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Weed control and soybean agronomic performance in response to application of sulfentrazone + diuron in pre-emergence

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Abstract
The use of pre-emergent herbicides is an important tool in weed management. Sulfentrazone + diuron mixture was recently launched onto the market. The objective of this work was to evaluate the weed control and the agronomic performance of soybean in response to application of sulfentrazone + diuron doses in pre-emergence. The experiment was conducted in Londrina PR, in an oxisol. The treatments were doses of sulfentrazone + diuron (62 + 123, 123 + 245, 184 + 368, 245 + 490, 306 + 613 e 368 + 735 g a.i. ha^{-1}). In addition to these treatments, isolated applications of sulfentrazone (245 g a.i. ha^{-1}) and diuron (490 g a.i. ha^{-1}) were evaluated, as well as a weedy and a weed-free control. For the weed control, the wild radish (*Raphanus raphanistrum*) and itchgrass (*Rottboellia cochinchinensis*) emergence were evaluated. In soybean, photosystem II (PSII) activity, stand, plant height, number of pods per plant, height of insertion of the first pod, number of nodes per plant, mass of a thousand grains and grain yield were evaluated. Results show that the mixture of sulfentrazone + diuron resulted in less than 50% wild radish control, regardless of the dose evaluated. However, for itchgrass, the control was greater than 90% in doses from 123 g sulfentrazone + 245 g diuron a.i. ha^{-1}. Regarding the soybean crop, in doses from 245 g sulfentrazone + 490 g diuron a.i. ha^{-1} there was a greater number of pods per plant and higher grain yield, of about 3,000 kg ha^{-1}. The application of herbicides led to a transient inhibition of PSII activity, which did not result in a reduction in crop grain yield, indicating plant recovery. Therefore, the mixture of sulfentrazone + diuron is a good alternative for the weed management in pre-emergence of soybean, and should be positioned according to the history of field infestation.
Keywords: photosystem II; *Glycine max*; PPO; *Raphanus raphanistrum*; *Rottboellia cochinchinensis.*

Controle de plantas daninhas e desempenho agronômico de soja em resposta à aplicação de sulfentrazone + diuron em pré-emergência

Resumo
A utilização de herbicidas pré-emergentes é uma ferramenta importante no manejo de plantas daninhas. Recentemente foi lançada no mercado a mistura de sulfentrazone + diuron. O objetivo deste trabalho foi avaliar o controle de plantas daninhas e o desempenho agronômico da soja em resposta à aplicação de doses de sulfentrazone + diuron em pré-emergência. O experimento foi conduzido em Londrina PR, em latossolo. Os tratamentos avaliados foram doses de sulfentrazone + diuron (62 + 123, 123 + 245, 184 + 368, 245 + 490, 306 + 613 e 368 + 735 g i.a. ha^{-1}). Além desses tratamentos, foram avaliadas as aplicações isoladas de sulfentrazone (245 g i.a. ha^{-1}) e de diuron (490 g i.a. ha^{-1}), além de uma testemunha infestada e outra capinada. Foram avaliados os controles de nabiça (*Raphanus raphanistrum*) e de capim-camalote (*Rottboellia cochinchinensis*). Na soja, foram avaliados a atividade do fotossistema II (FSII), a emergência, estatura de plantas, número de legumes por planta, altura de inserção do primeiro legume, número de nós por planta, massa de mil grãos e produtividade de grãos. A mistura de sulfentrazone + diuron apresentou controle de nabiça inferior a 50%, independentemente da dose avaliada. No entanto, para o capim-camalote, o controle foi satisfatório, sendo superior a 90% em doses a partir de 123 g sulfentrazone + 245 g diuron i.a. ha^{-1}. Em relação à soja, em doses a partir de 245 g sulfentrazone + 490 g diuron i.a. ha^{-1} houve maior número de legumes por planta e maior produtividade de grãos, de aproximadamente 3.000 kg ha^{-1}. A

aplicação dos herbicidas levou a uma inibição transitória da atividade do FSII, a qual não resultou em redução da produtividade da cultura, indicando a recuperação das plantas. Portanto, a mistura de sulfentrazone + diuron é uma boa alternativa para o manejo de plantas daninhas em pré-emergência da cultura da soja, devendo ser posicionada de acordo com o histórico de infestação da lavoura.
Palavras-chave: fotossistema II; *Glycine max*; PPO; *Raphanus raphanistrum*; *Rottboellia cochinchinensis*.

Introduction

Soybean (*Glycine max*) is one of the main agricultural crops in Brazil, occupying almost 36 million hectares, distributed in all regions of the country (CONAB, 2020). In addition to the expansion of the area, the production record in the last harvests is also attributed to increased grain yield, with the national average reaching 3,206 kg ha^{-1} in 2019/20 (CONAB, 2020). However, some farmers obtain grain yields considerably higher than the national average, demonstrating that it is possible to further increase average grain yield through the control of productivity limiting factors (BATTISTI *et al.*, 2018).

Among the factors that limit soybean grain yield, weeds stand out due to the interference caused in the crop and the high cost of control. The problem is aggravated when weeds are resistant to herbicides (ADEGAS *et al.*, 2017). For example, one plant per m^{-2} of sourgrass (*Digitaria insularis*) resistant to glyphosate results in a reduction of 500 to 1,400 kg ha^{-1} in soybean grain yield (GAZZIERO *et al.*, 2019), and its control cost is, on average, 165% higher compared to that of a susceptible infestation (ADEGAS *et al.*, 2017). There are currently 52 cases of weed resistance to herbicides in Brazil (HEAP, 2021), and measures to manage these populations and prevent the emergence of new cases are essential.

Integrated weed management (IWM) involves a series of chemical and non-chemical control methods. When implemented IWM minimize the impact of weeds and it could delay the evolution of herbicide resistant weeds (BECKIE; HARKER, 2017). Within the chemical method, the use of pre-emergent herbicides has been presented as a good alternative to significantly reducing infestations of weeds after some years of use (NUNES *et al.*, 2018). Among the advantages of using pre-emergent are the reduction in the number of herbicide applications, the lower development of weeds, making them more sensitive to post-emergence applications, the absence of weeds during the critical interference prevention period, and increase the diversity of herbicide sites of action (LOPES OVEJERO *et al.*, 2013).

