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Scientific Article

Intercropping systems of corn and forage grasses with application of low mesotrione herbicide rates

Sistema de consórcio de milho com gramíneas forrageiras e o uso de doses reduzidas do herbicida mesotrione

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ABSTRACT - Sowing forage grass species of the genera *Urochloa* and *Panicum* simultaneously with corn can hinder crop grain yield, requiring the application of low herbicide rates for suppressing their growth and preventing potential competition with corn plants. Therefore, the objective of this study was to evaluate the use of low rates of the herbicide mesotrione for inhibiting the growth of forage grass species (*Urochloa ruziziensis* and *Panicum maximum*, cultivars BRS Tamani and BRS Zuri) sown simultaneously with corn crop, as well as the recovery capacity of these grasses. Two experiments were installed, as first and second crop seasons, in a randomized experimental block design with four replications, using a 3×4 factorial arrangement and three control treatments with corn alone. Each of the three forage grasses was sown simultaneously with corn and subjected to post-emergence application of four mesotrione rates (0, 48, 96, and 144 g ha^{-1}) with atrazine (1.25 kg ha^{-1}). Weeds, forage grasses, and corn plants were evaluated. BRS Tamani was the most tolerant forage to mesotrione, while BRS Zuri was the most sensitive. The application of mesotrione + atrazine in the corn-forage grass intercropping system contributed to weed control. The tested forage grasses did not affect corn grain yield in the first or second crop season, even with no herbicide application.

Keywords: Congo grass. BRS Tamani. BRS Zuri. Green cover. Weed management.

RESUMO - Gramíneas forrageiras dos gêneros *Urochloa* e *Panicum*, semeadas simultaneamente à cultura do milho, podem prejudicar a produtividade de grãos da cultura, necessitando do uso de doses reduzidas de herbicida para supressão do seu crescimento e evitar possível competição das plantas com o milho. Por isso, objetivou-se avaliar o uso de doses reduzidas do herbicida mesotrione para inibição do crescimento de gramíneas forrageiras (*Urochloa ruziziensis* e *Panium maximum*, cultivares BRS Tamani e BRS Zuri) e a capacidade de recuperação destas, quando semeadas simultaneamente à cultura do milho, em sistema consorciado. Dois experimentos foram instalados em condições de safra e segunda safra, no delineamento experimental de blocos ao acaso, com quatro repetições, em esquema fatorial 3 x 4 mais 3 testemunhas de milho solteiro. As três forrageiras foram consorciadas com milho, com a semeadura simultânea, e pulverizados na pós-emergência das plantas com quatro doses de mesotrione (0, 48, 96 e 144 g ha^{-1}) em mistura com atrazine (1,25 kg ha^{-1}). Foram realizadas avaliações nas plantas daninhas, forrageiras e milho. Com base nos resultados obtidos, BRS Tamani foi a forrageira mais tolerante ao herbicida mesotrione, enquanto BRS Zuri, a mais sensível. O uso de mesotrione em mistura com atrazine no sistema de consórcio de milho com gramíneas forrageiras beneficiou o controle de plantas daninhas. As forrageiras testadas não interferiram na produtividade de grãos de milho, seja na condição de safra ou de segunda safra, mesmo sem a aplicação de herbicida.

Palavras-chave: Capim ruziziensis. BRS Tamani. BRS Zuri. Cobertura verde. Manejo de plantas daninhas.

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INTRODUCTION

The challenge of controlling some weed species using glyphosate in soybean crops requires not only substituting or adding new herbicides to the production system but changes in management practices by adopting an integrated weed management. Integrated weed management includes the maintenance of cover crops cover crops off-season, such as forage grass species of the genera *Urochloa* and *Panicum*. This practice is essential for improving soil physical, chemical, and biological quality and facilitating weed management through the interference of living forage plants or the mulch formed on the soil after burndown before sowing the following crop (ADAMI et al., 2020; CORREIA, 2023).

The most effective strategy for implementing forage grasses in the Brazilian Cerrado biome is through intercropping with corn (JAKELAITIS et al., 2004; GARCIA et al., 2013) because of the water deficit during the autumn-winter period. However, intercropping is a complex system; the crop system (corn intercropped with forage), establishing time, plant arrangement, and weed infestation can cause competition between plants, mainly when the crop and forage grasses are sown simultaneously (JAKELAITIS et al., 2004). Thus, chemical control should be used for inhibiting the development of forage grasses, preventing their competition with corn plants, and assisting in weed management without affecting the subsequent establishment of the forage (DAN et al., 2011; SILVA et al., 2023).

Mesotrione is among herbicides that can be used in intercropping systems to inhibit the development of forage grasses. This herbicide belongs to the chemical group of triketones, which inhibits the enzyme HPPD (4-hydroxyphenylpyruvate dioxygenase) in chloroplasts, affecting the synthesis of carotenoids; it is selective for corn plants (RODRIGUES; ALMEIDA, 2018). There are some studies on the potential use of mesotrione in corn intercropping systems with *Urochloa ruziziensis* and few for *Panicum maximum* cultivars BRS Tamani and BRS Zuri. The action of herbicide molecules in plants varies depending on the species, genotype, and developmental stages (MATIAS et al., 2019, CRUVINEL et al., 2021; GHENO et al., 2021). Additionally, the application of mesotrione in intercropping systems can assist in weed control when combined with atrazine, which is the most used herbicide in these systems, mainly for species that are poorly or not controlled by atrazine applications.

