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EFFECT OF PRE-EMERGENT HERBICIDES ON SOYBEAN CROPS GROWN IN ROTATION WITH SUGARCANE

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Abstract

The need for sugarcane field reform has driven the expansion of soybean cultivation in rotation with sugarcane. Weeds are one of the main reasons for this reform, requiring specific management in rotation. The use of pre-emergence herbicides in soybean is a viable option, but its effectiveness in sandy soils requires further study. In this experiment, we evaluated the performance of pre-emergence herbicides on sugarcane straw, focusing on the control of *Digitaria horizontalis*. We conducted a field experiment with 11 treatments and four replications, applying herbicides immediately after soybean sowing. All herbicides, except diclosulam, provided efficient control of *D. horizontalis*, with over 80% control in all evaluated periods. The clomazone+sulfentrazone association showed the highest residual effect, keeping the area clean for up to 21 days after application. Weed-free control resulted in productivity equivalent to 66% of the maximum obtained. The use of cell division inhibitors allowed soybean cultivation to grow without weed competition. We conclude that the use of pre-emergence herbicides in soybean under sugarcane straw resulted in productivity gains due to effective *D. horizontalis* control. *Poaceae* plants may have a higher competitive capacity with crops compared to other families; therefore, even with few plants per square meter, species like *D. horizontalis* can reduce crop productivity. The use of cell division inhibitor molecules, either alone or combined with PROTOX inhibitors, allowed the soybean crop to remain free of weed competition.

Keywords: Sugarcane field reform; *Glycine max* L.; *Digitaria horizontalis*; Integrated weed management.

EFEITO DE HERBICIDAS PRÉ-EMERGENTES NA CULTURA DA SOJA CULTIVADA EM ROTAÇÃO COM A CANA-DE-AÇÚCAR

Resumo

A necessidade de reforma do canavial tem impulsionado a expansão do cultivo de soja em rotação com a cana-de-açúcar. Plantas daninhas são uma das principais razões para essa reforma, exigindo manejo específico na rotação. O uso de herbicidas em pré-emergência da soja é uma opção viável, porém sua eficácia em solos arenosos requer mais estudos. Neste experimento, avaliamos o desempenho de herbicidas pré-emergentes sobre de cana, focando no controle de *Digitaria horizontalis.* O delineamento experimental utilizado foi de blocos casualizados, contendo 11 tratamentos em quatro repetições aplicando herbicidas imediatamente após a semeadura da soja. Exceto o herbicida, diclosulam, todos os outros proporcionaram controle eficiente da *D. horizontalis*, com mais de 80% de controle em todas as épocas avaliadas. A associação clomazone+sulfentrazona apresentou o maior efeito residual, mantendo a área limpa por até 21 dias após a aplicação. O controle sem capina resultou em produtividade equivalente a 66% da máxima obtida. O uso de herbicidas inibidores da divisão celular permitiu que a cultura da soja crescesse sem competição de plantas daninhas. O uso de herbicidas em pré-emergência da soja sob palhada de cana resultou em ganhos de produtividade devido ao controle eficaz de *D. horizontalis*. Plantas *Poaceae* podem ter maior capacidade de competição com as culturas do que outras famílias, portanto, mesmo com poucas plantas por m^2 espécies como *D. horizontalis* podem diminuir a produtividade da cultura. A utilização de moléculas inibidoras da divisão celular, isoladas ou associadas aos da inibidora da PROTOX permitiram que a cultura da soja permanecesse sem competição por plantas daninhas.

Palavras-chave: reforma de canavial; *Glycine max* L., *Digitaria horizontalis*, manejo integrado de plantas daninhas.

Introduction

Soybean is cultivated throughout the national territory due to advances in research and genetic improvement (Cabral; Pandey; Xu, 2022; Nehring, 2022). However, certain regions, such as Western São Paulo, where sandy soils predominate and the climate frequently experiences drought spells, may pose some risks of productivity losses for this crop (Cotrim *et al*., 2021). Production systems such as no-till farming (NTF), which aim to improve soil conditions by maintaining soil cover with straw, tend to support the continuous growth of this crop by minimizing risks and improving the efficient use of the environment. One of the ways to achieve quality and quantity soil cover is through crop rotation (Franchini *et al*., 2011). This management practice provides greater viability to the no-till farming (NTF) system for grain crops.