Another important IWM measure within the chemical method is the use of mixtures of herbicides with different mechanisms of action (BECKIE; HARKER, 2017). Among the advantages of mixtures are the reduction in the number of operations, the expansion of the spectrum of action, the possibility of improving control in cases of synergism and the prevention and management of resistance (BECKIE; REBOUD, 2009). Following these fundamentals, the industry has made formulated pre-emergent mixtures, composed of herbicides with different mechanisms of action, such as the commercial mixture of sulfentrazone + diuron (AGROFIT, 2021).

Sulfentrazone is a protoporphyrinogen oxidase (PPO) inhibitor, an enzyme responsible for the conversion of protoporphyrinogen to protoporphyrin. Its inhibition by the herbicide results in the accumulation of singlet oxygen, a reactive oxygen species (ROS) that causes the peroxidation of lipids constituting membranes (COBB; READE, 2010). The herbicide diuron inhibits the electron transport chain from quinone A (Qa) to quinone B (Qb) in photosystem II (PSII), which also leads to the accumulation of singlet oxygen, followed by membrane degradation and cell leakage (COBB; READE, 2010). Therefore, although in different ways, both herbicides culminate in lipid peroxidation and degradation of membranes in the presence of light, leading to cell leakage and tissue necrosis (HESS, 2000). This makes the use of this mixture interesting, since the production of singlet oxygen occurs concurrently by two different routes (HESS, 2000). In addition, the association of these herbicides can increase the spectrum of action, since diuron acts mainly on grasses, while sulfentrazone has good control over eudicotyledons and some monocot species (PROCÓPIO *et al*., 2008).

Despite the possible benefits of the sulfentrazone + diuron mixture on weed control, it is essential that this combination does not harm the germination, growth, development and grain yield of soybean. Although these herbicides are registered and selective for pre-emergence applications in soybean (AGROFIT, 2021), selectivity is variable and dependent on factors with dose, soil characteristics, environmental conditions and cultivar. Thus, the objective of this study was to evaluate weed control and the agronomic performance of soybean in response to application of sulfentrazone + diuron doses in pre-emergence.

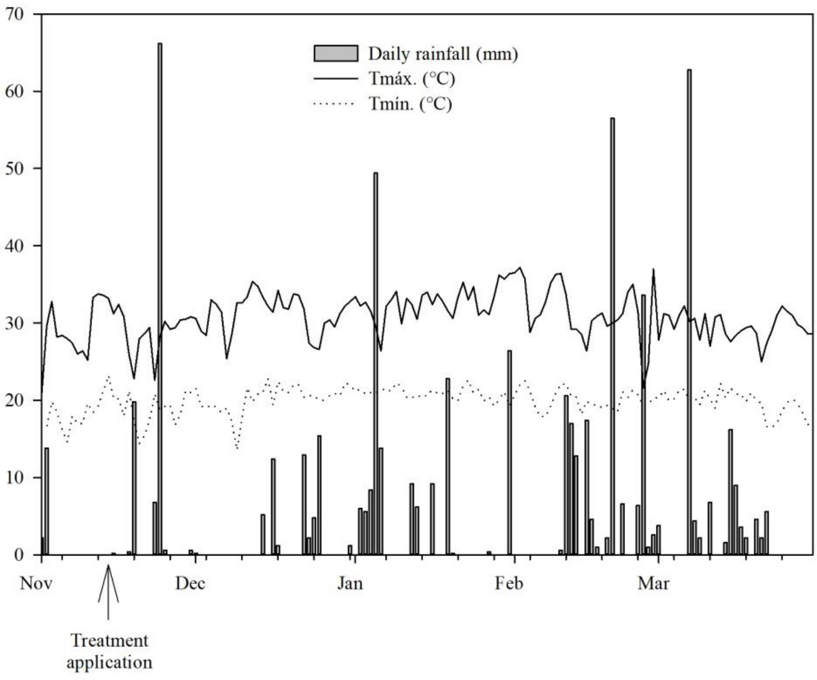
Material and Methods

Characterization and preparation of the experimental area

The experiment was conducted at Fazenda Escola da Universidade Estadual de Londrina (UEL), Londrina, Paraná (23°20'25''S; 51°12'36''O), at an altitude of 540 m, during the 2018/19 season. The area's soil is classified as an oxisol with a clay texture, with the following characteristics: 12% sand, 36% silt and 52% clay; pH 5.50; 2.28 g dm^{-3} of organic matter and 9.25 cmolc dm^{-3} of cation exchange capacity. Prior to the installation of the experiment, the area was cultivated with black oats (*Avena sativa*), which was terminated 15 days before soybean sowing. Were used the herbicides glyphosate (Roundup Original, 360 g a.e. L^{-1}), at a dose of 1,080 g a.e. ha^{-1}, in a mixture with clethodim (Select 240 EC, 240 g a.i. ha^{-1}), at a dose of 144 g a.i. ha^{-1}, with the addition of Lanzar adjuvant (0.5% v/v). The day before soybean sowing, another application with paraquat (Tocha, 200 g a.i. ha^{-1}) was performed, at a dose of 400 g a.i. ha^{-1}, in order to eliminate weeds that survived the first application, and also to control weeds that germinated after the previous application. Both weed control operations were performed with a spray solution rate of 150 L ha^{-1}. At that moment, the dry mass of the aerial part of oats was quantified at 4 ton ha^{-1}.

The meteorological data of pluviometric precipitation, maximum and minimum temperatures were obtained in a meteorological station of the Instituto de Desenvolvimento Rural do Paraná (IDR), in Londrina (Figure 1). It is observed that immediately after soybean sowing and application of the treatments there was a rainfall of approximately 20 mm, which is favorable both for the action of pre-emergent herbicides and for the germination of weeds and crop.

Figure 1. Data of daily rainfall (mm) and maximum (Tmax. (°C)) and minimum (Tmin. (°C)) temperatures during the conduction of the experiment.



Soybean sowing and crop management

Soybeans sowing was carried out mechanically (Vence Tudo SA 11500), with spacing between rows of 0.45 m, on November 13, 2018. It was used the cultivar NS 6601 IPRO (RMG 6.6), in the density of 267,000 seeds ha^{-1}, which corresponds to 12 seeds m^{-1}, deposited at a depth of 5 cm. The seeds were previously treated with pyraclostrobin + methyl thiophanate + fipronil (Standak Top, 25 + 225 + 250 g a.i. L^{-1}), at a doses of 2.5 + 22.5 + 25 g a.i. 100 kg^{-1} of seeds.