The growth of *P. maximum* provides several advantages, as it has a high potential of dry matter production per unit area, wide adaptability, good forage quality, and ease of establishment (DIAS et al., 2020); however, the implementation of this forage intercropped with corn is still little explored. This may be attributed to the lack of information on effects of these plants on corn crops (SILVA et al., 2023). These potential effects can be prevented by applying appropriated herbicide rates to ensure the establishment of forage plants in the area after corn grain harvest, without hindering animal grazing and the formation of mulch on the soil, adding advantages to weed management and the soil chemical, physical, and biological properties.

Therefore, the hypothesis raised here is that forage grass species sown simultaneously with corn crops require application of low rates of the herbicide mesotrione for suppressing the growth of the grass species and preventing potential competition with corn plants. Thus, the objective of this study was to assess the effects of applying low mesotrione rates on the growth of *U. ruziziensis* and *P. maximum* (cultivars BRS Tamani and BRS Zuri) sown simultaneously with corn and their recovery ability, weed management, and the development of corn plants grown in the first and second crop seasons.

MATERIAL AND METHODS

Two experiments were developed at the experimental area of the Brazilian Agricultural Research Corporation (EMBRAPA Cerrados), in Brasília, Federal District, Brazil. One experiment was conducted in the first crop season (November 18, 2021 to November 17, 2022) and another in the second crop season (February 9, 2022 to November 16, 2022).

The areas used in the first and second season experiments were at 15°36’05.2"S, 47°42'47.9"W, and altitude of 987 m, and at 15°36'27.8"S, 47°44'36.8"W, and altitude of 1129 m, respectively. The region's climate was classified as Aw, tropical humid, according to the Köppen classification (CARDOSO; MARCUZZO; BARROS, 2014).

The soils of the experimental areas are representative of the region, classified as Latossolo Vermelho Escuro (Typic Hapludox) (SANTOS et al., 2018) of clay texture (with 40.6% sand, 5.9% silt, and 53.5% clay; first crop season area) and silt clay texture (14.2% sand, 42.9% silt, and 42.9% clay; second crop season area). The soil chemical analysis of the first and second crop season areas showed, respectively: pH (in $CaCl_2$) of 5.1 and 5.3; 3.0 and 3.5 dag kg^{-1} of organic matter; 7.27 and 2.04 mg dm^{-3} of P (Mehlich); 149 and 152 mg dm^{-3} of K; 3.46 and 2.35 cmol$_c$ dm^{-3} of Ca; and 1.32 and 1.10 cmol$_c$ dm^{-3} of Mg.

The total monthly rainfall depths and monthly average maximum and minimum air temperatures, recorded from November 1, 2021 to November 30, 2022 by a weather station installed at 750 m from the experimental areas, are shown in the Figure 1.

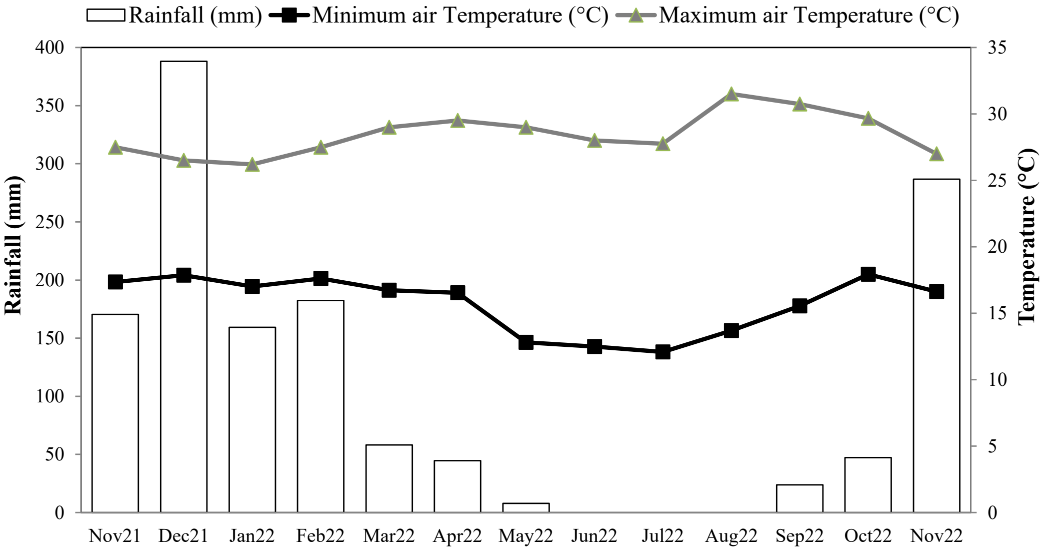

Figure 1. Total monthly rainfall depth and monthly average maximum and minimum air temperatures recorded by a weather station at approximately 750 m from the experimental areas.

The experiments were installed using a randomized block design with four replications, in a 3×4 factorial arrangement consisting of three forage grasses (*Urochloa ruziziensis* and *Panicum maximum* - cultivars BRS Tamani and BRS Zuri), each of them intercropped with corn with simultaneous sowing) and subjected to post-emergence application of four different mesotrione rates (0, 48, 96, and 144 g ha^{-1}) with atrazine (1.25 kg ha^{-1}) and 0.5% mineral oil. The intercropping treatments were compared to three controls treatments with corn alone: the first control was maintained with weeds throughout the corn cycle (infested control); the second control consisted of chemical control of weeds by applying mesotrione + atrazine (144 g ha^{-1} + 1.25 kg ha^{-1}, respectively) and 0.5% mineral oil (chemical control); and third control consisted of weed control through manual weeding (weeding control).

The plots had 3.0 m in width and 5 m in length each, totaling an area of 15.0 m^2, with an evaluation area of 6.0 m^2 (four meters of the three central rows). Corn was sown in the central 2.5 m of the plots using a five-row pneumatic seeder-fertilizer spreader. The forage grasses were sown and the herbicide treatments were applied to the total area of the plots (15.0 m^2).

