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RESEARCH ARTICLE

Herbicides to ruzigrass suppression in intercropping with corn

Herbicidas para supressão da *Brachiaria ruziziensis* em consórcio com milho

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Abstract: Background: The corn intercropping with *Brachiaria ruziziensis* has rapidly raised in South and Center-West of Brazil. However, the uncertainty about forage interference on corn yield has led growers to use herbicides to suppress ruzigrass.
Objective: Our objective was to evaluate sub-doses herbicides applied in different stages of ruzigrass to suppress the growth in an intercropping system with corn.
Methods: A greenhouse experiment was carried out to evaluate the forage intoxication by herbicides to select the best treatments. Subsequently, a field experiment was carried out to investigate corn yield and *B. ruziziensis* suppression, using sub-dose herbicides in two stages of application. The experiment were arranged in a 9x2+3 factorial scheme, carried out in a randomized block design with eight repetitions. The first factor was composed by herbicide treatments, the second factor was composed of two phenological stages of ruzigrass and their effects were compared with three additional treatments.
Results: Herbicides applied on ruzigrass plants with more than 3-tillers showed lower injury levels than 1-tiller stage. In the field, forage intoxication ranged from 2.5 to 54%, with higher suppression levels to nicosulfuron when compared to mesotrione.
Conclusions: The application of mesotrione (48 or 60 g ha^{-1}) and atrazine (1200 g ha^{-1}) at 1-3 tiller stage; and mesotrione (60 g ha^{-1}), mesotrione+atrazine (60+1200 g ha^{-1}) and atrazine (1200 g ha^{-1}) applied on more than 3-tillers are efficient treatments.

Keywords: *Brachiaria ruziziensis*, forage chemical control, sub-doses, *Zea mays*.

Resumo: Introdução: O consórcio de milho e *Brachiaria ruziziensis* tem crescido rapidamente no Sul e Centro-Oeste do Brasil. Entretanto, a incerteza sobre a interferência da forrageira na produção do milho incentivou os produtores a utilizarem herbicidas para a supressão da braquiária.
Objetivo: Nosso objetivo foi avaliar a aplicação de subdoses de herbicidas em diferentes estádios para supressão do crescimento da braquiária em consórcio com o milho.
Métodos: Um experimento em casa-de-vegetação foi conduzido para avaliar a fitointoxicação da forrageira e selecionar os melhores tratamentos. Posteriormente, um experimento em campo foi conduzido para avaliar a produtividade do milho e a supressão da *B. ruziziensis* com a aplicação de subdoses de herbicidas em dois estágios de desenvolvimento. O experimento foi conduzido em esquema factorial 9x2+3 em delineamento de blocos ao acaso, com oito repetições. O primeiro fator foi composto por tratamentos de herbicidas, o segundo por dois estádios fenológicos da braquiária e os efeitos foram comparados com três tratamentos adicionais.
Resultados: A aplicação de herbicidas no estádio de 3 ou mais perfilhos da braquiária demonstrou menor fitointoxicação quando comparado ao estádio de 1 perfilho. Em campo, a fitointoxicação da forrageira variou de 2,5 a 54%, com maiores níveis de supressão para o nicosulfuron quando comparado ao mesotrione.
Conclusões: A aplicação de mesotriona (48 ou 60 g ha^{-1}) e atrazina (1200 g ha^{-1}) no estádio de 1-3 perfilhos; e mesotriona (60 g ha^{-1}), mesotriona+atrazina (60+1200 g ha^{-1}) e atrazina (1200 g ha^{-1}) em aplicação com mais de 3 perfilhos foram os tratamentos mais eficientes.

Palavras-chave: *Brachiaria ruziziensis*, controle químico de forrageiras, subdoses, *Zea mays*.

