivars were less sensitive to metribuzin, even at twice the recommended dose (980 g a.i. ha^{-1}). This was the case for the cultivars M 5917 IPRO, M 6130 I2X, and M 6301 I2X, which did not show a significant reduction in Fv/Fm, even at the highest dose, at 21 DAE (Table 3). The variation in the effect on the cultivars is due to the ability of each one to metabolize the herbicide, with no apparent relation to variations in absorption or translocation (Abusteit et al., 1985).

The herbicide metribuzin is metabolized in soybean crops by an enzymatic system, and variations in the activity of this enzymatic system may explain the variability among cultivars (Mangeot et al., 1979). Soybean plants tolerate metribuzin through detoxification reactions such as N-deamination, N-glycosidic conjugation, and sulfoxidation followed by conjugation with homoglutathione. The N-deamination reaction appears to be mediated by enzymes with oxidase function, resulting in deaminated metribuzin (Fedtke, 1991). The rate of N-deamination appears to correlate with metribuzin tolerance in soybean cultivars. N-glucoside conjugation is mediated by the enzyme glucosyltransferase. The resulting glucoside is then conjugated with malonic acid, resulting in the formation of the malonyl β-D-(N-glucoside) conjugate (Frear et al., 1985; Fedtke, 1991).

Studies evaluating the sensitivity of soybean cultivars have already been developed for other herbicides. Recently, Amorim et al. (2025) verified the occurrence of variability in the sensitivity of soybean cultivars to the commercial mixture containing sulfentrazone + diuron, a protoporphyrinogen oxidase (PPO) inhibitor and a PSII inhibitor, as well as metribuzin. The authors also verified an interaction with the evaluated dose. It is important to highlight that other factors, besides the cultivar, are involved in the sensitivity of soybean cultivars to pre-emergent herbicides. Factors related to the soil (texture, organic matter, pH, and compaction), climate (temperature and rainfall), application time in relation to sowing, and sowing depth, among others, should be considered (Menalled & Dyer, 2004). For example, Belfry et al. (2015) observed that pre-emergent application of metribuzin led to variable damage and yield reduction among soybean cultivars in the locations where the studies were conducted in Canada. Damage was less pronounced in the experiment conducted in soil with a higher organic matter content.

Finally, it should be noted that the current work was carried out under controlled conditions, in a greenhouse, in clay soil, and serves only as a guideline for classifying the evaluated cultivars regarding their sensitivity to the herbicide metribuzin. Studies under field conditions, in different environments, including a larger number of cultivars, are necessary to ensure safe herbicide placement. Furthermore, these studies should be repeated with other herbicides, including mixtures of active ingredients that have become available on the market in recent years. It is also worth highlighting the importance of using pre-emergent herbicides for managing and preventing resistance in cropping systems.

Conclusion

The selectivity of the herbicide metribuzin applied pre-emergence to soybean plants varies according to the cultivar and dose applied. The herbicide metribuzin induced negative alterations in the physiological and growth characteristics of plants, demonstrating the phytotoxicity of the herbicide in some soybean cultivars, especially at the highest dose evaluated. The cultivars M 5917 IPRO, M 6130 I2X, M 6301 I2X, and NS 5252 I2X showed greater tolerance to metribuzin.

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