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# Sensitivity of soybean cultivars to the mixture of sulfentrazone + diuron applied in pre-emergence

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## ABSTRACT

New herbicides for soybean cultivation, mainly mixtures, have been launched on the market. However, little is known about the actual effects of these mixtures on the crop, and studies are needed to verify the sensitivity of cultivars to these herbicides. This work aimed to evaluate the sensitivity of soybean cultivars to the commercial mixture of pre-emergent herbicides sulfentrazone + diuron. The experiment was conducted in a greenhouse in a completely randomized design, with four replications, in a 20 x 3 factorial. Factor A was composed of 20 soybean cultivars. Factor B comprised two doses of sulfentrazone + diuron, being 175 + 350 g $ha^{-1}$, and 350 + 700 g $ha^{-1}$, equivalent to 1 and 2 L commercial product (cp) $ha^{-1}$, in addition to a control treatment (zero dose). The variables evaluated were phytotoxicity, FSII activity, relative electron transport rate (rETR), shoot length, and shoot dry mass (SDM). The data were subjected to analysis of variance, and the means were grouped using the Skott-Knott test ($p < 0.05$). The mixture of sulfentrazone + diuron caused negative changes in the physiological and growth characteristics, especially at the highest dose evaluated. However, variability was observed in the sensitivity of the studied cultivars. HO Amambay, HO Iguaçu, HO Paraguaçu, HO Pirapó, Lança IPRO, Lótus IPRO, M6410 IPRO, TMG 2356 IPRO, TMG 2359 IPRO, and TMG 2364 IPRO cultivars were more sensitive. Therefore, it is concluded that the selectivity of the sulfentrazone + diuron mixture depends on the dose applied and the soybean cultivar.

**Keywords:** Photosystem II, *Glycine max*, Residual herbicides, Protox, Selectivity.

## Sensibilidade de cultivares de soja à mistura de sulfentrazona + diuron aplicada em pré-emergência

## RESUMO

Novos herbicidas para a cultura da soja, principalmente misturas, têm sido lançados no mercado. Entretanto, pouco se sabe sobre os reais efeitos dessas misturas na cultura, sendo necessários estudos que verifiquem a sensibilidade das cultivares a esses herbicidas. Este trabalho teve como objetivo avaliar a sensibilidade de cultivares de soja à mistura comercial dos herbicidas pré-emergentes sulfentrazone + diuron. O experimento foi conduzido em casa de vegetação no delineamento inteiramente casualizado, com quatro repetições, em fatorial 20 x 3. O fator A foi composto por 20 cultivares de soja. O fator B compreendeu duas doses de sulfentrazone + diuron, sendo 175 + 350 g $ha^{-1}$ e 350 + 700 g $ha^{-1}$, equivalentes 1 e 2 L de produto comercial (pc) $ha^{-1}$, além de um tratamento controle (dose zero). As variáveis avaliadas foram fitotoxicidade, atividade do FSII, taxa relativa de transporte de elétrons (rETR), comprimento da parte aérea e massa seca da parte aérea (MSPA). Os dados foram submetidos à análise de variância e as médias foram comparadas pelo teste de Skott-Knott ($p < 0,05$). A mistura sulfentrazone + diuron causou alterações negativas nas características fisiológicas e de crescimento das plantas, principalmente na maior dose avaliada. Entretanto, foi observada variabilidade na sensibilidade das cultivares estudadas. As cultivares HO Amambay, HO Iguaçu, HO Paraguaçu, HO Pirapó, Lança IPRO, Lótus IPRO, M6410 IPRO, TMG 2356 IPRO, TMG 2359 IPRO e TMG 2364 IPRO foram mais sensíveis. Portanto, conclui-se que a seletividade da mistura sulfentrazone + diuron depende da dose aplicada e da cultivar de soja.

**Palavras-chave**: Fotossistema II, *Glycine max*, Herbicidas residuais, Protox, Seletividade.

## 1. Introduction

Soybeans (*Glycine max* (L.) Merrill) are one of Brazil's most socioeconomically essential crops and the most exported and produced commodities nationally. In Brazil, in the 2023/2024 cycle, 147 million tons were harvested in an area of 46 million hectares, which results in a grain yield of 3,200 kg ha$^{-1}$ (CONAB, 2024). Despite being a widely explored crop, some adversities compromise the productive capacity of soybeans, ranging from cultivar selection to phytosanitary management. Among the phytosanitary challenges that limit soybean grain yield is the presence of weeds, which can cause losses of up to 70% if no control method is used (López-Ovejero et al., 2016, Vitorino et al., 2017).

Currently, to mitigate the impacts resulting from weeds, control is mainly based on the application of herbicides, with emphasis on glyphosate. It has become the most used herbicide in the world, as it is efficient in controlling emerging plants with a broad spectrum of action, as well as selectivity in genetically modified soybean cultivars (Heap and Duke, 2018). However, the excessive use of glyphosate has caused selection pressure on weeds; according to International Herbicide-Resistant Weed Database, in the world, there are 61 species of weeds resistant to this herbicide. At the same time, in Brazil there are 12 cases registered. Furthermore, in Brazil there are cases of resistance involving herbicides belonging to other mechanisms of action, totaling 58 cases (Heap, 2025).