The corn hybrids used were P3707VYH in the first crop season and P3858PWU in the second crop season. The seeds were sown to a depth of 5 cm, at densities of 6.3 and 3.8 seeds per meter, respectively, with a spacing of 0.5 m between rows, under no-tillage system. The seeds were treated with insecticides and fungicides for protection against pests and initial diseases. Soil fertilizers were applied based on the soil analysis and crop nutritional needs, using 16 kg ha^{-1} of N, 120 kg ha^{-1} of P_2O_5, 64 kg ha^{-1} of K_2O, and 0.2 kg ha^{-1} of Zn, which were applied to the sowing furrows for both experiments.

Weeds in the experimental areas before corn sowing were controlled by applying glyphosate (1.44 kg a.e. ha^{-1}) at seven days before sowing in the first crop season, and glyphosate (1.44 kg a.e. ha^{-1}) + clethodim (0.192 kg ha^{-1}) and 0.5% mineral oil at 14 days before sowing in the second crop season. An additional herbicide application using glufosinate-ammonium (0.5 kg ha^{-1}) and 0.5% mineral oil was applied one day before corn sowing; this additional herbicide application in the second crop season was necessary due to the occurrence of a glyphosate-resistant species (sourgrass, *Digitaria insularis*).

The seeds of forage species were manually broadcast over the total area of the plots on the same day as corn sowing. The amounts of seeds used were 1200 cultural value points, with cultural value of 75.77 for *U. ruziziensis*, 72.71 for BRS Tamani, and 74.28 for BRS Zuri, resulting in equivalent amounts of 15.8 kg ha^{-1} for *U. ruziziensis*, 16.5 kg ha^{-1} for BRS Tamani, and 16.2 kg ha^{-1} for BRS Zuri.

Topdressing for corn crops was carried out in the two experiments at 21 days after corn sowing, using 95.2 kg ha^{-1} of N and 95.2 kg ha^{-1} of K_2O, which were manually distributed near the corn plant rows.

The herbicide treatments were applied at 22 and 26 days after corn sowing in the first crop and second crop season experiments, respectively. They were applied using a CO_2-pressurized backpack sprayer equipped with a bar containing six TTI 110015 flat fan spray nozzles spaced 0.5 m apart, at a constant pressure of 2.0 kgf cm^{-2} and flow equivalent to 150 L ha^{-1}. Weather conditions at the time of applications in the first and second crop seasons were, respectively: air temperature of 23.3 to 28.9 °C, soil temperature of 22.5 to 24.5 °C, relative air humidity of 54% to 83%, and wind speed of 2.5 to 4.1 km h^{-1}.

The herbicides were applied in the first crop season when the corn plants exhibited 5 fully developed leaves and density of 6.0 plants m^{-1}; *U. ruziziensis* plants exhibited 4 leaves to 2 tillers and density of 19.3 plants m^{-2}; BRS Tamani plants exhibited 3 leaves to 3 tillers (density of 28.3 plants m^{-2}); and BRS Zuri exhibited 2 to 4 leaves (density of 28.9 plants m^{-2}). Broadleaf weeds had 2 to 8 leaves (density of 44.4 plants m^{-2}), whereas grass weeds had 3 leaves to 3 tillers (density of 12.6 plants m^{-2}). The weed community in the area was composed of *Euphorbia heterophylla*, *Commelina benghalensis*, *Ipomoea quamoclit*, *I. triloba*, *Acanthospermum hispidum*, *Bidens subalternans*, *Richardia brasiliensis*, *Alternanthera tenella*, *Tridax procumbens*, *Chamaesyce hirta,* and *Conyza sumatrensis*, as well as grass weeds: *Cenchrus echinatus*, *Eleusine indica*, and *Digitaria* sp.

The herbicides were applied in the second crop season when the corn plants exhibited 5 to 6 leaves (mean density of 3.5 plants m^{-1}), whereas *U. ruziziensis* exhibited 2 leaves to 4 tillers (density of 11.8 plants m^{-2}), BRS Tamani 3 leaves to 4 tillers (density of 17.8 plants m^{-2}), and BRS Zuri 2 leaves to 2 tillers (11.1 plants m^{-2}). Broadleaf weeds exhibited 2 to 8 leaves (density of 34.6 plants m^{-2}), whereas grass weeds exhibited 2 leaves to 5 tillers (density of 13.2 plants m^{-2}). The weed community in the area was composed of *Bidens subalternans*, *Commelina benghalensis*, *Tridax procumbens*, *Galinsoga parviflora*, *Portulaca oleracea*, *Conyza sumatrensis*, *Chamaesyce hirta*, *Amaranthus* sp., *Mitracarpus hirtus,* as well as grass weeds:*Cenchrus echinatus*, *Eleusine indica,* and *Digitaria* sp.

Possible injuries in corn plants and forage grasses were visually evaluated at 10 and 25 days after herbicide application (DAA) in the first crop season and at 15 and 35 DAA in the second crop season, based on a scale from 0 to 100%, where zero represents absence of visual injuries and 100% represents plant death (SBCPD, 1995).

Forage plants were counted in two 0.5 m^2 sampled areas within the evaluation area of each plot (6.0 m^2) at 25 DAA (first crop season) and 28 DAA (second crop season). The results were expressed as density of plants m^{-2}.

Soil cover by forage grass plants was visually evaluated at corn grain harvest and at 188 and 119 days after corn grain harvest (DAH) in the first and second crop seasons, respectively. This evaluation was based on a scale from 0 to 100%, where zero represents the absence of forage plants and 100% represents total coverage of the area by forage plants.

