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RESEARCH ARTICLE

Association of pre-emergent herbicides with plant cover in weed management

Associação de herbicidas pré-emergentes com cobertura vegetal no manejo de plantas daninhas

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Abstract: **Background**: The species *Bidens pilosa*, *Euphorbia heterophylla*, and *Amaranthus hybridus* have shown high interference in soybean cultivation, especially due to biotypes resistant to various herbicides.

Objective: This study aimed to analyze the effectiveness of soil cover associated with pre-emergence herbicides in managing these species

Methods: Separate experiments were conducted for each weed species in a completely randomized design with a 4 × 4 factorial scheme and three replications. The evaluated factors were chemical management (diclosulam, flumioxazin, sulfentrazone, and an untreated control) and cover crop species (*Canavalia ensiformis*, *Pennisetum glaucum*, *Crotalaria juncea*, and a control without cover). At 35 days after treatment application, weed control percentage and aerial dry biomass were assessed.

Results: *A. hybridus* was satisfactorily controlled (>80%) by soil cover alone, regardless of herbicide use. The lowest control was observed with *P. glaucum*; however, when combined with herbicides, control reached approximately 100%. For *B. pilosa*, cover crop species alone provided nearly 90% control, with even greater efficacy in some herbicide associations. In contrast, for *E. heterophylla*, neither cover crops nor herbicides alone were effective. Flumioxazin provided only 26.7% control, whereas sulfentrazone reached 82.7%.

Conclusions: Effective control of this species required the combination of herbicides and cover crops. The results indicate that, depending on the weed species, specific interactions between soil cover and herbicides enhance weed suppression.

Keywords: management; hairy beggasticks, wild poinsettia, smooth pigweed, mulch.

Resumo: **Introdução**: As espécies *Bidens pilosa*, *Euphorbia heterophylla* e *Amaranthus hybridus* têm causado elevada interferência na cultura da soja, especialmente devido à presença de biótipos resistentes a herbicidas.

Objetivo: Avaliar a eficácia da cobertura vegetal associada a herbicidas aplicados em pré-emergência no manejo dessas espécies.

Métodos: Foram conduzidos experimentos independentes para cada espécie, em delineamento inteiramente casualizado, em esquema fatorial 4 × 4, com três repetições. Avaliaram-se quatro manejos químicos (diclosulam, flumioxazin, sulfentrazone e testemunha) e quatro coberturas vegetais (*Canavalia ensiformis*, *Pennisetum glaucum*, *Crotalaria juncea* e ausência de cobertura). Aos 35 dias após a aplicação, foram avaliados o controle (%) e a biomassa seca da parte aérea.

Resultados: *A. hybridus* apresentou controle satisfatório (>80%) apenas com coberturas, com menor eficiência para *P. glaucum*, sendo que a associação com herbicidas elevou o controle para próximo de 100%. Para *B. pilosa*, o controle foi próximo a 90% com coberturas, sendo ampliado com herbicidas. Já para *E. heterophylla*, coberturas ou herbicidas isolados foram insuficientes. Flumioxazin apresentou baixo controle (26,7%) e sulfentrazone controle moderado (82,7%), sendo necessária a associação entre estratégias.

Conclusão: A eficácia do manejo depende da espécie, havendo interação entre plantas de cobertura e herbicidas que potencializa o controle.

Palavras chave: manejo integrado, picão-preto (*Bidens pilosa*), amendoim bravo (*Euphorbia heterophylla*), caruru (*Amaranthus hybridus*), palhada.

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1. Introduction

Brazil has become the world's largest soybean producer, reaching a production of 154.6 million tons in the 2022/2023 harvest, with the states of Mato Grosso and Rio Grande do Sul as the leading producers (Conab, 2023). Soybean and corn are the main crop grown in the South, Southeast, and Midwest regions of the country. One of the key challenges to ensuring high productivity is the effective control of weeds, as soybean has low competitiveness and is highly sensitive to the effects of these species (Vargas and Roman, 2006).