Brazilian sugarcane production in the 2023/2024 harvest reached 713.2 million tons, setting a new record in the historical series monitored by the National Supply Company (Conab, 2024). In the Southeast, the region with the highest sugarcane production, there was a 21% increase in the harvested volume compared to the previous season, totaling 469 million tons. At the end of the sugarcane cycle, producers can choose to either immediately renew their planting or rotate with other crops. Options include planting legumes, particularly *Crotalaria* spp., soybeans, and peanuts (Conab, 2024)

The sugarcane crop, at the time of its renewal, leaves a large amount of straw, providing good soil cover and promoting the mineralization of residues, thus facilitating nutrient cycling for the next crop (Carvalho; Sousa, 2021). Therefore, it can be stated that the rotation of sugarcane with soybeans meets the basic requirements for an effective and viable NTF.

Practices adopted in sugarcane production, due to the need to reform areas, have contributed to the expansion of grain production under the NTF in regions not traditionally used for grain cultivation. Soybean planting in reformed areas is steadily increasing within this system. However, soybean crop management in this system must be adapted to the new reality, as the presence of straw can reduce the effectiveness of herbicides applied in NTF, requiring studies on herbicides with lower retention in straw or adjusted strategies to maximize their effect (Silva *et al*., 2019). Evaluating weed management using pre-emergent herbicides applied over sugarcane straw in NTF, seeking strategies to maximize weed control in soybean crops, becomes an important tool in this context.

Weed control in soybean crops must follow specific periods where the crop can coexist with weeds and periods where this cannot occur. These periods are: the period before interference (PBI), the total period of interference prevention (TPIP), and the critical period of interference prevention (CPIP) (Pitelli; Durigan, 1984). The field must remain weed-free during the critical period to express its maximum productive potential (Silva *et al*., 2019). With the advent of herbicide-resistant soybean cultivars, the use of these selective products in pre-emergence may have been neglected. Therefore, the study of combining resistant cultivars with pre-emergent management stands out as an alternative to keep soybeans weed-free throughout the critical period of interference (Gubiani *et al*., 2021).

Some weed species stand out in soybean/sugarcane rotation areas, such as milkweed (*Euphorbia heterophylla* (L.)), morning glory (*Ipomoea hederifolia* (L.)), sicklepod (*Senna obtusifolia* (L.)), velvetleaf (*Cissampelos glaberrima*), flamevine (*Pyrostegia venusta*), balsam pear (*Momordica charantia*), perennial soybean *(Neonotonia wightii*), purple nutsedge (*Cyperus rotundus* (L.)), and crabgrass (*Digitaria horizontalis*). After the ban on sugarcane field burning, there was a significant shift in the weed landscape in sugarcane cultivation, where grasses and some sedges previously predominated (Soares *et al.*, 2012). Therefore, with this change and the introduction of soybean/sugarcane crop rotation, it has become necessary to better understand the effect of pre-emergent herbicides applied in the presence of sugarcane straw and the control of weed species that remain after the cane harvest, which will be present in the soybean crop. The use of pre-emergent herbicides applied over sugarcane straw in NTF can provide effective control of *D. horizontalis* in soybean crops, overcoming the potential reduction in efficacy caused by residual straw. Thus, the objective of this study was to validate this hypothesis and identify the most effective strategies for integrated weed management in this crop rotation system.