Forage plant shoots were randomly collected from a 1.0 m² area within the evaluation area of each plot at 188 DAH (first crop season) and 119 DAH (second crop season) for determining the dry shoot weight (kg ha^{-1}) of the plants.

Weed control was visually evaluated based on a scale from 0 to 100%, in which zero represents the absence of control and 100% represents plant death (SBCPD, 1995). The evaluations were carried out at 10 and 25 DAA (first crop season) and 15 and 35 DAA (second crop season); at the time of corn grain harvest; and at 188 DAH (first crop season) and 119 DAH (second crop season).

Corn plants in the evaluation area of the plots were counted and their ears were collected and counted at the end of the crop cycle: at 166 days after sowing (DAS) in the first and at 145 DAS in the second crop season. The ears were threshed and the grains were cleaned, weighed, and evaluated for moisture. Grain production, plant population, and number of ears in the plot evaluation area (6.0 m^2) were determined and then converted to hectare; the results were used to calculate grain yield per plant and grain yield per ear; 100-grain weight was also measured.

The obtained data were subjected to analysis of variance using the F-test, and when significant ($p<0.01$ or $p<0.05$), the forage grass data were compared using the Tukey's test at a 5% significance level, whereas the data of mesotrione rates were compared through polynomial models. The control treatments were compared to each other and to the significant intercropping treatments through orthogonal contrast.

RESULTS AND DISCUSSION

Effects on weeds

In the first crop season, forage grasses had a significant effect on weed control only before sowing the subsequent crop (188 DAH); mesotrione rates had significant effects at 10 and 25 DAA (Table 1). The interaction between the factors (forage × mesotrione rate) was not significant to weed control at any evaluation time. In the second experiment, weed control was affected by the drought period, resulting in the growth of plants that survived chemical control. The effect of mesotrione rates was significant only at 15 and 35 DAA (Table 1).

Table 1. Analysis of variance (F-test) for weed control at 10 and 25 days after application (DAA) of herbicides, at corn grain harvest (zero), and at 188 days after corn grain harvest (DAH) as a function of forage species and mesotrione rates, and means of intercropping treatments and control treatments in the first crop season and at 15 and 35 DAA, 0 and 119 DAH in the second crop season.

Source of variation	First crop season - Weed control			
	10 DAA	25 DAA	0 DAH	188 DAH
Forage grasses	1.05	1.81	0.21	16.86**
Mesotrione rates	25.71**	3.05*	0.74	0.15
Forages × mesotrione rates	0.29	1.02	0.95	0.60
CV (%)	3.35	8.60	1.23	5.63
Treatments	Means (%)			
Intercropping treatment	84.79	74.55	99.36	92.06
Chemical control	78.92	67.15	100.00	52.50
Infested control	0.00	0.00	0.00	0.00
Weeding control	100.00	100.00	92.19	37.50
Source of variation	Second crop season - Weed control			
	15 DAA	35 DAA	0 DAH	119 DAH
Forage grasses	0.47	0.34	1.00	8.32
Mesotrione rates	17.13**	5.29**	1.00	7.21
Forages × mesotrione rates	0.55	0.73	1.00	3.22
CV (%)	3.79	6.25	1.00	40.38
Treatments	Means (%)			
Intercropping treatment	96.25	94.11	99.95	40.00
Chemical control	90.00	85.00	100.00	22.50
Infested control	0.00	0.00	0.00	0.00
Weeding control	100.00	100.00	100.00	30.00

**, and * = significant at 1% and 5% significance levels, respectively, by the F-test. Chemical control = corn alone with application of mesotrione (144 g ha^{-1}) + atrazine (1.25 kg ha^{-1}); Infested control = corn alone with weeds; Weeding control = corn alone with weed control by manual weeding.

Weed control increased with increasing mesotrione rates (mixed with atrazine) within the treatments of forages intercropped with corn crops, showing linear responses at 25 DAA and quadratic responses at 10 DAA in the first experiment (Figure 2). In the second crop season, control levels increased as the mesotrione rate (with atrazine) was increased, as in the first crop season (Figure 2). Regarding the other evaluations, weed control was not affected by the factors or the interaction between factors.