Among the main weed species infesting soybean fields in Brazil, *Bidens pilosa* (hairy beggarticks), *Euphorbia heterophylla* (wild poinsettia), and *Amaranthus hybridus* (smooth pigweed) stand out, causing significant problems for farmers (Gazziero, 2005). Furthermore, these species have biotypes resistant to major herbicide modes of action, such as acetolactate synthase (ALS) inhibitors, protoporphyrinogen oxidase (PROTOX) inhibitors, and enolpyruvylshikimate-phosphate synthase (EPSPS) inhibitors (Heap, 2024).

The rapid spread of multiple herbicide resistance, particularly to glyphosate and ALS/PROTOX inhibitors, has exhausted the main post-emergence control options for managing *Bidens pilosa*, *Euphorbia heterophylla*, and *Amaranthus hybridus*. In this critical context, the adoption of strategies aimed at preventing the emergence of new weed infestations such as the use of pre-emergence herbicides becomes not merely an alternative, but a key pillar for ensuring the long-term sustainability of soybean cultivation.

The first case of resistance in *B. pilosa* in Brazil was reported for ALS-inhibiting herbicides (Monquero et al., 2000). Resistance to glyphosate has been confirmed in neighboring Paraguay, where this herbicide is widely used for controlling the species in transgenic soybean crops. *E. heterophylla* has also become a problematic species in soybean cultivation due to the emergence of biotypes resistant to glyphosate, which was previously the main alternative for controlling populations already resistant to ALS inhibitors and later with multiple resistance to ALS and PROTOX inhibitors (Trezzi et al, 2009).

In the case of *A. hybridus*, the first herbicide resistance case was reported in 1996, involving ALS inhibitors. Resistance to glyphosate was first detected in Argentina's soybean fields in 2013 and more recently in Brazil (Heap, 2024). With the increasing resistance of these weed species to glyphosate and other herbicides, especially in transgenic crops, it has become essential to adopt alternative control methods.

In the context of increased emphasis on pre-emergence weed management, integration with no-till systems using crop residues has become a well-established and desirable practice due to its numerous agronomic benefits (Martins et al., 2016). However, this integration presents a central technical-scientific dilemma: while the mulch layer physically suppresses weed seed germination and seedling establishment (Borges et al., 2014), it can also act as a physical barrier, intercepting pre-emergence herbicide applications and reducing the amount of active ingredient that actually reaches the soil (Minozzi, 2014). The success or failure of this strategy depends on a complex interaction among mulch characteristics (such as carbon-to-nitrogen ratio, architecture, and decomposition rate, which vary considerably among species like *Crotalaria juncea*, *Canavalia ensiformis*, and *Pennisetum glaucum*), the physicochemical properties of the herbicide molecule, and the rainfall regime following application (Minozzi, 2014). Although this interaction is recognized in the literature, there is a lack of direct comparative studies evaluating how different cover crop species modulate the effectiveness of key pre-emergence herbicides for controlling a complex of problematic broadleaf and grass weeds with known resistance histories (Oliveira et al., 2020; Whalen et al., 2020).

Therefore, the objective of this study was to elucidate how crop residues from a fast-decomposing legume (*C. juncea*), a slower-decomposing legume (*C. ensiformis*), and a grass species (*P. glaucum*) modulate the efficacy of pre-emergence herbicides. The goal was to optimize integrated management recommendations for controlling resistant populations of *B. pilosa*, *E. heterophylla*, and *A. hybridus.*

2. Material and Methods

Three experiments were conducted in a greenhouse during the years 2023/2024, one for each weed species (*B. pilosa*, *E. heterophylla*, *and A. hybridus*), using a completely randomized design in a 4 x 4 factorial scheme with three repetitions. The factors consisted of chemical management with pre-emergent herbicides (diclosulam, flumioxazin, sulfentrazone, and a control without herbicide) and cover crop species (*Canavalia ensiformis* (40 t ha^{-1}), *Pennisetum glaucum* (40 t ha^{-1}), *Crotalaria juncea* (40 t ha^{-1}), and bare soil). The amount of plant material on the soil was adopted according to the production capacity of each cover crop species (Piraí Sementes, 2018). The cover crops were sown under field conditions, and the aboveground biomass was harvested at ground level using a manual cutter at the beginning of flowering. After harvesting, the biomass was chopped into fragments of approximately 5–10 cm using a forage chopper. The material was then air-dried in the shade for 48 hours to reduce excess moisture and immediately applied as surface mulch in the greenhouse experiment.