Integrated weed management (IWM) is recommended to prevent and manage these resistant weeds. The IWM includes measures such as crop rotation, the use of cover crops, reduction of the seed bank, and rotation and mixing of herbicides with different mechanisms of action, among other measures, to disfavor the selection and dispersion of resistance (Beckie and Hacker, 2017). In this sense, the use of herbicides with residual effects, when applied pre-emergence of weeds and crops, presents itself as an integrated management alternative, not only to minimize new cases of resistance but also for efficient weed control, especially in the initial stage of soybean development (Busi et al., 2020). Consequently, farmers have been using pre-emergent herbicides in soybean crops to reduce the degree of infestation of difficult-to-control weeds, being a tool to assist in the management of areas with a history of resistance (Mueller et al., 2014).

The mixture of sulfentrazone (Protoporphyrinogen oxidase - PPO inhibitor) + diuron (Photosystem II - PSII inhibitor) is selective for pre-emergence application of soybean crops and recommended for difficult control weed species, such as benghal dayflower (*Commelina benghalensis*), horseweed (*Conyza* spp.), sourgrass (*Digitaria insularis*) and smooth pigweed (*Amaranthus hybridus*) (Agrofit, 2024).

However, even if a particular active ingredient is considered selective for crops, it can promote changes in the physiology and morphology of the plant, which is called phytotoxicity. Phytotoxicity can be manifested by reduced germination and emergence, reduced height, leaf area, and mass of the shoot dry matter (Song et al., 2007). Some herbicides can reduce the productive potential of the crop without presenting visually observable effects; others cause more considerable damage, although the crop may show full recovery (Ferreira et al., 2005).

On the other hand, some phytotoxic effects are hidden, and even so, they can damage the growth and development of plants. To quantify them, it is necessary to use methodologies that evaluate aspects related to the photosynthetic activity of plants, among other techniques. In the case of herbicides that affect plant photosynthesis, such as PSII and PPO inhibitors, the evaluation of photosynthetic activity can help in the selection of cultivars that are more tolerant to these herbicides (Preisler et al., 2020).

The selectivity of herbicides is a relative characteristic (Silva et al., 2009), depending on the spectrum of action, stage of plant development, climatic conditions, soil type, dose, and application modality, among others. Another relevant factor is the cultivar used, which, according to Velini et al. (2000), for the herbicide to be considered selective and recommended for a given crop, it must demonstrate selectivity to the most common cultivars. Due to the lack of information on the behavior of soybean cultivars to pre-emergent herbicides, the aim of the present work was to evaluate the sensitivity of soybean cultivars to doses of the herbicide sulfentrazone + diuron.

## 2. Material and Methods

The experiment was conducted in a completely randomized design (CRD), arranged in a 20 x 3 factorial scheme, with four replications. The first factor (A) comprised 20 soybean cultivars (Table 1). The second factor (B) was based on two doses of the commercial herbicide mixture sulfentrazone + diuron (Stone, 175 g L$^{-1}$ sulfentrazone + 350 g L$^{-1}$ diuron, FMC Química do Brasil Ltda.), being doses 175 + 350 g ha$^{-1}$ and 350 + 700 g ha$^{-1}$, in addition to a control treatment (zero dose). The doses are equivalent to 1.0 and 2.0 L of the commercial product (cp) ha$^{-1}$. For soybean, the dose of sulfentrazone + diuron recommended by the manufacturer varies from 122.5 + 245 to 250 + 490 g a.i. ha$^{-1}$, depending on the soil characteristics and weeds present in the area (Agrofit, 2024). Therefore, a dose within the recommended range and another above the recommended range was used precisely to contrast the ability of each cultivar to tolerate the mixture of sulfentrazone + diuron.

**Table 1.** List of soybean cultivars subjected to the effects of sulfentrazone + diuron herbicides applied at pre-emergence of the crop.