For the crop management in post-emergence, three fungicide applications were performed with trifloxystrobin + protioconazole (Fox, 150 + 175 g a.i. L^{-1}), at doses of 60 + 70 g a.i. ha^{-1}, at R1, R1 + 18 days and R1 + 35 days stages. In the third application, the insecticide thiametoxan + lambda-cyhalothrin (Engeo Pleno S, 141 + 160 g a.i. L^{-1}) was added, at doses of 28.2 + 32 g a.i. ha^{-1}. Except for the application of pre-emergence treatments, no other herbicide applications were carried out during the crop cycle.

Experimental design and treatments

The experiment was implemented in a randomized complete block design, with four replications. Each experimental unit was 3.15 m wide (6 rows of soybean sowing) and 6 m long, totaling 18.90 m^2 per plot, and a useful area of 9.0 m^2 (4 crop lines x 4 m long). The evaluated treatments were composed by different doses of the commercial mixture of the sulfentrazone + diuron herbicides (Stone, 175 + 350 g a.i. L^{-1}) (Table 1). In addition to these treatments, sulfentrazone at a dose of 245 g a.i. ha^{-1} (Boral 500 SC, 500 g a.i. L^{-1}) and diuron at a dose of 490 g a.i. ha^{-1} (Diuron Nortox 500 SC, 500 g a.i. L^{-1}), one weedy and one weed-free control. For soybean, the recommended dose of sulfentrazone + diuron ranges from 123 + 245 to 245 + 490 g a.i. ha^{-1}, depending on the characteristics of the soil (AGROFIT, 2021).

Table 1. List of evaluated treatments, with the active ingredients, commercial product and doses of active ingredient and commercial product.

	Active ingredient (a.i.)	**g a.i. ha^{-1}**	**Commercial product (C.P.)**	**mL C.P. ha^{-1}**
1	Weedy	-	-	-
2	Sulfentrazone + Diuron	62 + 123	Stone	350
3	Sulfentrazone + Diuron	123 + 245	Stone	700
4	Sulfentrazone + Diuron	184 + 368	Stone	1,050
5	Sulfentrazone + Diuron	245 + 490	Stone	1,400
6	Sulfentrazone + Diuron	306 + 613	Stone	1,750
7	Sulfentrazone + Diuron	368 + 735	Stone	2,100
8	Sulfentrazone	245	Boral 500 SC	490
9	Diuron	490	Diuron Nortox 500 SC	980
10	Weed-free	-	-	-

The treatments were applied the day after soybean sowing, using a CO_2 pressurized sprayer, with a 3 m bar containing six TJ11002 tips, spaced 0.5 m apart. The application speed was 3.6 km h^{-1}, dispensing a spray volume equivalent to 150 L ha^{-1}. In the weeded control treatment, two applications of 890 g a.e. ha^{-1} of glyphosate (Gliz 480 SL, 356 g a.e. L^{-1}) were performed, at V2 and V7 crop stages, with the same equipment and regulation described above.

Assessments

Weed control

At 30 days after the application of treatments (DAT) weed control evaluation was performed. Weeds were counting at two points in each plot, randomly defined within the useful area. Each point was delimited by a 0.5 x 0.5 m square. The species present were identified and surveyed separately.

The most common weeds in the experimental area during the execution of the experiment were the wild radish (*Raphanus raphanistrum*) and the itchgrass (*Rottboellia cochinchinensis*). In the infested treatment, these species showed infestations of 207 and 66 plants m^{-2}, respectively. Therefore, these two species were considered for the evaluation of weed control.

Agronomic performance of soybeans

The evaluations in soybean started at V1 stage, being evaluated the emergence of plants in two linear meters per plot. When the crop was at V3 stage, the plant height, in 10 plants per plot, and the efficiency of the PSII were evaluated. For the evaluation of the efficiency of the PSII, two soybean leaflets per plot were randomly collected within the useful area of each plot and immediately packed in falcon tubes, filled with water and wrapped in aluminum foil for transport to the laboratory.

The maximum efficiency of the PSII was obtained by measuring the fluorescence of chlorophyll *a*, using a portable fluorometer model OS1p (OptiSciences). The collected leaflets were lightly dried with paper towels and inserted in the clips that are attached to the equipment to perform the measurements. The maximum efficiency of the PSII was determined by calculating the Fv/Fm ratio. The leaflets were left in the dark for at least an hour (time between collection and transport to the laboratory), thus allowing the measurement of initial fluorescence intensity (F0) in response to weak modulated light. The maximum fluorescence (Fm) was recorded after a pulse of saturating light (7,500 µmols m^{-2} s^{-1}), and the variable fluorescence (Fv) calculated as: Fv = Fm - F0 (BAKER, 2008).

At R9 stage, on March 28, 2019, final plant height, height of the first productive node, number of nodes per plant and number of pods per plant evaluations were performed in 10 plants per plot, collected randomly within the useful area. To determine the grain yield, four linear meters were harvested manually from two central lines of the plot, corresponding to 3.6 m^2 per plot. Then, the plants were thrashed and the samples were classified, removing impurities with the aid of sieves. The samples were weighed on an analytical balance and the values were extrapolated to kg ha^{-1}. Finally, the mass of a thousand grains (MTG) was determined, estimated from the determination of the mass of two subsamples of 100 grains per plot. Both for determining grain yield and for MTG the grain moisture was corrected to 13%.

Statistical analysis

The data were submitted to analysis of variance by the F test ($p \leq 0.05$) with the aid of the statistical program RStudio. When the herbicide dose effect was significant, the complementary analysis was performed adjusting regressions according to the degree of association (R^2 value) between the response variable and the predictor. For the variables of wild radish and itchgrass control, the best adjustments were obtained with sigmoidal (three parameters) and exponential regressions, respectively. For the variables efficiency of the PSII, plant height and number of pods per plant, linear regressions were adjusted. Finally, for the variable soybean grain yield, the second degree non-linear regression was adjusted.