The experimental units consisted of pots with a capacity of 5 L, filled with sieved soil taken from the arable layer (0-20 cm) of a dystrophic Red Latosol, with a clay texture (Embrapa, 2011). The chemical analysis of the soil samples used is described as follows: P mmol dm^{-3} = 15; organic matter = 38%; pH $CaCl_2$ = 5.6; K mmolc dm^{-3} = 5.4; Ca = 53 mmolc dm^{-3}; Mg = 13 mmolc dm^{-3}; H+Al = 26; sum of bases (SB) = 71.4; cation exchange capacity (CEC) = 97.4%; base saturation (V%) = 73.

The seeds of *B. pilosa*, *E. heterophylla*, and *A. hybridus* were acquired from a company specialized in the production of weed seeds (Agrocosmos). Sowing in the pots was performed at a depth of 1 cm from the soil surface, following the company's recommendation, using 20 seeds per pot for *B. pilosa* and *E. heterophylla*, and 30 seeds per pot for *A. hybridus*, in order to obtain approximately 10 emerged plants per pot. Subsequently, the pots were irrigated (5 mm of water), and each cover crop was applied on the soil according to the specified amounts in the treatments, maintaining a control without cover on the soil surface.

Immediately after applying the cover crops to the pots, the herbicides diclosulam (40 g i.a. ha^{-1}), flumioxazin (100 g i.a. ha^{-1}), and sulfentrazone (800 g i.a. ha^{-1}) were applied using a backpack sprayer, pressurized with CO_2 at a pressure of 35 lb pol^{-2}, equipped with a bar containing four XR11002 spray nozzles spaced 0.5 m apart, with a consumption of 200 L ha^{-1} of spray solution.

Following the herbicide application, the pots were placed in the greenhouse and irrigated on the same day with 10 mm of water (measured with rain gauges installed in the greenhouse), a volume selected based on Mendes et al. (2014). Subsequently, the pots were maintained with daily irrigation (3 mm per day).

At 35 days after application (DAA), the percentage of weed control was evaluated, and the dry biomass of the aerial part was obtained. For the qualitative control evaluation, the SBCPD (1995) scale was used, with percentage scores, where 0 (zero) corresponds to no injury to the plant and 100 (one hundred) to plant death. To obtain the dry biomass of the aerial part, the plants were cut at ground level, placed in paper bags, and subsequently taken to a forced-air circulation oven at a temperature of 60°C until a constant weight was achieved. The data were presented as the percentage (%) reduction of dry biomass relative to the control (without soil cover and without herbicide application).

Data analysis was performed individually for each treatment. The obtained data were subjected to normality tests and analyzed using the F-test, with treatment means compared using the Scott-Knott test at the 5% level ($p \leq 0.05$).

3. Results and Discussion

There was a significant interaction between pre-emergent herbicides and the crop residues of different cover crops in controlling the evaluated weed species, highlighting the importance of determining the appropriate relationship between herbicide and cover crop species to enhance control (Tables 1, 2 and 3).

The suppression of the species *A. hybridus* was significantly influenced by the presence of crop residue (Table 1). In the treatment without herbicide application, only the cover crops *C. juncea* and *C. ensiformis* resulted in control percentages between 80% and 90%, respectively, while the control exerted by *P. glaucum* was slightly lower. The seeds of *A. hybridus* are very small, meaning they have few reserves, which makes it more difficult for the species to penetrate the crop residue layer. Oliveira et al. (2009) reported the seed size of *Amaranthus* sp to be only 1.21 mm.