| No. | Cultivar | RMG[1] | Holder |
|---|---|---|---|
| 1 | DM56I59 IPRO | 5.6 | Dommario Sementes |
| 2 | DM60I63 IPRO | 6.0 | Dommario Sementes |
| 3 | DM64I63 IPRO | 6.4 | Dommario Sementes |
| 4 | DM66I68 IPRO | 6.6 | Dommario Sementes |
| 5 | DM70I71 IPRO | 7.0 | Dommario Sementes |
| 6 | Fibra IPRO | 6.4 | Brasmax Genética |
| 7 | HO Amambay | 5.8 | HO Genética |
| 8 | HO Iguaçu | 6.4 | HO Genética |
| 9 | HO Paraguaçu | 6.4 | HO Genética |
| 10 | HO Pirapó | 6.4 | HO Genética |
| 11 | HO Tererê | 6.6 | HO Genética |
| 12 | Lança IPRO | 5.8 | Brasmax Genética |
| 13 | Lótus IPRO | 6.1 | Brasmax Genética |
| 14 | M6410 IPRO | 6.4 | Bayer Crop Science |
| 15 | NEO 660 | 6.6 | Neogen |
| 16 | TMG 2356 IPRO | 5.7 | TMG Tropical Melhoramento & Genética |
| 17 | TMG 2359 IPRO | 5.9 | TMG Tropical Melhoramento & Genética |
| 18 | TMG 2360 IPRO | 6.0 | TMG Tropical Melhoramento & Genética |
| 19 | TMG 2364 IPRO | 6.4 | TMG Tropical Melhoramento & Genética |
| 20 | TMG 7067 IPRO | 6.5 | TMG Tropical Melhoramento & Genética |

[1] Relative maturation group.

The experiment was conducted twice in a greenhouse in the Department of Agronomy at the State University of Londrina (UEL) - PR, latitude of 23º 23’ south and longitude of 51º 11’ west, with an approximate altitude of 560 meters.

The experimental units were pots with a volume of 1 $dm^3$, filled with oxisol collected at FAZESC, UEL-PR. According to the analysis, the soil has the following characteristics: 12% sand, 36% silt, and 52% clay; pH 5.50; 2.28 g $dm^{-3}$ of organic matter and 9.25 $cmol_c$ $dm^{-3}$ of cation exchange capacity.

In each pot, 10 seeds of the respective cultivar were manually sown at a depth of 3 cm. After sowing, the pots were irrigated so that the soil reached moisture close to field capacity. Herbicide treatments were applied the day after sowing. Spraying was conducted with a carbon dioxide ($CO_2$) pressurized sprayer equipped with a bar with two TeeJet® 110.02 fan-type tips with air induction, with a working pressure of 30 psi and a spray volume equivalent to 200 L $ha^{-1}$. During the experiment, irrigation was conducted periodically by sprinkler, keeping soil moisture close to field capacity.

The injuries caused by the herbicide in the soybean crop were evaluated at 15, 30, and 45 days after application of the treatments (DAA). For this evaluation, the scale from zero to 100% proposed by Frans et al. (1986) was used, as shown in Table 2, where zero means the absence of symptoms, and 100 corresponds to total control (death) of the plants. Control evaluations were conducted by two evaluators, with each treatment being compared to its respective control (cultivar without herbicide application).

Because the herbicides sulfentrazone (PPO inhibitor) and diuron (PSII inhibitor) affect processes related to photosynthesis, analyzes were conducted regarding the maximum and effective efficiencies of PSII and the relative rate of electron transport (rETR) in soybean plants at 15, 30, and 45 DAA. For this purpose, an OS1p fluorometer (OptiSciences) was used.

Measurements of physiological characteristics were performed from 7:00 a.m. to 9:00 a.m. Chlorophyll fluorescence analysis to determine the maximum quantum efficiency of PSII was performed by calculating the Fv/Fm ratio (variable fluorescence/maximum fluorescence).

The analyses were conducted on two leaflets of two randomly defined plants from the experimental unit. The effective efficiency of PSII (YII) was also evaluated by adapting the leaves to PAR (Photosynthetically Active Radiation), that is, the portion of the photosynthetically active light spectrum of 500 and 1000 µmol $m^{-2}$ $s^{-1}$ for 30 seconds each. The values of rETR were calculated from rETR = YII x PAR x 0.5 x 0.84 (Baker, 2008).

At 45 DAA, the length of each plant’s shoot was evaluated using a millimeter ruler. Data were expressed in cm $plant^{-1}$. The shoot dry mass (SDM) was also determined. For this, 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 weighed on a precision scale. Data were expressed in g $pot^{-1}$.

**Table 2**. Phytotoxicity visual assessment scale used in the experiment (Frans et al., 1986).

| Injury (%) | Main categories | Detailed description of the injury |
|---|---|---|
| 0 | No effect | No injury |
| 10 | | Mild discoloration or atrophy |
| 20 | Mild effect | Some discoloration or atrophy |
| 30 | | More pronounced but not lasting injury |
| 40 | | Moderate injury, usually with recovery |
| 50 | Moderate effect | Longer lasting injury, doubtful recovery |
| 60 | | Lasting injury, no recovery |
| 70 | | Heavy injury, stand reduction |
| 80 | Severe effect | Culture close to destruction |
| 90 | | There are rarely any plants left |
| 100 | Full effect | Complete destruction of culture |

The data were subjected to exploratory analyses, where the homoscedasticity of variances was tested using the Bartlett test ($p < 0.05$) and the normality of the residuals using the Shapiro-Wilk test ($p < 0.05$) to satisfy the assumptions of variance analysis (ANOVA). Subsequently, ANOVA was performed ($p < 0.05$), and the means were grouped by the Scott-Knott test ($p < 0.05$) using the statistical program RStudio. The means of the two replications of the experiment were considered.