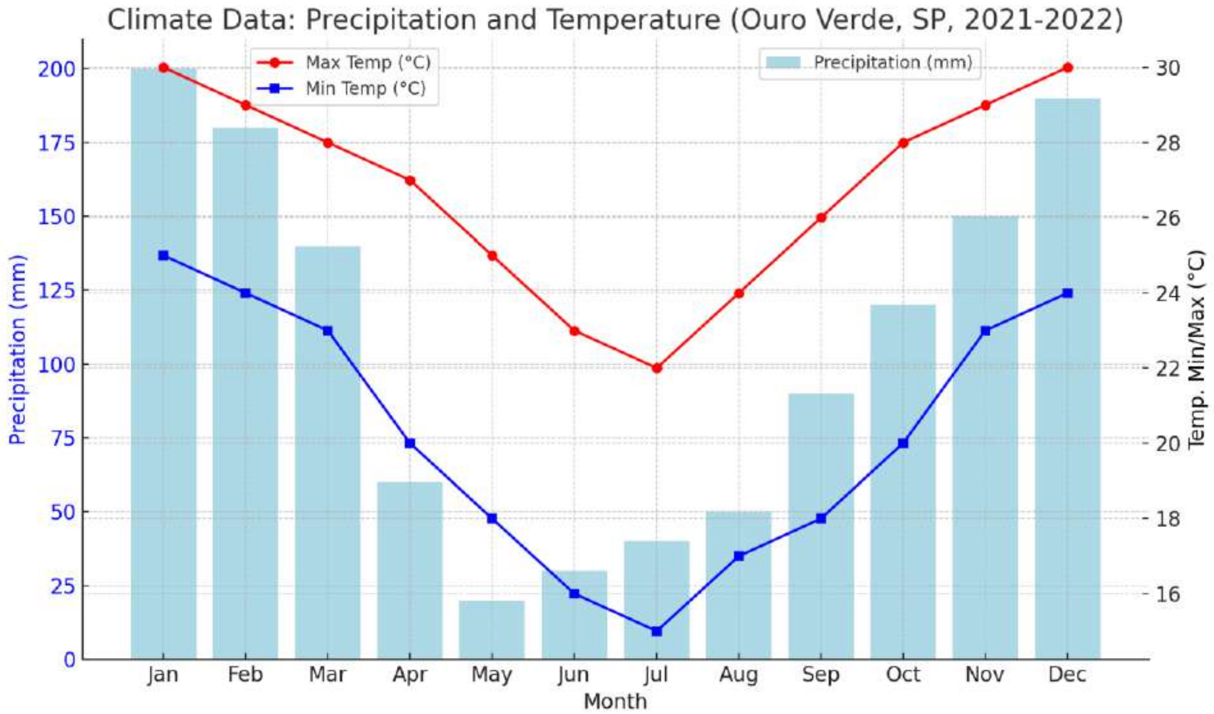
Material and Methods

The experiment was conducted in the field at Fazenda Arizona, located in the municipality of Ouro Verde - SP, with geographic coordinates of latitude -21.552911 south, longitude -51.777861 west, and an altitude of 321 meters. The experimental area is characterized by sandy soil with 13% clay (Table 1). The area had been under sugarcane cultivation for the past 5 years. Due to the need to reform the sugarcane field, soybeans were grown in a rotation system using no-till farming.

Table 1. Results of the soil chemical analysis from the experimental area Ouro Verde - SP, harvest 2021-2022.

Parameter	Unit	Value
pH ($CaCl_2$)	-	5.2
Organic Matter	g/dm³	25.5
Phosphorus (P)	mg/dm³	18.7
Potassium (K)	$mmol_c/dm^3$	3.4
Calcium (Ca)	$mmol_c/dm^3$	28.1
Magnesium (Mg)	$mmol_c/dm^3$	8.7
H+Al	$mmol_c/dm^3$	27.5
Base Saturation (V%)	%	56.4

Figure 1. The data presented represent the behavior of rainfall and temperature throughout the year.



The climatological averages are values calculated from a 30-year data series observed. It is possible to identify the rainiest/driest and hottest/coldest periods in Ouro Verde - SP.

The area, predominantly covered by regrowth of sugarcane plants and crabgrass (*D. horizontalis*), was desiccated 15 days before soybean planting using a dose of 2.5 kg ha^{-1} of glyphosate acid equivalent (a.e.).

The amount of straw left after the sugarcane harvest was 8.5 tons ha^{-1}. To obtain this data, a sample of the residue was collected using a frame constructed from PVC pipe measuring 0.5 x 0.5 m, which was randomly placed at 10 points within the experimental area. All plant material within the frame was collected and then taken to the laboratory for drying in an oven at a constant temperature of 70 ºC for 72 h. Once the straw was completely free of moisture, the material was weighed, and the quantity per area was determined.

Soybean planting, cultivar NS 6700, was carried out on November 15, 2021, using a mechanized seeder-fertilizer with a row spacing of 0.45 m, distributing 13 seeds per linear meter. The soybean seeds were inoculated with *Bradyrhizobium japonicum* immediately before planting, using 300 mL of inoculant (SEMINA 5079-CPAC 15 and SEMINA 5080-CPAC7) per 50 kg of soybean seeds. In all treatments, 100 kg ha^{-1} of P2O5 was applied in the planting furrow in the form of monoammonium phosphate (MAP), and 100 kg ha^{-1} of potassium chloride (KCl) was applied 25 days after emergence.