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1. Introduction

The corn (*Zea mays* L.) intercropping and forage grass, also known as the 'Santa Fé System', is an agricultural management practice widely used in tropical and subtropical areas, with a considerable adoption by growers across South and West-Center of Brazil (Jacques et al., 2021). This cropping system can be installed in intensive grain production under no-tillage such as soybean/corn double cropping or in the integrated crop-livestock systems (Garcia et al., 2012).

Corn is widely grown in Brazil and it can be cultivated in the summer season from October to May (main season) or in the winter season between February and September (second season). In Brazil, approximately 13.8 million hectares are cultivated during the second season, representing the largest occupied area, whereas 4.2 million hectares are sown the main season, totaling 18 million tons produced annually (Conab, 2020). Normally, corn/forage intercropping is installed in the second season, when forage biomass increases the straw mulching formation after corn harvest to protect the soil. Therefore, this system makes it possible the cover soil in the off-season period, providing a conservationist tool to the no-tillage cropping or to produce the food grazing animals (Almeida et al., 2018).

Several forage species can be used in intercropping systems with corn. One of the most adopted species is ruzigrass (*Brachiaria ruziziensis*, syn. *Urochloa ruziziensis*), a forage with slow initial development in comparison with corn, and able to generate higher dry mass quantities on the soil (Richart et al., 2010).

Several researches have been shown the benefits of corn/forage intercropping to improve the chemical and physical soil qualities, and enhance the cultural and physical weed control (Santos et al., 2016; Pariz et al., 2016; Marochi et al., 2018; Mechi et al., 2018). On the other hand, depending on the sowing method, plant density or forage species, the intercropping can reduce the corn grain yield due to the forage competition (Cruz et al., 2009; Chioderoli et al., 2010). The reduction of interference can be performed using cultural practices. For example, forage sown after the corn emergence or lower forage plant density are practices that reducing the negative effects (Jakelaitis et al., 2006). Moreover, low rates of herbicide can suppress the forage plant growth, and be used as an interesting management option (Jakelaitis et al., 2005; Ceccon et al., 2010). However, the results of herbicide doses, possible use in tank-mix, and forage stages to perform the application are still not enough available in the literature.

Possibly, there are herbicide treatments already used in corn which cause ruzigrass suppression avoiding forage interference on corn. However, the knowledge about these herbicides and the best stage for application is still poorly studied. Thus, this research aimed to evaluate sub-doses herbicides applied in different stages of ruzigrass to suppress the growth in an intercropping system with corn.

2. Material and methods

Greenhouse herbicide trial

Experiment was carried out in randomized complete block design, with five repetitions. The experimental units were composed by 10 dm^3 pots filled with sifted soil (66% clay, 15% silt and 19% sand, pH H_2O=6.1, and 14.2 mg dm^{-3} of C). The ruzigrass was sowed at 2 cm-depth, keeping three seedlings per plot after emergence. The experimental units were maintained under a daily irrigation of 4-6 mm.

Treatments were conducted in a 20x2 factorial arrangement. The first factor (Factor A) were sub-doses herbicide application : nicosulfuron (5; 10; 15 g ha^{-1}); nicosulfuron+atrazine (5+1200; 10+1200; 15+1200 g ha^{-1}); mesotrione (36; 48; 60 g ha^{-1}); mesotrione+atrazine (36+1200; 48+1200; 60+1200 g ha^{-1}); tembotrione (33.6; 42; 50.4 g ha^{-1}); tembotrione+atrazine (33.6+1200; 42+1200; 50.4+1200 g ha^{-1}), atrazine (1200 g ha^{-1}) compared to the untreated control. The second factor (factor D) was evaluated the application in two development phenological stages of ruzigrass: beginning of tillering (S1) and eight to ten tillers (S2). The trade names of herbicides were: nicosulfuron (Accent®, 750 g kg^{-1}, WG, Dupont), atrazine (Proof®, 500 g L^{-1}, SC, Syngenta), mesotrione (Callisto®, 480 g L^{-1}, SC, Syngenta), tembotrione (Soberan®, 420 g L^{-1}, SC, Bayer).