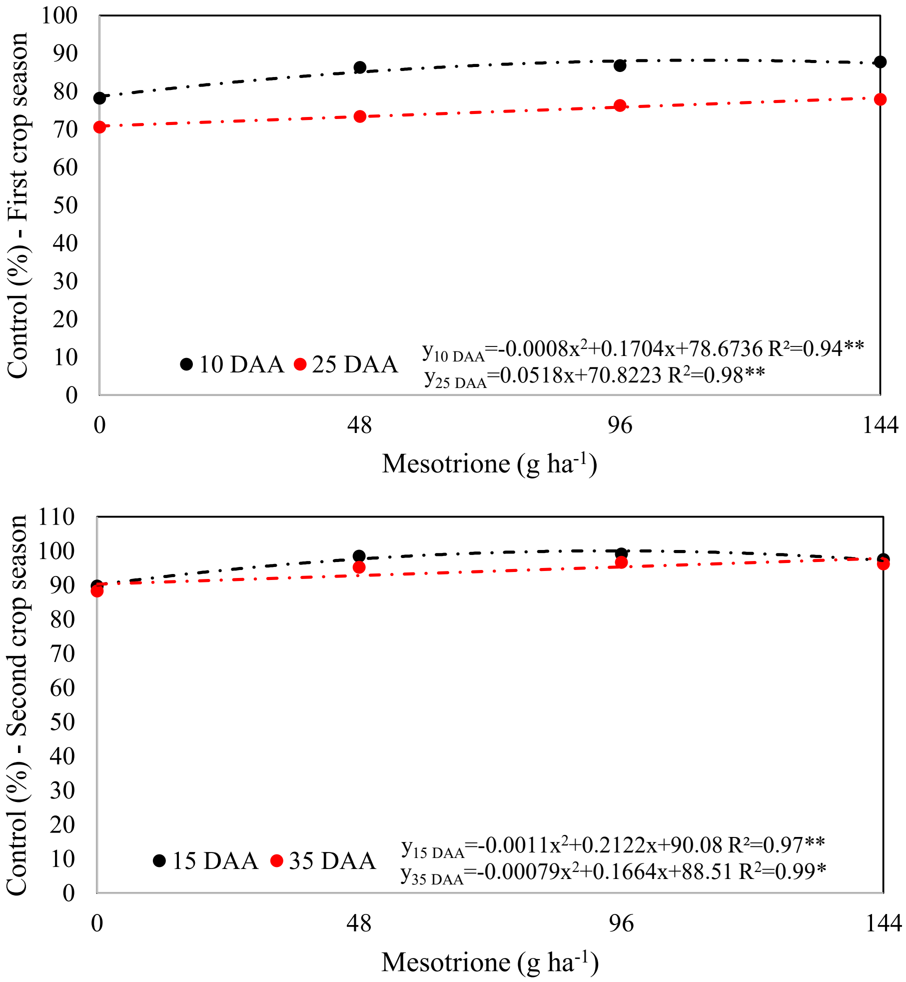

Figure 2. Weed control (%) at 10 and 25 days after application (DAA) of increasing rates of mesotrione in the first crop season of corn intercropped with forage species, and at 15 and 35 DAA after intercropping implementation in the second crop season.

The mixture of mesotrione with atrazine enhances the control of weed species for which atrazine application is ineffective, mainly grass weeds such as *Digitaria* species and *Cenchrus echinatus*, or atrazine-resistant biotypes, such as *Amaranthus palmeri*, explaining the use of this herbicide mixture in corn crops (MATTE et al., 2018; CHAHAL; JUGULAM; JHALA, 2019; CHHOKAR et al., 2019).

In the first crop season, weed control was higher than 90% in the intercropping treatments and in control treatments (chemical and weeding) at the corn harvest, with no significant difference between them. However, weed control after corn harvest was maintained only in intercropping treatments. The comparison between the means of control treatments (chemical and weeding) and intercropping treatments, through orthogonal contrasts, showed that weed control in intercropping treatments was significantly higher ($p<0.01$) than that in the controls. This result can be attributed to the maintenance of soil cover by forage plants in the off-seasons, which hindered the emergence and development of weeds.

These benefits were also reported by Correia (2023) when evaluating the control of sourgrass plants in the off-season by soil cover with forage grasses (*Panicum maximum* and *Urochloa ruziziensis*) after soybean harvest, with decreases of approximately 75% in plant density and weed infestation in the area compared to treatments with no soil cover in the off-season. This emphasizes the importance of complementing chemical treatments in the crop of interest by growing cover species in the off-season (autumn-winter), mainly fast-growing and vigorous cover species, rather than leaving the field fallow with weed growth.

In the second crop season, the comparison between the means of intercropping treatments and chemical control treatment through orthogonal contrasts showed significant differences ($p<0.01$) at 15 and 35 DAA, with higher weed control percentages in the intercropping treatments. No significant difference between intercropping treatments and control treatments (chemical and weeding) was found at corn grain harvest, with weed control exceeding 99%. Despite no significant difference between them at 119 DAH, weed control was very low, ranging from 22% (chemical control treatment) to 40% (mean of intercropping treatments).

The low dry matter production of forage plants (<1200 kg ha^{-1}) in the second crop season explains the absence of weed control maintenance from corn harvest to the begging of the next crop season (November). Thus, the benefits of intercropping system regarding the infesting weed community were not evaluated due to the drought that hindered the growth of forage plants.

Effects on forage species

In the first crop season, the effects of the factors and their interaction on forage plants were significant in terms of phytotoxicity at 10 DAA (Table 2). The results of the second crop were similar to those of the first crop season. However, forage species were more sensitive to the action of the herbicide mesotrione, with slower and, in some cases, only partial plant recovery. The factors and their interaction were significant for phytotoxicity (in the two evaluations), plants density, and soil cover (Table 2).

Table 2. Analysis of variance (F-test) for phytointoxication in forage grasses at 10 days after application (DAA) of herbicides, plant density at 25 DAA, and soil cover and shoot dry matter of forage species at 188 days after corn grain harvest (DAH) as a function of forage species and mesotrione rates in the first crop season; and phytotoxicity at 15 and 35 DAA, plant density at 28 DAA, and soil cover and shoot dry matter at 119 DAH in the second crop season.

Source of variation	First crop season			
	Phytointoxication 10 DAA	Density 25 DAA	Soil cover 188 DAH	Dry matter 188 DAH
Forage grasses	21.91**	2.39	39.75**	50.62**
Mesotrione rates	24.22**	1.76	1.55	2.43
Forages × mesotrione rates	3.41**	0.42	0.99	1.48
CV (%)	30.99	24.60	12.60	26.19
	%	Plants m^2	%	kg ha^{-1}
Means	9.17	24.02	70.16	1572.72

Source of variation	Second crop season				
	Phytointoxication		Density 28 DAA	Soil cover 119 DAH	Dry matter 119 DAH
	15 DAA	35 DAA			
Forage grasses	26.66**	38.34**	20.41**	79.29**	15.17**
Mesotrione rates	34.01**	24.19**	3.12*	24.19**	9.79**
Forages × mesotrione rates	4.09**	6.08**	3.09*	4.11**	1.35
CV (%)	33.28	39.26	29.77	14.06	34.98
	%		Plants m^2	%	kg ha^{-1}
Means	27.92	7.60	13.81	56.56	918.69

**, and * = significant at 1% and 5% significance levels, respectively, by the F-test.

No significant difference between mesotrione rates was found for the cultivar BRS Tamani in the first crop season. Regarding *U. ruziziensis* and BRS Zuri, the phytotoxicity increased linearly as the mesotrione rate was increased (Figure 3). The subsequent evaluation (25 DAA) showed no visual injuries in the plants of the three forage species, indicating their recovery. In the second crop season, BRS Tamani was not significantly affected by mesotrione rates at 15 and 35 DAA. Contrastingly, phytointoxication scores for *U. ruziziensis* and BRS Zuri increased as the mesotrione rate was increased, fitting linear or quadratic models (Figure 3).