The experimental design used was a randomized block design with 11 treatments in four replications (Table 2). The experimental plots were 15 m² (2.5 m x 6 m). Herbicides were applied in a planting and application system immediately after soybean planting. A CO_2-pressurized backpack sprayer with a bar, equipped with four XR 110.02 fan-type nozzles, was used for the application, with a spray volume of 200 L ha^{-1}.

The parameters evaluated were weed control at 7, 14, 21, and 45 days after application (DAA). A percentage scale of 0%-100% was used to assess infestation, with 0% representing no control and 100% representing total weed death, respectively. At 14 DAA, the density of *D. horizontalis* plants was determined by counting the plants per plot using a frame constructed from PVC pipe measuring 0.5 x 0.5 m, which was randomly placed in the usable area of the plot.

At the time of application, the soil had ideal moisture for crop planting; however, the first rains occurred only on the seventh and eighth days after the treatment application, with volumes of five and 13 mm, respectively.

Table 2. Description of treatments, herbicides applied in pre-emergence.

Treatments	**Trade name**	**Dose (L ou kg ha^{-1})**	
		a.i	**c.p**
non-weeded control			
weeded control			
Diclosulam	Spider	0,036	0,042
Diclosulam+ S-Metolacloro	Spider + Dual Gold	0,036 + 1,15	0,042+1,5
Clomazone	Gamit Star	0,96	1,2
Clomazone + Sulfentrazona	Gamit Star + Boral	0,96 + 0,25	1,2+0,5
Trifluralina	Trifluralina Gold	1,35	3
Imazetapir + Flumioxazina	Zethamaxx	0,12 + 0,06	0,6
Piroxasulfona + Flumioxazina	Kiojin	0,12 + 0,08	0,4
Sulfentrazona + Diuron	Stone	0,175 + 0,35	1
Sulfentrazona + Diuron + Clomazona	Stone + Reator	0,175 + 0,35 + 0,8	1,0 + 2,2

1. Active ingredient, 2. Comercial products.

To determine grain yield and the weight of 1,000 grains, the soybean plants were manually harvested, considering the usable area of the plot in 4 meters from each of the four central rows. All plants removed from this area were subjected to mechanical threshing to separate the pods. The grains were mechanically separated from the pods, air-dried, and weighed to determine grain weight. The values for grain yield and the mass of 100 grains were adjusted to 13% moisture content.

After data collection and tabulation, an analysis of variance was performed, and the means of the significant variables were grouped using the LSD criterion at a 5% significance level.

Results and Discussion

Soybean plant density showed no differences between treatments. Therefore, the use of herbicides did not restrict, through mortality or phytotoxicity, the number of emerged plants at 14 DAS (days after sowing). All treatments were similar to the control (without herbicide use). Herbicide selectivity is one of the key requirements for its specific action in weed control (Galon *et al*., 2022). The pre-emergent herbicide molecule, when applied, is solubilized in the soil solution and later absorbed by plant roots (Silva *et al.*, 2013). Thus, any plant can absorb it, including soybeans, which may cause injuries. It is necessary for the soybean plant to metabolize this herbicide to a point where it does not cause death or phytotoxicity. The absence of phytotoxicity or plant death in soybeans indicates that the tested products are selective for the soybean crop and can, therefore, be applied as pre-emergent herbicides (Table 3).

Table 3. Soybean plant density per linear meter (Stand) as a result of pre-emergent herbicide application in the crop over sugarcane straw. Ouro Verde – SP, 2021-2022 season.

Treatments	**Stand (mL)**
non-weeded control	10,8 ns
weeded control	10,2
Diclosulam	10,5
Diclosulam+ S-Metolacloro	11,2
Clomazone	11,7
Clomazone + Sulfentrazona	12,5
Trifluralina	11,3
Imazetapir + Flumioxazina	11
Piroxasulfona + Flumioxazina	10,8
Sulfentrazona + Diuron	11,4
Sulfentrazona + Diuron + Clomazona	12,5
F	0,34ns
CV (%)	12,77
D.M.S (<= 0,05)	2,95

ns Not significant at the 5% probability level according to the F-test. CV% = Coefficient of Variation. DMS = Minimum Significant Difference. Means followed by the same letter do not differ significantly according to the test t $(p \geq 0{,}05)$.