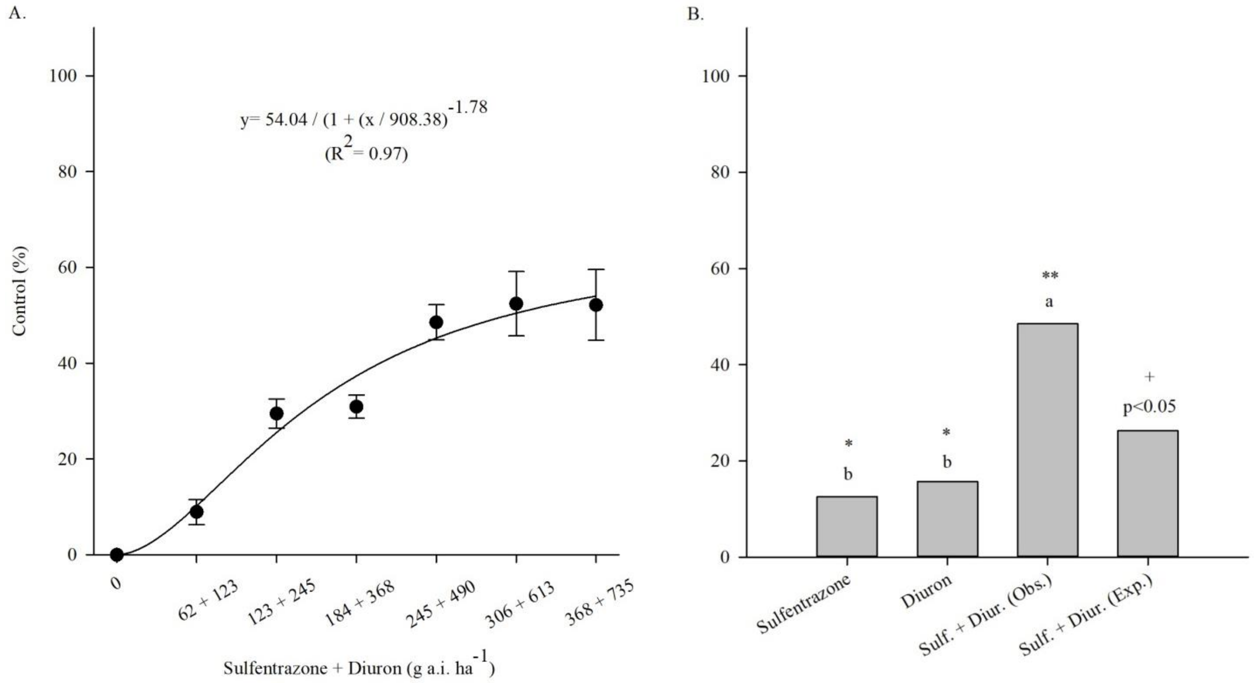
For the variables plant height, number of pods per plant, and soybean grain yield, the treatments (doses) were individually compared with the weedy control treatment by the Dunnett's test ($p \leq 0.05$). The effect of the mixture of sulfentrazone + diuron at the dose of 245 + 490 g a.i. ha^{-1} was also evaluated in comparison to the same doses of herbicides applied separately. The means of these treatments were separately compared with each other and with the controls by the Tukey's test ($p \leq 0.05$). Colby's method (1967) was used to estimate the efficiency of the mixture from the controls observed for each herbicide. The estimated value was compared to that observed in the application of the mixture, and submitted to Student's t test ($p \leq 0.05$). In this method, the effect of the mixture is considered antagonistic when the estimated value is higher than that observed. Likewise, the effect is considered synergistic when the estimated value is lower than that of the mixture. Finally, the effect of the mixture is considered additive when the estimated value is equal to that of the mixture.

Results and Discussion

Weed control

In the evaluation of weed control performed at 30 DAT, it was observed that the wild radish control was increasing with the increase in the herbicide dose (Figure 2A). However, even at the highest doses evaluated, the control did not exceed 50%. Considering a satisfactory control index from 80%, it can be said that the mixture of sulfentrazone + diuron was not efficient. In addition, it is observed that the dose increase from 245 g sulfentrazone + 490 g diuron a.i. ha^{-1} did not result in an increase in the control of this weed.

Figure 2. Wild radish (*Raphanus raphanistrum*) control at 30 DAT in response to the application of doses of sulfentrazone + diuron (A); and wild radish control observed by applying the herbicides alone and in mixture, and estimated by the Colby's method (B). In figure A, vertical bars indicate the confidence interval. In figure B, means followed by the same letter do not differ by Tukey's test (p ≤ 0.05); * and ** indicate a significant difference in control in relation to the control infested by the Dunnett's test (p ≤ 0.05 and 0.01, respectively); + indicates a synergistic effect between the observed control and the one estimated by the Colby's method, submitted to Student's t test (p ≤ 0.05).