Table 1. Percentage of control of *Amaranthus hybridus*, 35 days after the application of pre-emergent herbicides, over the residues of different cover crops.

	Control (%)			
	Without cover crop	*C. juncea*	*C. ensiformes*	*P. glaucum*
Without herbicide	0.0 dC	80.0 bA	90.0 cA	75.0 cB
Diclosulan	73.3 bB	86.7aA	95.0 bA	98.3 aA
Flumioxazin	93.3 aA	81.7 bB	90.0 cB	87.0 bB
Sulfentrazone	71.8 bB	81.7 bB	98.3 aA	100.0 aA
CV(%)	1.83			
	Biomass reduction (%)			
	Without cover crop	*C. juncea*	*C. ensiformes*	*P. glaucum*
Without herbicide	0.00 dC	74.76 cB	84.13 aA	73.17 cB
Diclosulan	42.70 cC	70.00 bB	85.71 aA	84.13 bA
Flumioxazin	90.48 aA	71.90 bC	76.21 bB	75.35 cB
Sulfentrazone	53.97 bD	80.00 aC	88.17 aB	100.00 aA
CV(%)	4.60			

CV: Coefficient of Variation. means followed by the same lowercase letters in the column and uppercase letters in the row do not differ from each other by the Scott-Knott test at 5% significance.

Table 2. Percentage of control of *Bidens pilosa*, 35 days after the application of pre-emergent herbicides, over the residues of different cover crops.

	Control (%)			
	Without cover crop	*C. juncea*	*C. ensiformes*	*P. glaucum*
Without herbicide	0.0 dD	75.0 bC	80.7 cB	87.3 dA
Diclosulan	86.7 bC	98.0 aA	98.3 aA	97.7 bB
Flumioxazin	95.7 aA	91.0 aC	93.3 bB	90.5 cC
Sulfentrazone	76.7 cD	96.7 aB	81.7 cC	100.0 aA
CV(%)	1.02			
	Biomass reduction (%)			
	Without cover crop	*C. juncea*	*C. ensiformes*	*P. glaucum*
Without herbicide	0.00 dD	61.37 dC	77.95 bB	83.33 bA
Diclosulan	79.35 bD	91.18 aA	78.36 bC	84.62 bB
Flumioxazin	90.50 aA	77.25 cD	84.62 aB	86.13 aA
Sulfentrazone	61.25 cD	85.00 bB	75.05 bC	100.00 aA
CV(%)	5.42			

CV: Coefficient of Variation. means followed by the same lowercase letters in the column and uppercase letters in the row do not differ from each other by the Scott-Knott test at 5% significance.

Table 3. Percentage of control of *Euphorbia heterophylla*, 35 days after the application of pre-emergent herbicides, over the residues of different cover crops.

	Control (%)			
	Without cover crop	*C. juncea*	*C. ensiformes*	*P. glaucum*
Without herbicide	0.0 dC	48.3 dA	48.3 cA	45.0 cB
Diclosulan	77.3 bC	85.0 aB	73.3 bD	90.0 aA
Flumioxazin	71.7 cA	68.3 cB	40.0 dC	60.5 bB
Sulfentrazone	88.0 aA	80.0 bC	85.0 aB	90.0 aA
CV(%)	3.47			
	Biomass reduction (%)			
	Without cover crop	*C. juncea*	*C. ensiformes*	*P. glaucum*
Without herbicide	0.00 bC	20.00 cB	30.00 cA	20.00 cB
Diclosulan	67.23 aB	70.00 aB	65.00 bC	80.00 aA
Flumioxazin	65.26 aA	30.00 bB	22.36 dC	37.89 bB
Sulfentrazone	70.00 aB	68.25 aB	72.01 aB	85.00 aA
CV(%)	6.03			

CV: Coefficient of Variation. means followed by the same lowercase letters in the column and uppercase letters in the row do not differ from each other by the Scott-Knott test at 5% significance.