For crabgrass (*D. horizontalis*) control, a response to herbicide use was observed. All herbicides provided some level of control over this weed, performing better than the untreated control (Table 3). However, not all treatments achieved effective control when compared to hand weeding. Initial control at 7 DAA, with the exception of Diclosulam, showed that all herbicides provided similar control to the hand-weeding treatment for *D. horizontalis*. At 14 DAA, the treatments with Diclosulam and Diclosulam + S-metolachlor provided inferior control compared to hand weeding, but still superior to the untreated control. At 21 DAA, only the treatment with Clomazone + Sulfentrazone provided the same level of control as the hand-weeding treatment. During this evaluation period, all herbicides showed better control than the untreated control, although Diclosulam had a much lower-than-ideal percentage (Table 3). By 40 DAA, the percentage of control for all herbicides decreased. The hand-weeding treatment was superior to all tested herbicides, with only Clomazone + Sulfentrazone, Trifluralin, and Sulfentrazone + Diuron being comparable to hand weeding. Except for Diclosulam and Diclosulam + S-metolachlor, all other treatments provided more than 80% control.

Straw and crop residues present in no-tillage systems (NT) can act as a barrier between the herbicide and the soil (Silva *et al*., 2021). The retention and reduction of the active ingredient concentration reaching the soil can decrease product efficacy, leading to reduced weed control (Munhoz-Garcia *et al*., 2023). Some pre-emergent herbicides, when applied on the surface (without soil incorporation), may lose efficacy due to photodegradation (Volf *et al*., 2021). Except for Diclosulam and Diclosulam + S-Metolachlor, up to 40 DAA, herbicides applied without incorporation i.e., over sugarcane straw were able to control *D. horizontalis* and provide residual control above 80%. Soybean crops should remain free of weeds until approximately 40 days after emergence (DAE), with the critical pre-interference period (CPIP) between 20 and 40 DAE (Silva *et al*., 2023). Therefore, herbicides that maintained over 80% control were able to mitigate or prevent the competitive effect of crabgrass on the soybean crop.

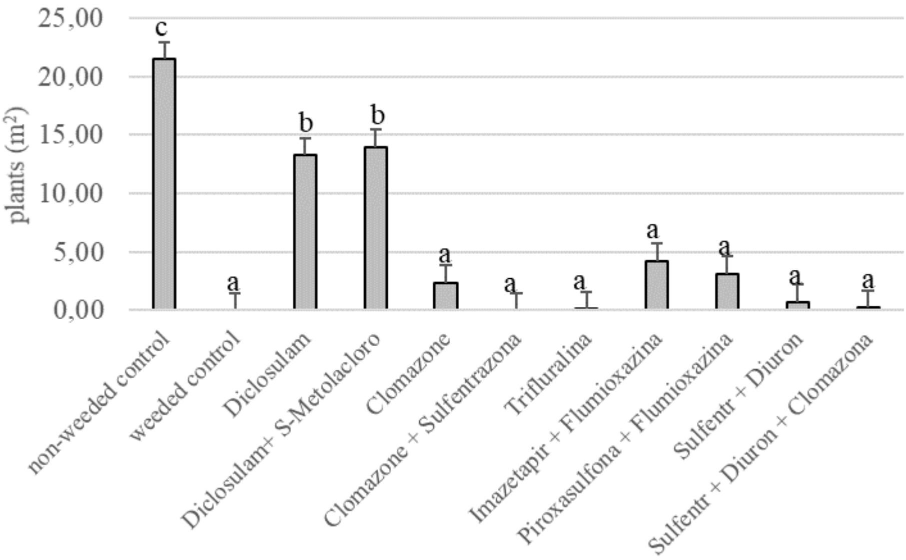
Table 4. Control (%) of *D. horizontalis* (crabgrass) plants through pre-emergent herbicide application management in soybean cultivation over sugarcane straw. Ouro Verde - SP, 2021-2022 season.