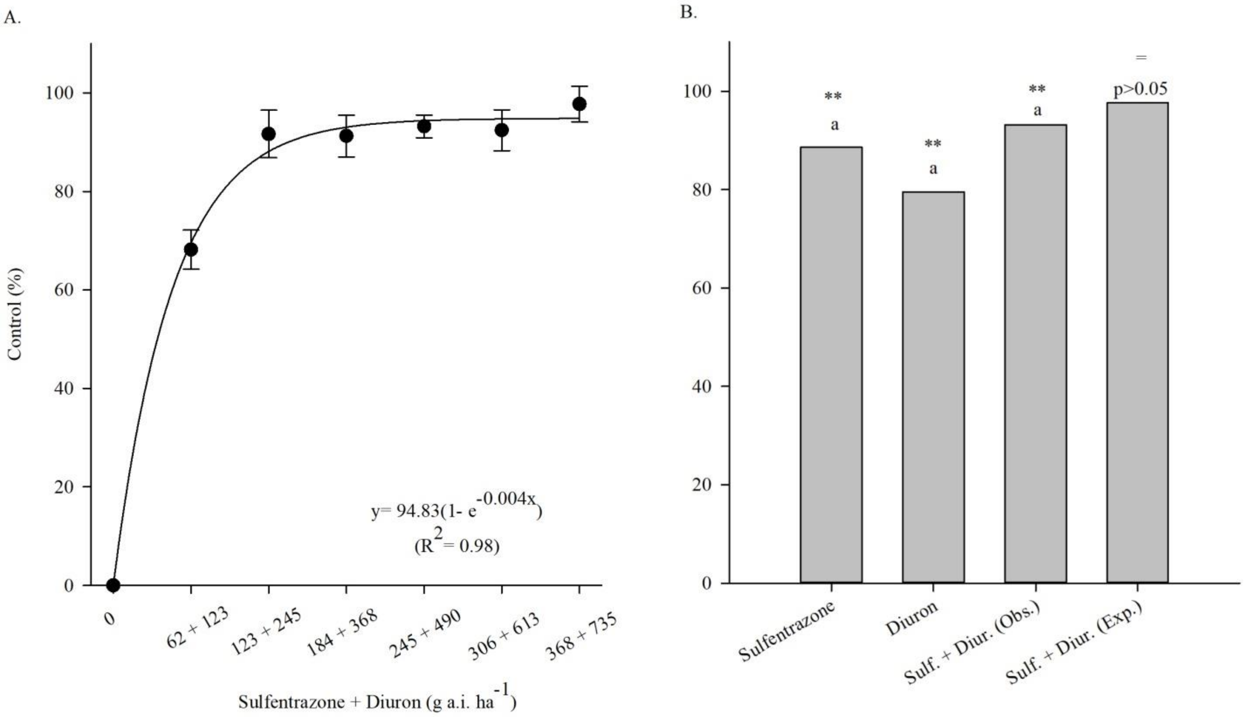


Although the low control of wild radish, the mixture of sulfentrazone + diuron resulted in a control significantly superior to that observed by the herbicides applied separately in the additional treatments with the same doses (Figure 2B). The application of the mixture resulted in a control of 49%, while the controls for sulfentrazone and diuron were 13 and 16%, respectively, not differing from each other (Figure 2B). In this way, Colby's analysis indicated the occurrence of synergism of the mixture for the wild radish control, since the expected (estimated) control was only 26%, significantly lower than that observed in the field.

The low efficiency of these herbicides on wild radish has already been reported by Santos *et al.* (2012), who observed a control of only 5% at 30 days after the application of 200 g a.i. ha^{-1} of sulfentrazone in pre-emergence. Similarly, Fonseca *et al.* (2018) observed 40% control of wild radish 30 days after the application of 125 g i.a. ha^{-1} sulfentrazone in pre-emergence. For diuron, Campos *et al.* (2012) reported satisfactory control of wild radish, but in high doses, above 1600 g a.i. ha^{-1}. However, these doses are recommended only for crops more tolerant to diuron than soybean, such as sugarcane and cotton (AGROFIT, 2021). Considering the mixture of sulfentrazone + diuron, Santin *et al.* (2019) observed a 45% control at 28 DAT, with the application of 245 + 490 g a.i. ha^{-1} in pre-emergence of soybean.

For the control of itchgrass, it was observed that the control was satisfactory in doses from 123 g sulfentrazone + 245 g diuron a.i. ha^{-1}, being greater than 90% (Figure 3A). From that dose, the increase of the dose did not result in a significant increase in control. Even at the lowest dose evaluated, it was already possible to observe a control of approximately 70%, affirming the good efficiency of the mixture on the itchgrass.

Figure 3. Itchgrass (*Rottboellia cochinchinensis*) control at 30 DAT in response to the application of doses of sulfentrazone + diuron (A); and itchgrass control observed by applying the herbicides alone and in mixture, and estimated by the Colby's method (B). In figure A, vertical bars indicate the confidence interval. In figure B, means followed by the same letter do not differ by Tukey's test (p ≤ 0.05); ** indicates a significant difference in control in relation to the control infested by Dunnett's test (p ≤ 0.01); = indicates an additive effect between the observed control and the one estimated by the Colby method, submitted to Student's t test (p ≤ 0.05).



When comparing the mixture of sulfentrazone + diuron with the respective herbicides applied alone in the additional treatments, it is observed that the mixture did not result in a significant increase in control (Figure 3B). Both the mixed application and the application of sulfentrazone and diuron alone resulted in satisfactory control, above 80%. Thus, according to Colby's method, the herbicide mixture resulted in an additive effect, since the observed control did not differ from that expected by the method.

Because itchgrass is a common weed in sugarcane crops (CONCENÇO *et al.*, 2016), until now, there are no studies in the literature that report the control of this species in soybeans in Brazil with the sulfentrazone and diuron. However, a large part of the expansion of soybean crops has occurred in traditional sugarcane areas, in addition to the use of rotating soybean in the reform of sugarcane fields, which increases the occurrence of itchgrass in soybean crops. In sugarcane, however, total control of itchgrass plants until 70 DAT was observed, with the application of sulfentrazone + diuron at a dose of 350 + 700 g a.i. ha^{-1} (SOUZA *et al.*, 2019). For other poaceae, the mixture of sulfentrazone + diuron was also shown to be efficient, as in the control of *Urochloa plantaginea* and *Digitaria horizontalis* (BUNHOLA; SEGATO, 2017; SOUZA *et al.*, 2019). The same occurs for the isolated application of sulfentrazone, in doses of 500 to 600 g a.i. ha^{-1} applied in pre-emergence of soybean culture, with excellent control of *Cenchrus echinatus* up to 50 DAT (CARVALHO *et al.*, 2000).

Agronomic performance of soybeans

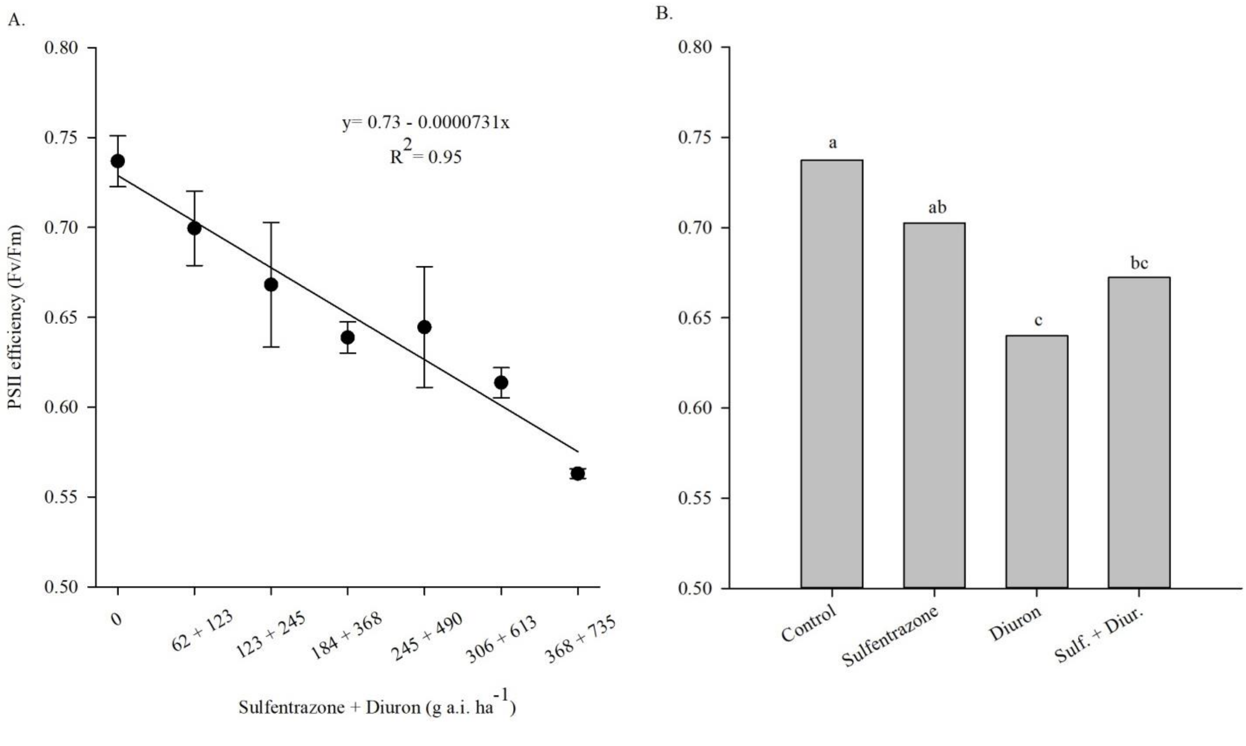
For the variables plant density at V1, plant height at V3, height of insertion of the first pod, number of nodes per plant and mass of a thousand grains, there was no significant effect in response to the application of treatments. The averages obtained for these variables are shown in Table 2.