At 21 days after treatment (DAT), forage intoxication was quantified using a percentage scale, in which zero value represents the absence of symptoms and 100% indicated plant death. Plant shoots were cut-off at 21 DAT, and dried by forced air-circulation at 60° C for forage biomass mensuration.

The herbicide treatment was considered effective when suppressed the ruzigrass and was selective to allow its development, using as criteria up to 50% of forage intoxication and biomass reduction between 20 and 60% compared to the untreated.

Field experiment

The experiment was conducted in a randomized experimental block design, with eight repetitions. The soil had a pH H_2O of 6.1, 14.8 g dm^{-3} C; 70% clay; 20% silt, and 10% sand. Meteorological conditions during the experimental period are illustrated in Figure 1.

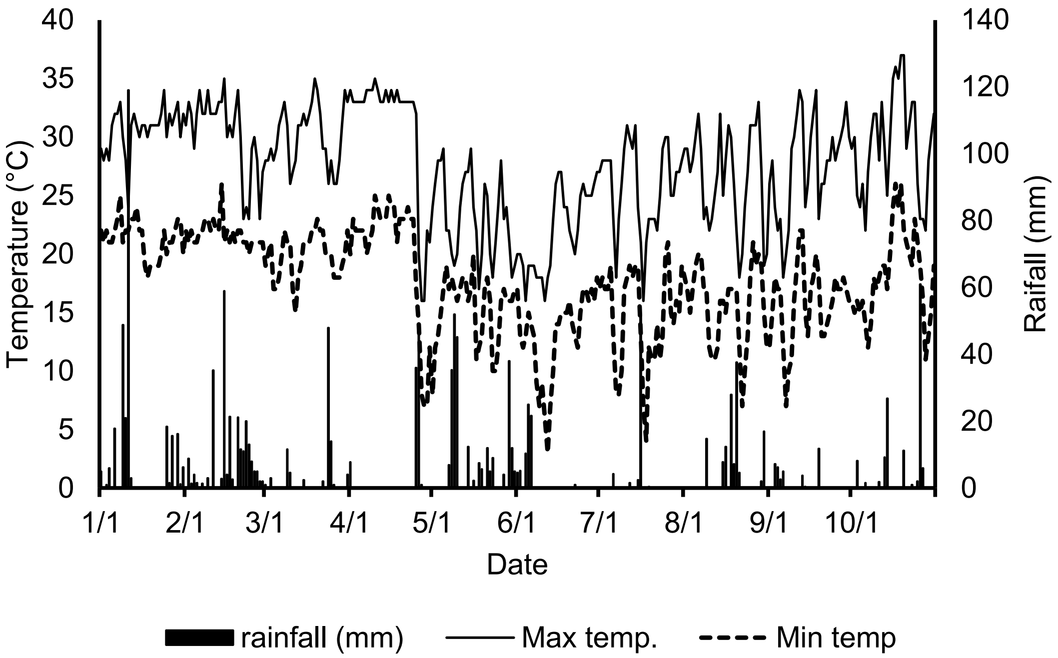

Figure 1. Rainfall and average temperatures during the field experimental period.

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The corn (hybrid P3431) was sown with a machine in 01/26/2016, using rows spaced at 0.45 m and adjusted to distribute 3.1 seeds m^{-1}. The sowing fertilization was 350 kg ha^{-1} of 8 (N) 20 (P) 18 (K), and topdressing (V_3-stage) was performed with urea at 50 kg ha^{-1}. The ruzigrass was sown simultaneously at 10 kg ha^{-1} (65% of viable seeds) in corn inter-rows and slightly incorporated by sower machine discs. Plots were constituted by nine rows with 5m corn each, discounting 0.5 m of the edges for the util area. Hand pulling of weeds was performed in all plots and experimental period.