Treatments	Control (%)							
	07 DAA		14 DAA		21 DAA		49 DAA	
non-weeded control	0	c	0	d	0	e	0	e
weeded control	100	a	100	a	100	a	100	a
Diclosulam	25	b	18	c	15	d	0	e
Diclosulam+ S-Metolacloro	93,75	a	70	b	82,5	c	77,5	d
Clomazone	100	a	92,5	a	86,25	bc	82,5	cd
Clomazone + Sulfentrazona	100	a	100	a	100	a	93,75	ab
Trifluralina	93,75	a	87,5	a	90	abc	93,75	ab
Imazetapir + Flumioxazina	96,25	a	95	a	82,5	c	83,75	cd
Piroxasulfona + Flumioxazina	100	a	90	a	85	bc	85	bcd
Sulfentrazona + Diuron	95	a	93,75	a	87,5	bc	90	abc
Sulfentrazona + Diuron + Clomazona	98,75	a	93,75	a	93,75	abc	86,25	bcd
F	0,001		0,001		0,001		0,001	
CV (%)	5,43		10,65		12,42		9,53	
D.M.S (<= 0,05)	6,39		11,42		13,61		9,90	

DAA= Not significant at the 5% probability level according to the F-test. CV% = Coefficient of Variation. DMS = Minimum Significant Difference. Means followed by the same letter do not differ significantly according to the test *t* ($p \geq 0,05$).

The density of *D. horizontalis* plants was influenced by the use of herbicides, as all herbicides reduced the number of plants compared to the untreated control. Except for Diclosulam and Diclosulam + S-Metolachlor, the other herbicides resulted in plant densities similar to the hand-weeding control (Figure 2). The reduction in weed density is a direct result of controlling their emergence through the use of pre-emergent herbicides (Galon *et al*., 2022). The competitive effect of weeds with the soybean crop may be related to the number of plants per area (Soybean, 2022), and lower densities may not reduce productivity due to the low competition between weeds and the crop (Silva *et al*., 2022).

Figure 2. Plant density (plants m²), at 14 DAA (Days After Application) of *D. horizontalis* (crabgrass) as a result of pre-emergent herbicide application in soybean cultivation over sugarcane straw. Ouro Verde - SP, 2021-2022 season

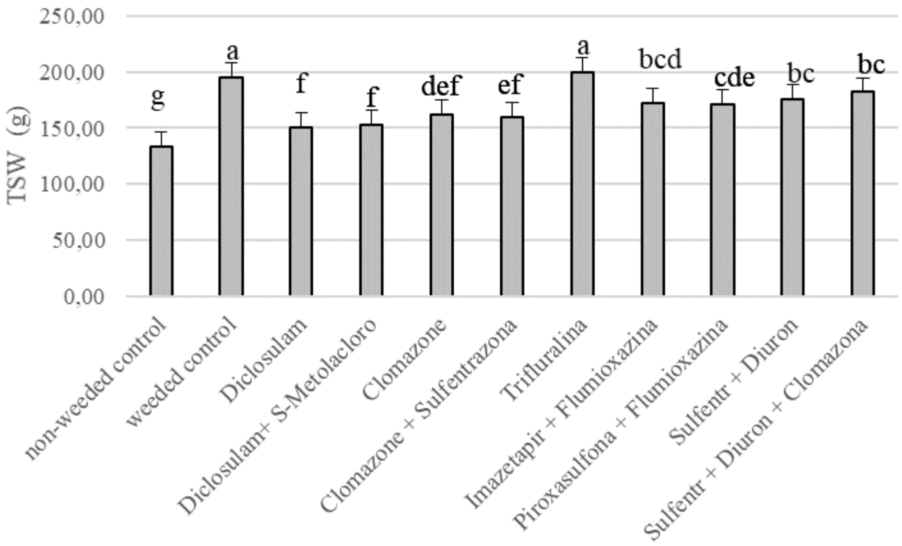


Error bars represent the standard error. Means followed by the same letter do not differ significantly according to the *t*-test ($p \geq 0.05$).

The use of herbicides resulted in a higher thousand-grain weight (TGW) compared to the untreated control, regardless of the herbicide used (Figure 3). However, among the herbicides, trifluralin stood out, with TGW similar to the hand-weeding control, while treatments with Diclosulam and Diclosulam + S-Metolachlor were superior to the untreated control but inferior to the others.