Table 2. Mean values of variables that did not have altered responses due to treatments.

Variable	Mean	CV (%)
Plant density at V1 (plants.m^{-1})	10.74	9.00
Plant height at V3 (cm)	10.95	5.54
Height of insertion of the first pod (cm)	17.20	16.58
Number of nodes per plant	11.57	14.13
Mass of a thousand grains (g)	151.77	4.14

PSII activity, assessed at V3, showed a linear reduction with the increase in the dose of sulfentrazone + diuron, at a rate of 0.025 for each dose increase in the order of 62 + 123 g a.i. ha^{-1} (Figure 4A). In the treatment without herbicide application, the Fv/Fm ratio was 0.73, being reduced to 0.58 in the highest dose evaluated, from 368 + 735 g a.i. ha^{-1}, corresponding to a 20.5% reduction in activity PSII. For doses within the range recommended by the manufacturer (123 + 245 to 245 + 490 g a.i. ha^{-1}), the reduction in the Fv/Fm ratio was 6.8 to 13.7% compared to treatment without herbicide. When considering the isolated application of the herbicides, it is observed that the diuron caused the greatest inhibition of PSII, followed by the mixture (sulfentrazone + diuron) and sulfentrazone (Figure 4B). Both the isolated application of diuron and in a mixture with sulfentrazone differed from the control.

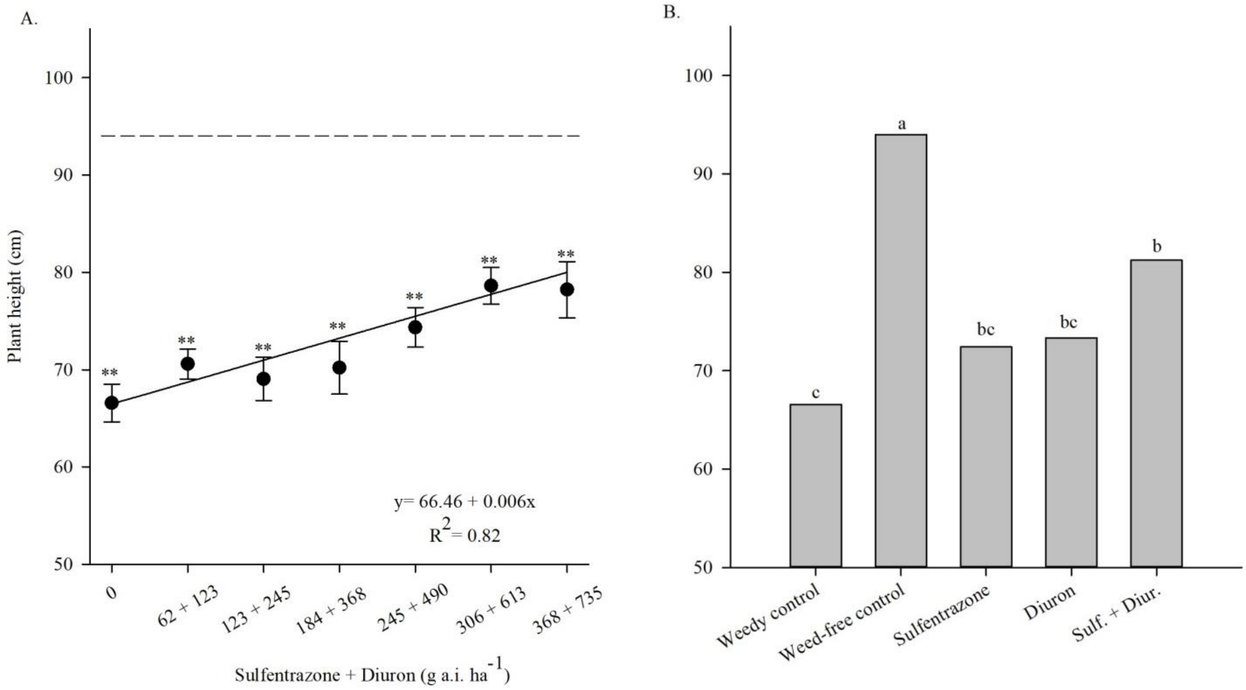
Figure 4. PSII activity in soybean (*Glycine max*) plants at V3 stage in response to sulfentrazone + diuron doses applied in pre-emergence of the crop (A). PSII activity in soybean plants at V3 stage in response to application of the herbicides sulfentrazone and diuron alone or in mixture (B). In figure A, vertical bars indicate the confidence interval. In figure B, means followed by the same letter do not differ by Tukey's test (p ≤ 0.05).



In untreated plants, the Fv/Fm ratio considered normal for most crops is 0.8 (BAKER, 2008), which can vary from 0.75 to 0.85 (RIBEIRO *et al.*, 2004). When the values are below this range, it means that the electron transport chain is being affected, due to the action of diuron, an electron transport inhibiting herbicide in PSII (ARAUS; HOGAN, 1994). However, the lower Fv/Fm ratio observed in the application of sulfentrazone + diuron doses cannot be attributed exclusively to the PSII inhibitor, since sulfentrazone, by inhibiting PPO, produces reactive oxygen species (ROS) that also lead to inhibition in the activity of photosystems (TRIPATHY *et al*., 2007). This can be seen in Figure 4B, in which the application of sulfentrazone alone caused a small reduction in the PSII activity of soybean plants.