The interaction between herbicides and crop residue was particularly important for the herbicides diclosulam and sulfentrazone, demonstrating a synergistic effect with the crop residue, which increased control efficiency compared to the isolated application of the herbicides directly on the soil. For sulfentrazone, there was a difference in control among the crop residues, with the control associated with *C. juncea* residue being slightly lower than that of the other cover crops. On the other hand, flumioxazin exhibited greater control efficacy when applied directly to the soil (93.30%), with no significant differences among the residues of the cover crops, maintaining efficacy above 80% in all scenarios. This behavior can be explained by its low water solubility (~0.79–1.8 mg L^{-1}) and its high organic carbon adsorption coefficient (Koc ≈ 889 mL g^{-1}), properties that favor its retention in the superficial soil layer, close to the weed emergence zone (Epa, 2001). In soils with plant residue coverage, even under a light water application (10 mm), flumioxazin remains effective as it reaches the seed contact zone without moving into deeper layers.

Among the most important characteristics of herbicides that interfere with their ability to penetrate the crop residue layer is water solubility. The solubility of diclosulam in water is pH-dependent and varies from ~100 mg kg^{-1} at pH between 5 and 7 to > 4,000 mg kg-1 at pH 9. Sulfentrazone has a water solubility of 490 mg L^{-1}, while flumioxazin has a solubility of 1.80 mg L^{-1} in water (25°C), with the latter being considered low, which may have resulted in greater retention in the residue even after simulated rainfall. According to Eason et al. (2022), flumioxazin has a low leaching potential, with an inverse correlation observed between the concentration of this herbicide in the soil, precipitation, and solar radiation.

According to Brunetto et al. (2023), without crop residue, the application of diclosulam resulted in low percentages of control of *A. hybridus*, corroborating the results of this study, which indicated that the association of the herbicide with crop residue aids in control.

Carbonari et al. (2008) found that applying diclosulam on dry or wet *Sorghum bicolor* residue without subsequent rainfall led to unsatisfactory control of the weeds *Ipomoea grandifolia* and *Sida rhombifolia*, demonstrating the dependency on rainfall for leaching and absorption of diclosulam by the plants.

It is important to emphasize the significance of water in percolating herbicides through the crop residue. Simoni et al. (2006) reports that complete mobility of sulfentrazone in the soil, necessary to reach soil solution, requires a water depth of over 10 mm.

For *A. hybridus*, there was a significant reduction in dry biomass solely due to the cover crop residues, particularly *C. ensiformis* (Table 1). For diclosulam and sulfentrazone, the combination with the crop residues enhanced the reduction of the species' dry biomass, which exhibited low control levels when applied alone. In contrast, flumioxazin showed a significant reduction in the dry biomass of *A. hybridus*, which was diminished by the presence of crop residue.

For the control of *B. pilosa*, the residue of *P. glaucum* had a greater suppressive effect compared to the other types of crop residues, especially when compared to *C. juncea*, which showed a control of 75% (Table 2). According to Souza et al. (2009), the emergence of black jack seedlings is significantly affected by the location of the achene in the soil profile, showing considerable reduction from a depth of 2 cm; thus, crop residue can play an important role in controlling this species. Regarding herbicides, flumioxazin was the most effective when applied directly to the soil, followed by diclosulam. Sulfentrazone exhibited control below 80%. The crop residue significantly contributed to the increased efficiency of sulfentrazone, with the cover of *P. glaucum* achieving 100% control. In the case of diclosulam, the interaction with the crop residue was also positive, resulting in control rates above 97%. Silva (2020) observed that excessive cover makes it difficult for flumioxazin to control weeds, necessitating at least 20 mm of rain after application to achieve adequate control. However, in this study, this herbicide demonstrated control above 90% even when associated with cover crop residues in controlling this species.

The crop residue also achieved good reductions in the dry biomass of *B. pilosa*, with a lesser effect from the residue of *C. juncea* (Table 2). Flumioxazin applied directly to the soil also stood out as the best chemical management for this species, although its control was reduced by the presence of crop residue, except for the residue of *P. glaucum*. For sulfentrazone and diclosulam, there was synergy with some types of residue, particularly the residue of *P. glaucum* combined with sulfentrazone, increasing control from 61% to 100% compared to the herbicide applied alone.