## 3. Results and Discussion

Table 3 presents the results regarding phytotoxicity evaluations of soybean cultivars in response to the application of doses of sulfentrazone + diuron. An interaction was observed between cultivars and herbicide doses. Due to the similarity of the results at 30 and 45 DAA, the data at 30 DAA will not be presented.

In the first evaluation, at 15 DAA, the highest levels of phytotoxicity were caused by the highest dose of the herbicide (2 L cp ha$^{-1}$) in the DM56I59 IPRO (66.2%) and Lança IPRO (57.5%) cultivars. DM64I63 IPRO, M6410 IPRO, NEO 660, and TMG 2360 IPRO cultivars were more tolerant to sulfentrazone + diuron, with phytotoxicity rates in the range of 30%, regardless of the herbicide dose.

At 30 and 45 DAA, the cultivars most tolerant to the highest evaluated dose of sulfentrazone + diuron were DM64I63 IPRO, HO Amambay, NEO 660, and TMG 2360, with phytotoxicity values of 28.9 and 36.2%. In contrast, the DM56I59 IPRO cultivar proved more sensitive, with a phytotoxicity of 90%. It is also observed that, at 45 DAA, the cultivars DM70I71 IPRO, Fibra IPRO, and TMG 7067 IPRO were more tolerant when subjected to a dose of 1 L cp ha$^{-1}$, with low phytotoxicity, without differing from the treatment control (without herbicide).

According to Neto et al. (2009), using herbicide mixtures can lead to possible phytotoxicity effects that can result in injuries to soybean crops. However, sensitivity may be due to the genotypic and intrinsic characteristics of each cultivar, which was observed in the study in question. The mixture of sulfentrazone + diuron, even though it was registered for soybean crops, resulted in a difference in the sensitivity responses of the cultivars

It should be noted that many herbicides considered selective for soybean cultivation can cause some poisoning, aggravated mainly by inadequate management and the use of overdoses. Dalazen et al. (2020) observed that high doses of sulfentrazone in pre-emergence of soybean in a sandy soil (17% clay) resulted in high levels of injury, reaching 76% at 30 DAA at the dose of 400 g i.a. ha$^{-1}$ under low rainfall conditions. However, in a year considered rainy, the injury did not exceed 10% at the same dose and soil.

According to Gehrke et al. (2020), tolerance to sulfentrazone depends on factors formed by lower absorption and translocation, rapid metabolization, and the ability to tolerate oxidative stress. About soybeans, the choice of cultivar impacts tolerance to sulfentrazone (Reiling et al., 2006). This fact can be explained by the differential tolerance to peroxidative stress intrinsic to each cultivar (Dayan et al., 1997). Other factors that affect crop sensitivity include adverse weather conditions, as well as cultivars and their cycles (Galon et al., 2011, Gazola et al., 2016).

Regarding the physiological aspects of quantum (Fv/Fm) and effective (YII) efficiency of PSII, it was observed at 15 DAA (Figure 1) that there was no interaction between cultivar and dose, with dose being the determining factor in these characteristics. Regardless of the dose used, there was a decrease in both variables compared to the control treatment (without herbicide), showing that the doses used can compromise photosynthetic activity in the initial stages of the culture. On average, compared to control treatment, at 15 DAA, the Fv/Fm was reduced by 10% for the dose of 1 L cp ha$^{-1}$ and 21% for the dose of 2 L cp ha$^{-1}$ (Figure 1A). For variable YII, the reduction was 35% and 43% for doses of 1 L cp ha$^{-1}$ and 2 L cp ha$^{-1}$, respectively, compared to the control treatment (Figure 1B).

**Table 3.** Percentage of phytotoxicity of soybean cultivars at 15 and 45 days after application (DAA) of sulfentrazone + diuron doses.