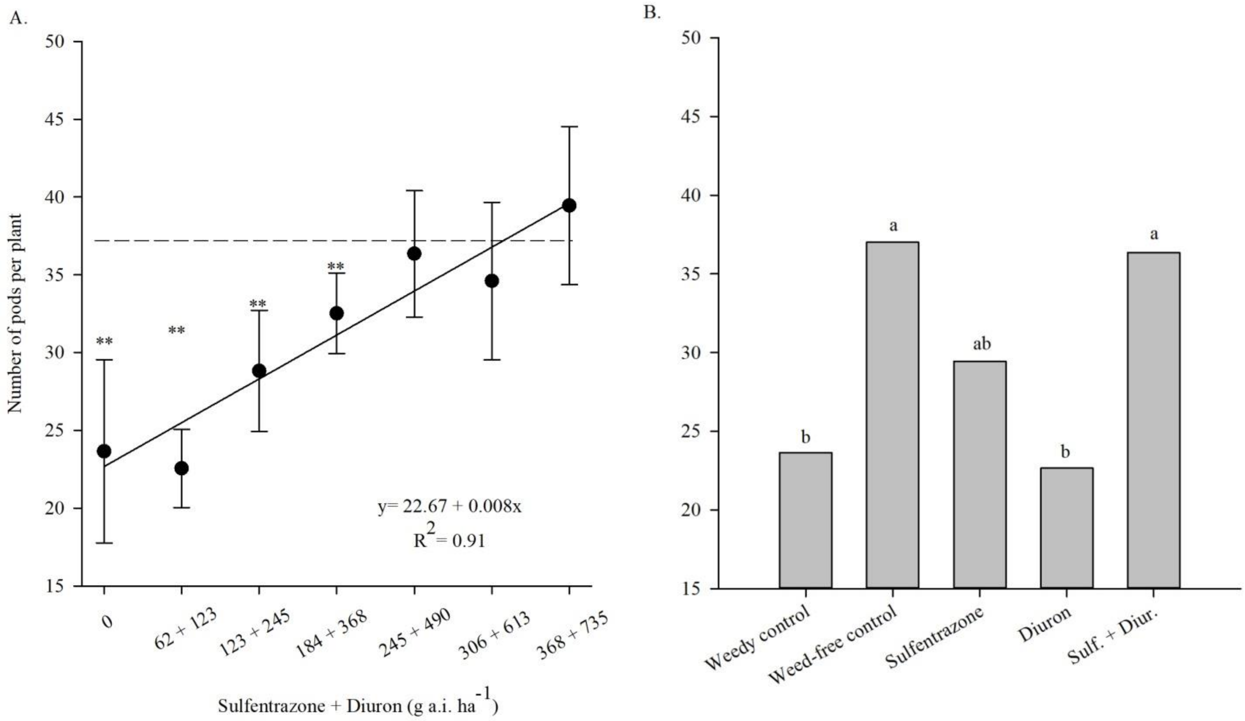
The height of soybean plants, assessed at R5.1, showed a linear increase as the dose of sulfentrazone + diuron was increased, at a rate of 2.1 cm for each 62 + 123 g a.i. ha^{-1} (Figure 5A). At zero dose (weedy control) the height of plants was 66 cm, while in the highest dose evaluated, height was 79 cm, resulting in an increase of approximately 20%. However, all treatments composed of sulfentrazone + diuron, in addition to the weedy control, had plant height lower than that observed for the weed-free control, which had an average height of 94 cm. Considering the effect of herbicides applied alone (Figure 5B), the applications of sulfentrazone and diuron did not differ from the mixture, although the latter treatment differed from the weedy control treatment. The weed-free control showed greater plant stature, differentiating itself from all other treatments.

Figure 5. Height of soybean (*Glycine max*) plants in R5.1 in response to sulfentrazone + diuron doses applied in pre-emergence of the crop (A); height of soybean plants in response to the application of the herbicides sulfentrazone and diuron alone or in mixture (B). In figure A, the dashed line (---) indicates the height of plants in the weed-free control; ** indicate significant effect ($p \leq 0.01$) in each dose compared to the weeded control by Dunnett's test; vertical bars indicate the confidence interval. In figure B, means followed by the same letter do not differ by Tukey's test ($p \leq 0.05$).



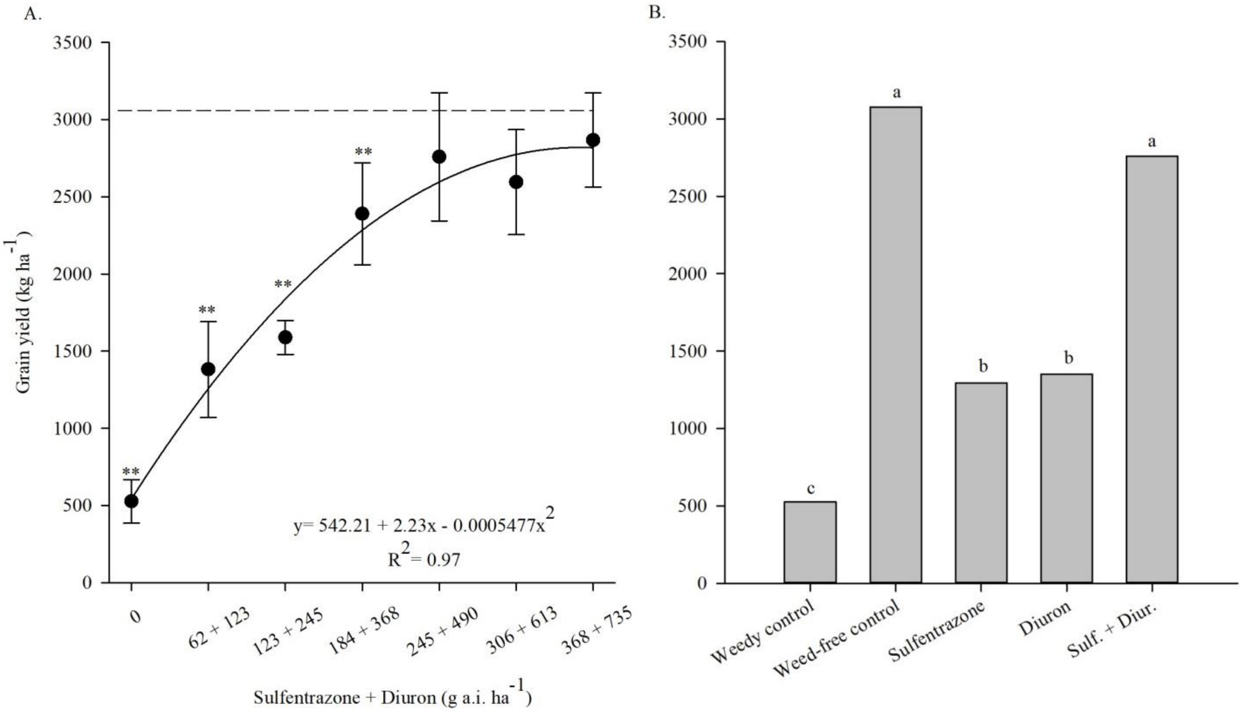
The application of herbicides also influenced the number of pods per plant (Figure 6A). The increase in this variable was linear with the increase in the dose of sulfentrazone + diuron, at a rate of 2.8 pods for each 62 + 123 g a.i. ha^{-1}. The infested control, the number of pods per plant was approximately 23, reaching approximately 40 pods per plant in the dose of 368 + 735 g a.i. ha^{-1}. In doses from 245 + 490 g a.i. ha^{-1} there was no significant difference compared to the weeded control, which obtained 37 pods per plant. When considering the effect of the isolated herbicides, it is observed that the isolated application of diuron resulted in fewer pods per plant, not differing from the isolated application of sulfentrazone (Figure 6B). These treatments did not differ from the weedy control. On the other hand, when applied in mixture, the number of pods per plant did not differ from the weeded control.