The treatments were arranged in a 9x2+3 factorial scheme, in which the first factor (Factor A) was composed by herbicide treatments, following the criteria of the trials experiment carried out in greenhouse: nicosulfuron (5 and 10 g ha^{-1}); nicosulfuron+atrazine (5+1200 and 10+1200 g ha^{-1}), mesotrione (48 and 60 g ha^{-1}); mesotrione+atrazine (48+1200 and 60+1200 g ha^{-1}), and atrazine (1200 g ha^{-1}). The second factor (Factor D) was evaluated the herbicide application performed in two phenological stages of ruzigrass: 15 (S1) and 30 days after emergency (S2). Their effects were compared with three additional treatments: corn/ruzigrass intercropping without herbicide (IWH), single corn (SC), and single ruzigrass (SSG). Previously of the herbicide applications, the forage tillers number was quantified in two 0.25 m^2 random samples per plot to calculate the tiller's number frequency in each stage (S1 and S2).

The sprayer equipment used in both experiments was a CO2-pressurized backpack with four XR 110.02 spray nozzles (0.5 m between nozzles) on 2 m long bar. The sprayer pressure was 250 kpa that delivered a spray volume of 200 L ha^{-1}. At the time of application, the temperature at 26ºC, the relative humidity of the air was 62%, winds of 5 km h^{-1} and a cloudless sky.

Forage intoxication was evaluated at 28 DAT using the same method described for the greenhouse experiments. At 54 days after corn emergence (DAE), the number of tillers m^{-2} was quantified in 0.25 m^2 in two random samples per plot. The corn was harvested (five central rows) manually on 06/20/2016. The corn cobs were threshed with a manual plotter and grain moisture obtained with portable moisture detector (Mini GAC®), with final values adjusted to 13%. At 94 days after corn harvest (DAH), forage shoot was cut-off in two samples of 0.25 m^2 per plot and kept in forced air-circulation at 60 °C for seven days to mensuration of ruzigrass dry biomass m^{-2}.

Statistical analysis

Data from greenhouse and field experiments were subject to ANOVA ($p<0.05$), and when significant, herbicide treatment effects were compared by Scott-Knott test ($p<0.05$) and application stages by F test ($p<0,05$). Additionally, the number of tillers m^{-2}, corn yield and ruzigrass dry biomass were compared by orthogonal contrasts, and performed to compare IWH, SC and SSG vs other treatments ($p<0.05$). The SISVAR 12 software was used to conduct statistical analyses.

3. Results and Discussion

Greenhouse herbicide trial

Significant interaction between herbicides and application stages was reported on ruzigrass plants. Higher injury levels occurred to all herbicides applied at S1 than S2. At S1, the most treatments caused irreversible injury levels to forage plants (>90%), among them (g ha^{-1}): nicosulfuron (5), nicosulfuron (10), nicosulfuron (15), nicosulfuron+atrazine (5+1200), nicosulfuron+atrazine (10+1200), nicosulfuron+atrazine (15+1200), mesotrione+atrazine (36+1200), mesotrione+atrazine (48+1200), mesotrione+atrazine (60+1200), tembotrione (33.6), tembotrione (42), tembotrione (50.4), tembotrione+atrazine (33.6+1200), tembotrione+atrazine (42+1200) and tembotrione+atrazine (50.4+1200). The treatments considered safe, that is, those meaning visible intoxication but not resulted in high injury on forage plants were mesotrione (36, 48 and 60 g ha^{-1}) and atrazine (1200 g ha^{-1}) (Table 1). Those herbicides reduced forage biomass in S1 at most 68% demonstrating efficient suppression.

There were more efficient herbicide treatments to forage suppression at S2 than S1. Applications of tembotrione, tembotrione+atrazine and nicosulfuron+atrazine (10 or 15+1200 g ha^{-1}) resulted in high injury levels (>71%) and treatments containing mesotrione alone and mesotrione+atrazine (36+1200 g ha^{-1}) caused low suppression rates, reducing forage biomass at most 16.7% (Table 1).