| Cultivar | 15 DAA | | | 45 DAA | | |
|---|---|---|---|---|---|---|
| | Dose (L cp ha$^{-1}$) | | | | | |
| | 0 | 1 | 2 | 0 | 1 | 2 |
| DM56I59 IPRO | 0.0 aC | 40.0 bB | 66.2 aA | 0.0 aC | 38.8 aB | 90.0 aA |
| DM60I63 IPRO | 0.0 aC | 26.2 dB | 36.2 cA | 0.0 aB | 22.5 bA | 42.5 bA |
| DM64I63 IPRO | 0.0 aB | 25.0 dA | 28.8 dA | 0.0 aB | 20.0 bA | 33.8 bA |
| DM66I68 IPRO | 0.0 aC | 30.0 cB | 42.5 cA | 0.0 aC | 26.2 bB | 70.0 aA |
| DM70I71 IPRO | 0.0 aC | 21.2 dB | 42.5 cA | 0.0 aB | 23.8 bB | 53.8 aA |
| Fibra IPRO | 0.0 aC | 18.8 eB | 36.2 cA | 0.0 aB | 11.2 bB | 43.8 bA |
| HO Amambay | 0.0 aC | 27.5 dB | 40.0 cA | 0.0 aB | 45.0 aA | 28.8 bA |
| HO Iguaçu | 0.0 aB | 37.5 cA | 37.5 cA | 0.0 aB | 60.0 aA | 52.5 aA |
| HO Paraguaçu | 0.0 aC | 60.0 aA | 50.0 bB | 0.0 aB | 56.2 aA | 48.8 bA |
| HO Pirapó | 0.0 aB | 47.5 bA | 47.5 bA | 0.0 aB | 58.8 aA | 51.2 aA |
| HO Tererê | 0.0 aC | 30.0 cB | 41.2 cA | 0.0 aB | 25.0 bA | 42.5 bA |
| Lança IPRO | 0.0 aC | 35.0 cB | 57.5 aA | 0.0 aB | 41.2 aA | 62.5 aA |
| Lótus IPRO | 0.0 aC | 33.8 cB | 46.2 bA | 0.0 aC | 37.5 aB | 66.2 aA |
| M6410 IPRO | 0.0 aB | 33.8 cA | 33.8 dA | 0.0 aB | 50.0 aA | 56.2 aA |
| NEO 660 | 0.0 aC | 12.5 eB | 30.0 dA | 0.0 aB | 30.0 bA | 36.2 bA |
| TMG 2356 IPRO | 0.0 aC | 60.0 aA | 40.0 cB | 0.0 aB | 58.8 aA | 63.8 aA |
| TMG 2359 IPRO | 0.0 aB | 45.0 bA | 45.0 bA | 0.0 aB | 48.8 aA | 45.0 bA |
| TMG 2360 IPRO | 0.0 aB | 23.8 dA | 27.5 dA | 0.0 aB | 30.0 bA | 28.8 bA |
| TMG 2364 IPRO | 0.0 aB | 37.5 cA | 41.2 cA | 0.0 aB | 47.5 aA | 60.0 aA |
| TMG 7067 IPRO | 0.0 aC | 22.5 dB | 45.0 bA | 0.0 aB | 22.5 bB | 57.5 aA |
| Mean | 0.0 | 33.38 | 41.74 | 0.0 | 37.69 | 51.695 |
| CV (%) | 26.22 | | | 21.40 | | |

Means followed by the same lowercase letter in the column and uppercase letters in the row belong to the same group by the Scott-Knott test ($p < 0.05$).

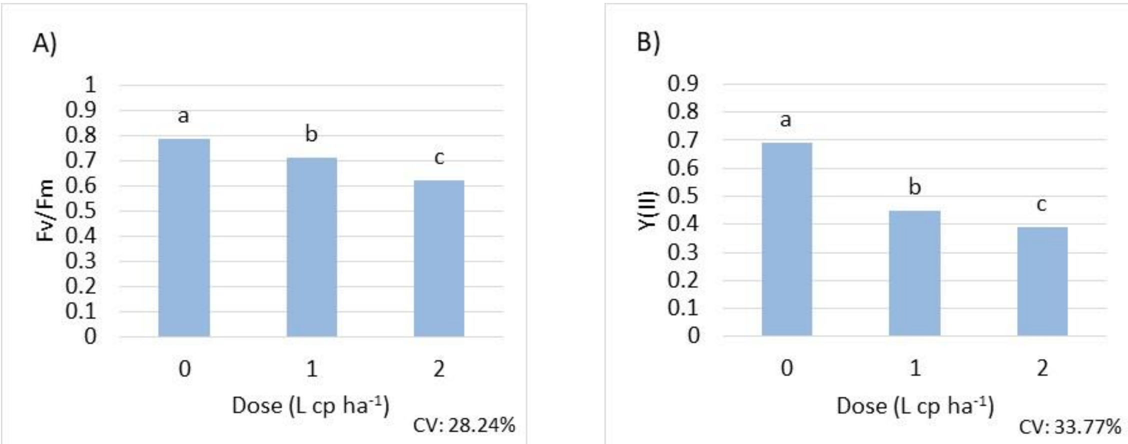


**Figure 1**. Quantum (Fv/Fm) (A) and effective (YII) (B) efficiency of photosystem II at 15 days after application (DAA) of sulfentrazone + diuron doses in soybean cultivars. Means followed by the same lowercase letter belong to the same group by the Scott-Knott test ($p < 0.05$).

Both diuron and sulfentrazone are herbicides in which the mechanisms of action are directly linked to the chloroplast. Sulfentrazone is an herbicide that inhibits PPO enzyme, promoting the accumulation of protoporphyrin IX (Hess, 2000). When inhibited, reactive oxygen species (ROS) are formed in the presence of oxygen, which cause lipid peroxidation and, consequently, the destruction of cell membranes, leading to plant death (Shaner, 2014).