Figure 6. Number of pods per soybean (*Glycine max*) plant in response to sulfentrazone + diuron doses applied in pre-emergence of the crop. Number of pods per soybean plant in response to application of the herbicides sulfentrazone and diuron alone or in mixture (B). In figure A, the dashed line (---) indicates the height of plants in the weeded control; ** indicate significant effect ($p < 0.01$) in each dose compared to the weed-free control by Dunnett's test; vertical bars indicate the confidence interval. In figure B, means followed by the same letter do not differ by Tukey's test ($p < 0.05$).



The grain yield data show that the application of sulfentrazone + diuron resulted in an increase in the grain yield of soybeans (Figure 7A). The highest yields were obtained in doses from 245 + 490 g a.i. ha^{-1}, with an average of 2,740 kg ha^{-1}. These doses did not differ from each other nor from the weeded control, which obtained a grain yield of 3,070 kg ha^{-1}. However, treatments with doses equal to or less than 184 + 368 g a.i. ha^{-1} obtained grain yields significantly lower than the weeded control. The infested control showed grain yield of only 542 kg ha^{-1}, which represents an 82% reduction in grain yield compared to the weeded control. Finally, the association of sulfentrazone + diuron resulted in higher soybean grain yield compared to the isolated application of the herbicides (Figure 7B).

Figure 7. Grain yield of soybean (*Glycine max*) in response to sulfentrazone + diuron doses applied in pre-emergence of the crop. Grain yield of soybean in response to application of the herbicides sulfentrazone and diuron alone or in mixture (B). In figure A, the dashed line (---) indicates the height of plants in the weeded control; ** indicate significant effect ($p < 0.01$) in each dose compared to the weed-free control by Dunnett's test; vertical bars indicate the confidence interval. In figure B, means followed by the same letter do not differ by Tukey's test ($p < 0.05$).



The increase in plant height (Figure 5A), number of pods per plant (Figure 6A) and grain yield (Figure 7A) in response to the increased dose of sulfentrazone + diuron may have been due to greater weed control (Figure 3A; Figure 4A). At lower doses, the greater survival of wild radish and itchgrass led to greater competition for resources, limiting the growth and productivity of soybeans. Bianchi *et al.* (2011) observed that infestations of *Raphanus sativus*, a species very close to the wild radish, in a density of 42 to 50 plants m^{-2}, caused a reduction of 12 to 25% in the height of soybean plants, depending on the cultivar. The authors also observed a reduction in the length of soybean branches and grain yield of up to 15% for soybean cultivars with less competitive ability. For itchgrass, the presence of the weed close to the soybean sowing line led to a reduction in plant height, number of grains and grain yield (LEJEUNE *et al.*, 1994). A single plant of itchgrass m^{-2} is capable of reducing the grain yield of soybeans by more than 30%, and in the density of 16 plants m^{-2}, the reduction in grain yield can reach 65% (JANTAWINYURAG, 1995; SUWUNNAMEK, 1996).

In general, the mixture of sulfentrazone + diuron led to better weed control and agronomic performance of soybean compared to the application of isolated herbicides. Likewise, the increase in the dose of sulfentrazone + diuron has led to greater controls for wild radish and itchgrass and, consequently, greater soybean agronomic performance. However, it is observed that the dose increase from 245 + 490 g a.i. ha^{-1} does not result in a significant increase in species control (Figure 2A and Figure 3A), nor in the number of pods per plant (Figure 6A) and soybean grain yield (Figure 7A). It is also observed that the initial inhibition of PSII activity (Figure 4A) did not result in a significant reduction in the grain yield of soybeans, indicating the recovery of the plants during the crop cycle. These results corroborate the technical recommendation of the formulation manufacturer, in which a dose of 123 + 245 to 245 + 490 g a.i. ha^{-1} is recommended for soils with sandy and clayey texture, respectively (AGROFIT, 2021).

Conclusion

The herbicide sulfentrazone + diuron has low efficiency in the control of wild radish, with control below 50%, regardless of the evaluated dose. However, for itchgrass, the control is satisfactory, being greater than 90% in doses from 123 g sulfentrazone + 245 g diuron a.i. ha^{-1}. Regarding the agronomic performance of soybeans, in doses from 245 g sulfentrazone + 490 g diuron a.i. ha^{-1} there is a greater number of pods per plant and higher grain yield, not differing from the weed-free control, indicating the selectivity of the herbicide for the soybean cultivar evaluated, although there is an initial inhibition of photosynthetic activity of plants. Therefore, the mixture of sulfentrazone + diuron is a good alternative for the management of weeds in pre-emergence of soybean, and should be positioned according to the history of crop infestation, since its efficacy depends on the weed species present in the area.

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