In the first crop season, the density of forage plants was not affected by the factors. Soil cover and shoot dry matter production was significantly affected by the forage species, but not by the mesotrione rate factor. BRS Tamani and BRS Zuri presented higher shoot dry matter production and percentages of soil vegetation cover than *U. ruziziensis*, in the first crop season (Table 3). In another study conducted in Brazilian Cerrado biome, an integrated system with BRS Tamani overseeded at the R6-R7 stages of soybean crops was effective in producing shoot dry matter and adding N, K, Ca, Mg, and S to the soil (DIAS et al., 2020).

In the second crop, the different mesotrione rates did not show significant differences in plant density and soil cover for BRS Tamani and in plant density for *U. ruziziensis* (Figure 4). BRS Zuri presented lower number of plants and percentage of soil cover with increasing mesotrione rates, fitting a linear model. The percentage of soil cover by *U. ruziziensis* plants also decreased as the mesotrione rate was increased. Thus, although the herbicide did not significantly affect forage density, plant growth was impaired, reflecting in soil cover by the plants. Shoot dry matter of the three forage species was significantly affected by the factors individually, showing a quadratic reduction with increasing mesotrione rate

(Figure 4); BRS Zuri and BRS Tamani plants had higher dry matter accumulation, differing significantly from *U. ruziziensis* (Table 3).

Martins et al. (2019) reported that mesotrione rates from 9.6 to 57.6 g ha^{-1} did not affect the dry matter production and nutritional quality of *U. brizantha*, showing the variability in responses of *Urochloa* species to the herbicide, although the mesotrione rates evaluated in the present study were higher, ranging from 48 to 144 g ha^{-1}.

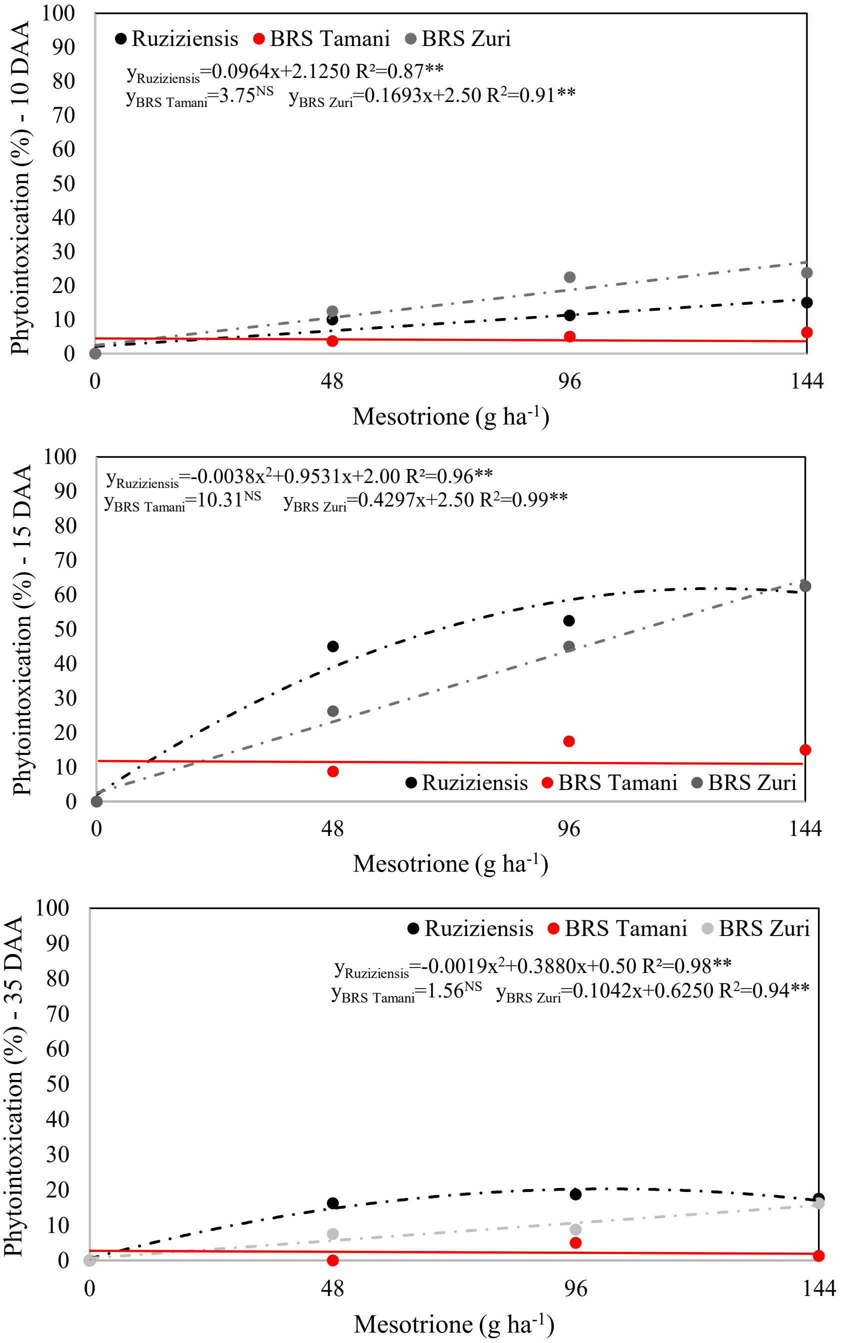

Figure 3. Phytointoxication in forage species intercropped with corn plants, evaluated at 10 days after application (DAA) of increasing rates of the herbicide mesotrione in the first crop season and at 15 and 35 DAA in the second crop season.