Diuron's mechanism of action is the inhibition of PSII, promoted by the binding of herbicides from this group to the quinone B (Qb) binding site on the D1 protein, which is located in the thylakoid membranes of chloroplasts. The herbicide causing transport blockage of electrons from quinone A (Qa) to Qb. Therefore, there is a reduction and even cessation of $CO_2$ fixation and the production of ATP and $NADPH_2$, which are essential for plant development (Menendez, 1997). In the same way as PPO inhibitors, what leads treated plants to death is the accumulation of ROS, which leads to lipid peroxidation and destruction of membranes (Hess, 2000).

According to Maxwell and Johnson (2000), if the plant is under normal conditions, without stress, most species' Fv/Fm values can vary from around 0.750 to

0.850. Values lower than these indicate stress and reduced photosynthetic efficiency of the plant.

However, when evaluated at 45 DAA (Table 4), it is noticeable that the characteristics evaluated varied depending on the cultivar and the herbicide dose; that is, there was an interaction between the factors evaluated at this date. In this sense, it is worth highlighting that even though the doses affected physiological parameters in the initial phase (15 DAA), at 45 days, some cultivars did not differ from the control, even at the highest dose studied, showing that some cultivars tend to recover from the stress caused by the herbicide.

Lower Fv/Fm and YII rates were observed in cultivars when subjected to a higher dose, with the negative highlights being the DM56I59 IPRO and DM66I68 IPRO. Both cultivars presented the lowest photosynthetic indices at a dose of 2 L cp ha$^{-1}$ compared to the control and the other cultivars (Table 4).

Regarding the relative electron transport rate (rETR) at 15 and 45 DAA (Figure 2), it is possible to corroborate the data described previously for Fv/Fm and YII. It was found that with an increase in herbicide dose, there is a decrease in the flow of electrons in PSII, indicating damage to the plant's photosynthetic apparatus.

**Table 4.** Quantum (Fv/Fm) and practical (Y II) efficiency of photosystem II at 45 days after application (DAA) of sulfentrazone + diuron doses in soybean cultivars.

| Cultivar | Fv/Fm | | | Y (II) | | |
|---|---|---|---|---|---|---|
| | Dose (L cp ha$^{-1}$) | | | | | |
| | 0 | 1 | 2 | 0 | 1 | 2 |
| DM56I59 IPRO | 0.764 aA | 0.790 aA | 0.197 bB | 0.678 aA | 0.702 aA | 0.180 bB |
| DM60I63 IPRO | 0.794 aA | 0.774 aA | 0.583 bA | 0.723 aA | 0.583 aA | 0.398 bB |
| DM64I63 IPRO | 0.771 aA | 0.792 aA | 0.778 aA | 0.682 aA | 0.653 aA | 0.631 aA |
| DM66I68 IPRO | 0.789 aA | 0.775 aA | 0.395 bB | 0.694 aA | 0.635 aA | 0.321 bB |
| DM70I71 IPRO | 0.774 aA | 0.774 aA | 0.772 aA | 0.702 aA | 0.691 aA | 0.642 aA |
| Fibra IPRO | 0.772 aA | 0.770 aA | 0.781 aA | 0.706 aA | 0.680 aA | 0.658 aA |
| HO Amambay | 0.784 aA | 0.581 bA | 0.787 aA | 0.717 aA | 0.334 aB | 0.699 aA |
| HO Iguaçu | 0.771 aA | 0.781 aA | 0.591 bA | 0.724 aA | 0.633 aA | 0.476 bA |
| HO Paraguaçu | 0.780 aA | 0.380 bB | 0.778 aA | 0.698 aA | 0.481 aA | 0.711 aA |
| HO Pirapó | 0.776 aA | 0.386 bB | 0.775 aA | 0.690 aA | 0.514 aA | 0.649 aA |
| HO Tererê | 0.778 aA | 0.784 aA | 0.766 aA | 0.751 aA | 0.634 aA | 0.619 aA |
| Lança IPRO | 0.769 aA | 0.781 aA | 0.597 bA | 0.686 aA | 0.700 aA | 0.486 bA |
| Lótus IPRO | 0.786 aA | 0.771 aA | 0.585 bA | 0.666 aA | 0.706 aA | 0.515 bA |
| M6410 IPRO | 0.777 aA | 0.581 bA | 0.588 bA | 0.714 aA | 0.487 aA | 0.468 bA |
| NEO 660 | 0.792 aA | 0.782 aA | 0.778 aA | 0.730 aA | 0.557 aA | 0.545 aA |
| TMG 2356 IPRO | 0.770 aA | 0.590 bA | 0.576 bA | 0.730 aA | 0.624 aA | 0.447 bA |
| TMG 2359 IPRO | 0.784 aA | 0.774 aA | 0.782 aA | 0.652 aA | 0.624 aA | 0.669 aA |
| TMG 2360 IPRO | 0.783 aA | 0.583 bA | 0.777 aA | 0.677 aA | 0.649 aA | 0.625 aA |
| TMG 2364 IPRO | 0.777 aA | 0.761 aA | 0.567 bA | 0.723 aA | 0.690 aA | 0.493 bA |
| TMG 7067 IPRO | 0.782 aA | 0.797 aA | 0.581 bA | 0.632 aA | 0.661 aA | 0.478 bA |
| Mean | 0.779 | 0.700 | 0.652 | 0.699 | 0.612 | 0.536 |
| CV (%) | | 29.21 | | | 28.43 | |