E. heterophylla were not adequately controlled when only the residues of the cover species were used (Table 3). Several studies have shown that *E. heterophylla* (wild poinsettia) is capable of germinating and emerging even under thick mulch layers, which makes it a challenging weed in systems with crop residue cover (Ferreira et al., 2017).

Among the herbicides, flumioxazin was the least effective (71.7%), especially when combined with the different plant residues, particularly *C. ensiformis*. Sulfentrazone applied alone showed high efficacy in controlling the species, with only the combination with *P. glaucum* equating to this control. Diclosulam proved efficient, especially when associated with *C. juncea* and *P. glaucum*, achieving controls of 85% to 90%, respectively.

For *E. heterophylla*, the reduction in dry biomass, as observed for the percentage of control, was low in treatments involving only plant residues (Table 3). The herbicide flumioxazin did not stand out in controlling this species as it did with others, and again no gains were observed in association with the crop residue. On the other hand, for diclosulam and sulfentrazone, there was synergy with the species *P. glaucum*, whose residue enhanced the suppressive effect on the dry biomass of the species.

The results obtained for the species *E. heterophylla* align with those observed by Patel (2018) with diclosulam and flumioxazin associated with soil cover, and Correia and Kronka (2020) with the herbicide sulfentrazone.

It is important to emphasize that morphological and biological characteristics significantly impact the differences in control of weed species by crop residue, with seed size being a crucial factor. According to Araldi et al. (2013), the seed size of each species represents the requirements for dispersal, favoring small seeds, and the needs for seedling establishment, favoring large seeds. For these species, the most successful strategy prioritizes size over the quantity of seeds.

The differences in the results of the interaction between the crop residue and herbicides can be explained by the interception, adsorption, and leaching of these pre-emergent herbicides in different types of crop residue, affecting their efficacy in controlling weeds.

These effects are directly related to the amount of biomass produced and accumulated over the soil, as well as the chemical composition of the plant cover (Gaston et al., 2001), which can modify the behavior of herbicides, reducing their control efficiency. This occurs because plant residues hinder the direct deposition of herbicides in the soil, retaining molecules on the surface.

These retained herbicide molecules are subject to various forms of dissipation, such as volatilization and photodegradation caused by sunlight. Laboratory tests showed that the effect of wheat residue on herbicide degradation differed depending on the herbicide and incubation temperature, highlighting that sustainable agricultural practices can prevent soil and groundwater contamination (Douibi et al., 2024).

Each compound belongs to a different chemical group, with different structures and physicochemical properties (water solubility, hydrophobicity, leaching potential, and degradation rate) (Lewis et al., 2016).

According to Trezzi et al. (2009), factors that displace herbicides from the soil's surface layer, such as surface erosion, or those that increase their retention in this layer, such as low water availability and increased organic matter content, tend to decrease the availability of the product for weeds and therefore reduce control efficiency.

The results of this study highlighted the significant interaction between pre-emergent herbicides and cover crop residues in weed control. The combination of the herbicides diclosulam and sulfentrazone with crop residues demonstrated high efficacy in suppressing *B. pilosa*, *E. heterophylla*, and *A. hybridus*. In contrast, for the herbicide flumioxazin, the presence of crop residue did not lead to an increase in control, indicating that the effectiveness of this combination is dependent on the specific herbicide molecule.

4. Conclusions

It is concluded that the combined use of cover crop residues with the herbicides diclosulam and sulfentrazone constitutes an effective and recommended strategy for the integrated management of *B. pilosa*, *E. heterophylla*, and *A. hybridus*. However, herbicide selection is a critical factor for the success of this practice, as molecules with high sorption and low solubility, such as flumioxazin, can have their bioavailability compromised by crop residues. Therefore, the careful selection of the herbicide and cover crop system combination is fundamental to optimize weed control and promote more sustainable agricultural practices.

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