Table 3. Shoot dry matter of forage species at 188 days after corn grain harvest (DAH) in the first crop season and at 119 DAH in the second crop season, and soil cover (%) at 188 DAH in the first crop season.

Forage grasses	Dry matter (kg ha^{-1})		Soil cover (%) 188 DAH
	188 DAH	119 DAH	
Urochloa ruziziensis	737.62 b	573.09 b	54.69 b
BRS Tamani	2107.51 a	1182.76 a	81.72 a
BRS Zuri	1873.03 a	1000.24 a	74.06 a
Minimum significant difference	357.46	278.92	7.67

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test at a 5% significance level.

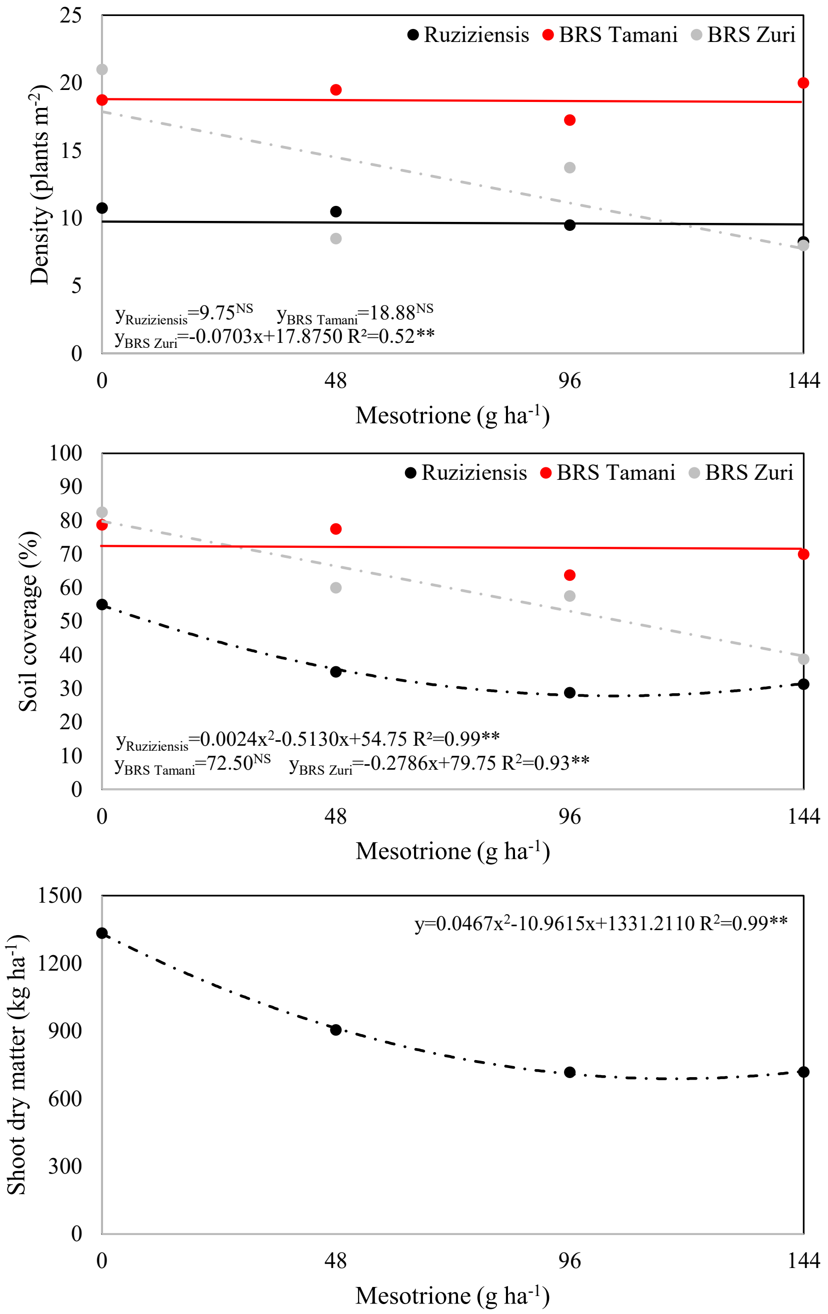

Figure 4. Plant density (plants m^{-2}), soil coverage (%), and shoot dry matter (kg ha^{-1}) of forage species at 119 after corn grain harvest (DAH) in the second crop season, as a function of increasing mesotrione rates.

Edaphoclimatic conditions, mainly soil moisture, affected the recovery of forage plants, especially BRS Zuri and *U. ruziziensis*. Soil moisture was low from May 17, corresponding to 97 days after the intercropping implementation in the second crop season, and rainfall depths were low during March (58.2 mm) and April (44.6 mm). In this context, efficient biochemical pathways for herbicide detoxification within cells, along with many cytoplasmatic enzymes involved in this process, require water for molecule metabolization (OGLIARI, et al., 2014). Additionally, water is essential for plant growth and development.