Means followed by the same lowercase letter in the column and uppercase letters in the row belong to the same group by the Scott-Knott test ($p < 0.05$).

No significant effect was observed for this variable for the cultivar factor. This decrease in rETR due to dose increase in all cultivars can be explained mainly by the direct-action mechanism of diuron, which blocks the passage of electrons from PSII to photosystem I (PSI). However, the low rETR cannot be attributed exclusively to the PSII inhibitor (diuron) since sulfentrazone, when inhibiting PPO, produces ROS that also lead to the inhibition of photosystem activity (Tripathy et al., 2007).

In the table 5 are presented the results of shoot dry mass (SDM) and plant height at 45 DAA of the sulfentrazone + diuron mixture. It is possible to verify that these characteristics were affected, with a significant interaction between the herbicide dose and cultivar factors.

Osipe et al. (2014), working with sulfentrazone, found a reduction in the height of soybean plants compared to the control without herbicide. These results corroborate the present research, which can be explained by the processes described previously, as with the drop in photosynthetic processes, the plant's capacity to accumulate dry matter is reduced.

Zacharias et al. (2021), evaluating the agronomic performance of soybeans in response to the application of doses of sulfentrazone + diuron in pre-emergence, observed that herbicides, both alone and in mixtures, reduced plant height.

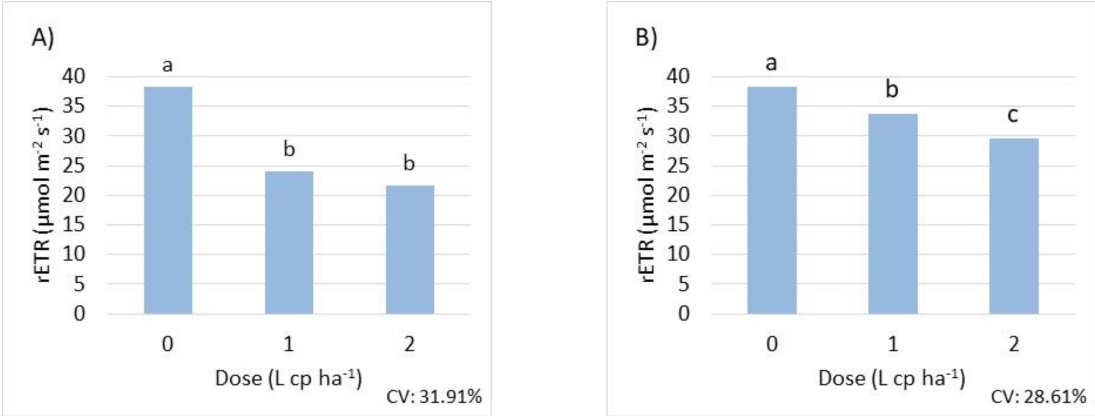


**Figure 2**. Relative electron transport rate (rETR) at 15 (A) and 45 (B) days after the application (DAA) of sulfentrazone + diuron doses in soybean cultivars. Means followed by the same lowercase letter belong to the same group by the Scott-Knott test ($p < 0.05$).

**Table 5**. Shoot dry mass (SDM) and plant height at 45 days after application (DAA) of sulfentrazone + diuron doses in soybean cultivars.