Thousand-grain weight is an important indicator of yield losses caused by both herbicide phytotoxicity and competition (Carvalho *et al*., 2022). Plants that suffer from injuries (phytotoxicity) or resource restrictions (competition) tend to produce lighter grains than those kept free from these effects. Yield reduction can also occur due to competition between the crop and weeds, as weeds are more efficient at obtaining environmental resources like nutrients and water, thus reducing the availability of these resources for the crop (Rizzardi *et al*., 2001; Zanatta *et al*., 2006).

Figure 3. Thousand seed weight (TSW) of soybean as a result of pre-emergent herbicide application in soybean cultivation over sugarcane straw. Ouro Verde - SP, 2021-2022 season.

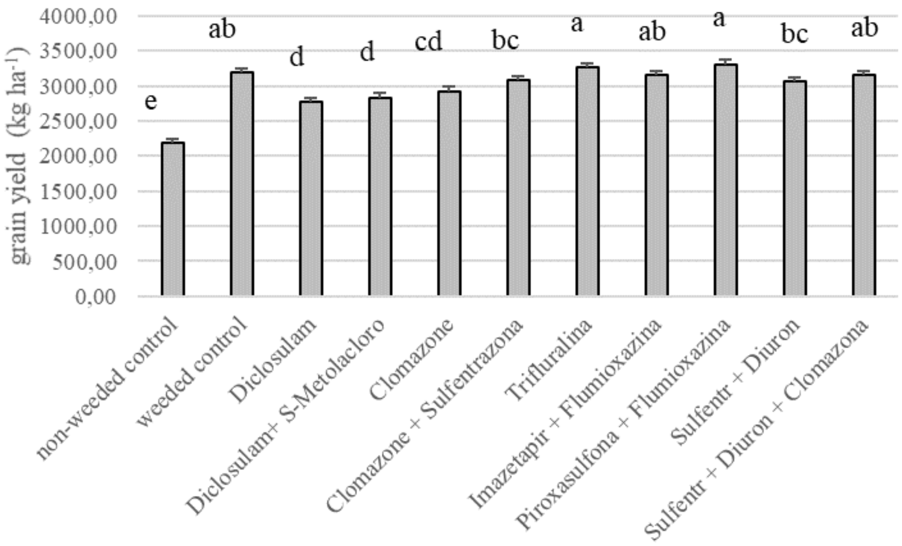


Error bars represent the standard error. Means followed by the same letter do not differ significantly according to the *t*-test ($p \geq 0.05$).

Soybean crop yield was directly affected by herbicide use, and thus influenced by how well *D. horizontalis* plants were controlled. The untreated control resulted in the lowest grain yield; therefore, herbicide use, regardless of the type, resulted in higher productivity compared to no control (Figure 4). Herbicides based on Trifluralin and Pyroxasulfone + Flumioxazin produced yields similar to the hand-weeding control. The application of Diclosulam and Diclosulam + S-Metolachlor resulted in the lowest yield among the herbicides tested, reflecting the presence of weeds, which was only superior to the untreated control. The untreated control led to a 44% decrease in productivity compared to the highest yield achieved with Trifluralin and Pyroxasulfone + Flumioxazin. Weed competition can drastically reduce crop productivity (Silva *et al.*, 2023). *Poaceae* plants may have a greater competitive ability with crops compared to other families (Silva *et al.*, 2021), so even with few plants per m², species like *D. horizontalis* can decrease crop yield.

The use of pre-emergent herbicides should be evaluated based on their residual effect, which indicates how long the crop remains free from weeds, ideally until the end of the CPIP. The herbicide with the longest residual effect was the combination of Clomazone + Sulfentrazone, maintaining the area free of weeds until 21 DAA (Figure 2 and Table 4). The combination of herbicides with synergistic effects can enhance control efficacy and contribute to a broader spectrum of weed control (Figure 2).

Figure 4. Soybean grain yield as a result of pre-emergent herbicide application in soybean cultivation over sugarcane straw. Ouro Verde - SP, 2021-2022 season.



Error bars represent the standard error. Means followed by the same letter do not differ significantly according to the *t*-test ($p \geq 0.05$).

Conclusions

Among the herbicides tested, the use of cell division inhibitors, either alone or in combination with PROTOX inhibitors, allowed the soybean crop to remain free from weed competition and consequently resulted in higher productivity. The use of pre-emergent herbicides on soybean under sugarcane straw led to increased productivity due to better control of *D. horizontalis* plants.

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