Effects on corn plants

The application of mesotrione with atrazine caused no visual damage to corn plants, denoting the high selectivity of this herbicide mixture to the crop (OLIVEIRA NETO et al., 2011; CHHOKAR et al., 2019). Furthermore, the effects of the factors and their interaction were not significant for any of the evaluated characteristics of corn plants in the first and second crop seasons (Tables 4 and 5). Corn intercropped with forages was not harmed by competition, regardless of the mesotrione rate applied to inhibit forage growth, even for BRS Tamani and BRS Zuri. Studies also have reported that corn grain yield was not affected by intercropping with *P. maximum* (ALMEIDA et al., 2017; SILVA et al., 2023), *U. ruziziensis*, or *U. brizantha* (MARTINS et al., 2019; SOUZA et al, 2022).

In the first crop season, the comparison between the means of intercropping treatments and control treatments (chemical, infested, and weeding) through orthogonal contrasts showed no significant difference between them, even between the means of weeding and infested controls, which presented approximately 14% lower yield for plants in the infested control. In the second crop season, the comparison of the means of infested control with those of intercropping treatments and weeding control showed significant grain yield losses ($p<0.01$), corresponding, on average, to 39% for corn plants in the infested control. However, no significant difference was found between controls (chemical and weeding) and intercropping treatments for corn grain yield.

The post-emergence application of mesotrione for inhibiting the growth of forage grasses and preventing potential competition with corn plants was unnecessary, as the intercropping did not harm corn plants, regardless of herbicide application. However, applying mesotrione with atrazine assisted in weed control, mainly in the second crop season.

The hypothesis that forage grasses sown simultaneously with corn require treatments with low rates of the herbicide mesotrione for suppressing their growth and avoiding competition with corn plants was not confirmed in this study for the corn hybrids P3707VYH and P3858PWU and forage species and plant densities used (*U. ruziziensis*, with 19.3 and 11.8 plants m^{-2}; BRS Tamani, with 28.3 and 17.8 plants m^{-2}; and BRS Zuri, with 28.9 and 11.1 plants m^{-2}) in the experiments of first and second crop seasons, respectively.

Table 4. Analysis of variance (F-test) for plant population, number of ears per hectare, grain yield per plant, grain yield per ear, 100-grain weight, and grain yield of corn as a function of forage species and of mesotrione rates, and mean results of intercropping treatments and controls treatments in the first crop season.

Source of variation	Plant population	Number of ears per hectare	Grain yield per plant	Grain yield per ear	100-grain weight	Grain yield
Forage grasses	1.17	0.59	0.58	0.58	0.58	1.20
Mesotrione rates	0.58	0.40	1.86	3.12	2.36	1.15
Forage x mesotrione	0.77	0.78	0.14	0.06	1.08	0.32
CV (%)	9.21	9.81	12.44	10.90	3.07	14.11
	Mean values					
Treatments	Thousand plants per hectare	Thousand ears per hectare	g per plant	g per ear	g	kg per hectare
Intercropping	92.43	89.76	105.22	108.26	35.16	9712.54
Chemical control	91.25	87.08	120.49	126.72	36.21	10936.82
Infested control	97.92	90.42	94.83	103.94	35.38	9262.86
Weeding control	99.17	96.66	108.26	111.29	36.18	10744.59

Chemical control = corn alone with application of mesotrione (144 g ha^{-1}) + atrazine (1.25 kg ha^{-1}); Infested control = corn alone with weeds; Weeding control = corn alone with weed control by manual weeding.

The competitive potential of the tested corn hybrids (P3707VYH and P3858PWU) was sufficient to inhibit the growth of both forage species (*U. ruziziensis* and *Panicum)* and prevent interference from these plants in the corn crop. Highly competitive cultivars have a rapid initial growth, with intense recruitment of environmental resources and high sunlight interception, making it difficult for unwanted plants to access and use resources (PITELLI; PITELLI, 2008).

Table 5. Analysis of variance (F-test) for plant population, number of ears per hectare, grain yield per plant, grain yield per ear, 100-grain weight, and grain yield of corn as a function of forage species and of mesotrione rates, and means of intercropping treatments and control treatments in the second crop season.

Source of variation	Plant population	Number of ears per hectare	Grain yield per plant	Grain yield per ear	100-grain weight	Grain yield
Forage grasses	0.64	0.52	0.48	1.32	1.52	0.95
Mesotrione rates	0.05	1.34	1.44	2.24	0.46	1.18
Forage × mesotrione	0.72	0.52	0.31	0.48	0.61	0.44
CV (%)	9.72	11.82	19.53	15.98	9.71	22.68
Treatments	Mean values					
	Thousand plants per hectare	Thousand ears per hectare	g per plant	g per ear	g	kg per hectare
Intercropping	67.15	62.99	56.72	60.30	19.79	3817.42
Chemical control	66.67	67.08	59.39	59.22	19.66	3918.48
Infested control	63.33	55.84	37.17	41.57	18.79	2344.91
Weeding control	66.25	64.58	57.72	58.46	19.73	3852.35

Chemical control = corn alone with application of mesotrione (144 g ha^{-1}) + atrazine (1.25 kg ha^{-1}); Infested control = corn alone with weeds; Weeding control = corn alone with weed control by manual weeding.

CONCLUSIONS

BRS Tamani was the most tolerant forage to the herbicide mesotrione and BRS Zuri was the most sensitive.

The application of mesotrione with atrazine in the corn-forage grass intercropping system contributed to weed control.

The tested forage grasses (*Urochloa ruziziensis* and *Panicum maximum* cultivars BRS Tamani and BRS Zuri) did not affect corn grain yield in the first or second crop season, even with no herbicide application.

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