| Cultivar | SDM (g) | | | Height (cm) | | |
|---|---|---|---|---|---|---|
| | Dose (L cp ha$^{-1}$) | | | | | |
| | 0 | 1 | 2 | 0 | 1 | 2 |
| DM56I59 IPRO | 6.64 aA | 1.90 bB | 0.130 aB | 52.25 bA | 32.25 bA | 6.25 bB |
| DM60I63 IPRO | 7.58 aA | 3.71 aB | 3.063 aB | 74.75 bA | 65.75 aA | 51.25 aA |
| DM64I63 IPRO | 7.20 aA | 4.45 aB | 2.809 aB | 63.50 bA | 64.50 aA | 71.50 aA |
| DM66I68 IPRO | 7.47 aA | 3.64 aB | 0.903 aC | 76.25 bA | 65.75 aA | 27.00 bB |
| DM70I71 IPRO | 8.08 aA | 4.51 aB | 2.026 aC | 92.25 aA | 66.50 aB | 44.25 aB |
| Fibra IPRO | 7.67 aA | 4.96 aB | 2.077 aC | 60.00 bA | 61.00 aA | 38.00 bA |
| HO Amambay | 5.10 bA | 2.39 bB | 2.522 aB | 69.25 bA | 49.25 aA | 50.75 aA |
| HO Iguaçu | 4.95 bA | 1.14 bB | 1.329 aB | 57.00 bA | 33.50 bA | 34.75 bA |
| HO Paraguaçu | 5.14 bA | 1.71 bB | 2.182 aB | 62.50 bA | 32.50 bA | 41.75 aA |
| HO Pirapó | 6.33 aA | 0.66 bB | 0.940 aB | 53.25 bA | 14.50 bB | 21.75 bB |
| HO Tererê | 7.79 aA | 4.12 aB | 1.617 aC | 97.00 aA | 60.25 aB | 46.50 aB |
| Lança IPRO | 6.84 aA | 1.37 bB | 0.806 aB | 61.00 bA | 33.50 bB | 19.00 bB |
| Lótus IPRO | 8.21 aA | 2.79 aB | 0.957 aB | 106.75 aA | 35.50 bB | 22.75 bB |
| M6410 IPRO | 7.19 aA | 3.86 aB | 1.326 aC | 82.00 aA | 41.25 bB | 36.50 bB |
| NEO 660 | 6.77 aA | 4.07 aB | 2.258 aB | 70.75 bA | 57.25 aA | 49.00 aA |
| TMG 2356 IPRO | 5.55 bA | 1.01 bB | 0.954 aB | 68.75 bA | 23.75 bB | 23.00 bB |
| TMG 2359 IPRO | 5.16 bA | 0.88 bB | 1.386 aB | 89.50 aA | 32.50 bB | 34.75 bB |
| TMG 2360 IPRO | 6.98 aA | 2.95 aB | 4.031 aB | 60.00 bA | 49.25 aA | 61.75 aA |
| TMG 2364 IPRO | 6.65 aA | 1.04 bB | 0.930 aB | 79.00 aA | 26.25 bB | 22.00 bB |
| TMG 7067 IPRO | 5.41 bA | 3.65 aA | 1.676 aB | 65.00 bA | 57.50 aA | 36.00 bA |
| Mean | 6.64 | 2.74 | 1.70 | 72.04 | 45.13 | 36.93 |
| CV (%) | | 39.46 | | | 35.86 | |

Means followed by the same lowercase letter in the column and uppercase letters in the row belong to the same group by the Scott-Knott test ($p < 0.05$).

However, Dalazen et al. (2020), when evaluating the yield components of the soybean crop, concluded that, although initial injuries occurred, grain yeld was not limited when the recommended doses of sulfentrazone were applied to sandy soil, with this herbicide considered an excellent tool in weed control.

It is important to emphasize that this study was carried out under controlled conditions, which does not represent the totality and magnitude of the processes involved in the dynamics of herbicides in the field. However, this work serves to classify soybean cultivars according to sensitivity to the mixture of sulfentrazone + diuron. Thus, studies with other cultivars and herbicides, including different field environments, are necessary to contribute to the recommendation of pre-emergent herbicides.

## 4. Conclusions

The selectivity of the sulfentrazone + diuron mixture is dependent on the dose and cultivar of soybean. DM56I59 IPRO, HO Amambay, HO Iguaçu, HO Paraguaçu, HO Pirapó, Lança IPRO, Lótus IPRO, M6410 IPRO, TMG 2356 IPRO, TMG 2359 IPRO, and TMG 2364 IPRO cultivars were the most affected, even at the recommended dose (1 L cp ha$^{-1}$). On the other hand, the cultivars NEO 660, Fibra IPRO and TMG 7067 were the ones that stood out positively in most evaluations, being more tolerant to the mixture of sulfentrazone + diuron. In this sense, the mixture of sulfentrazone + diuron must be adjusted, considering the cultivars' sensitivity and herbicide dose. Therefore, more studies with a more considerable number of cultivars and environments are needed to determine the correct product positioning.

**Authors' Contribution**

Conceptualization and methodology: Edson Araújo de Amorim, José Flávio Firmani, Giliardi Dalazen; data collection and curation: Edson Araújo de Amorim, José Flávio Firmani, Gustavo Henrique Gasque, Alexandre Chiang, Giliardi Dalazen; formal analysis: Edson Araújo de Amorim, José Flávio Firmani, Giliardi Dalazen; data interpretation: Edson Araújo de Amorim, José Flávio Firmani, Giliardi Dalazen; project administration: Edson Araújo de Amorim, Giliardi Dalazen; supervision: Giliardi Dalazen; original draft preparation: Edson Araújo de Amorim, José Flávio Firmani, Gustavo Henrique Gasque, Alexandre Chiang, Giliardi Dalazen; writing-review and editing: Edson Araújo de Amorim, José Flávio Firmani, Giliardi Dalazen. All authors read and approved the final version of the manuscript.

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