Based on previous established criteria to consider the herbicide efficient to reduce the forage growth without to cause damage on forage yield (up to 50% of plant intoxication and biomass reduction between 20 and 60%), the better treatments were mesotrione (48 and 60 g ha^{-1}) applied at S1 stage, and nicosulfuron (5 and 10 g ha^{-1}), nicosulfuron+atrazine (5+1200 g ha^{-1}), mesotrione+atrazine (48 or 60+1200 g ha^{-1}) and atrazine (1200 g ha^{-1}) applied at S2 stage. Although nicosulfuron+atrazine (10+1200 g ha^{-1}) did not fit the criteria, it was evaluated in the field due to the wide adoption of this tank mixture in areas of intercropped corn/ruzigrass. Additionally, once nicosulfuron (10 g ha-1) was adopted as an isolated treatment, we have chosen to take this herbicide associated with atrazine in the field protocol as well.

Table 1. Ruzigrass intoxication (%) and biomass reduction (%) in comparison to untreated control at 21 days after treatment (DAT) in two stages of application (one tiller – S1 or three tillers – S2) performed at a greenhouse.

Treatments (g ha^{-1})	21 DAT			
	Plant intoxication (%)		Dry mass reduction (%)	
	S1	S2	S1	S2
Untreated check	0 Ah	0 Ak	-	-
Nicosulfuron (5)	99.2 Aa	41 Bf	98.8 Aa	46.6 Bc
Nicosulfuron (10)	100 Aa	40.8 Bf	100 Aa	53.4 Bc
Nicosulfuron (15)	100 Aa	49 Be	100 Aa	65.0 Bb
Nicosulfuron+atrazine (5+1200)	100 Aa	40.4 Bf	100 Aa	46.4 Bc
Nicosulfuron+atrazine (10+1200)	100 Aa	75.8 Bc	100 Aa	75.5 Bb
Nicosulfuron+atrazine (15+1200)	100 Aa	80.8 Bb	100 Aa	89.0 Aa
Mesotrione (36)	17 Ag	2.6 Bj	25.4 Ad	10.2 Ad
Mesotrione (48)	29 Af	4.2 Bj	41.8 Ac	16.6 Bd
Mesotrione (60)	34 Ae	5 Bj	53.6 Ab	14.6 Bd
Mesotrione+atrazine (36+1200)	90.6 Ac	31 Bh	90.2 Aa	16.7 Bd
Mesotrione+atrazine (48+1200)	95.8 Ab	34 Bg	95.7 Aa	45.1 Bc
Mesotrione+atrazine (60+1200)	95 Ab	34 Bg	93.3 Aa	37.3 Bc
Tembotrione (33.6)	98 Aa	71.4 Bd	97.7 Aa	51.3 Bc
Tembotrione (42)	99.4 Aa	73.8 Bc	99.1 Aa	62.3 Bb
Tembotrione (50.4)	100 Aa	75.2 Bc	100 Aa	65.7 Bb
Tembotrione+atrazine (33.6+1200)	100 Aa	89.4 Ba	100 Aa	96.4 Aa
Tembotrione+atrazine (42+1200)	100 Aa	89.8 Ba	100 Aa	97.8 Aa
Tembotrione+atrazine (50.4+1200)	100 Aa	90.4 Ba	100 Aa	98.4 Aa
Atrazine (1200)	55 Ad	11.2 Bi	68.13 Ab	44.9 Bc
CV (%)	2.65		18	

Means followed by the same uppercase letters (rows) do not differ by F test ($p<0.05$). Means followed by the same lowercase letters (columns) do not differ by Scott-Knott test ($p<0.05$).

Field experiment

The quantification of tillers number per plant made it possible to ensure the correct moment to perform the application, demonstrating that most ruzigrass plants had one to three tillers class´s frequency in both stages (Figure 2). In the first application, 84.8% of the plants showed up to three-tillers (S1), whereas the second application, 92.7% of the plants had one-six tillers per plant (S2) (Figure 2).

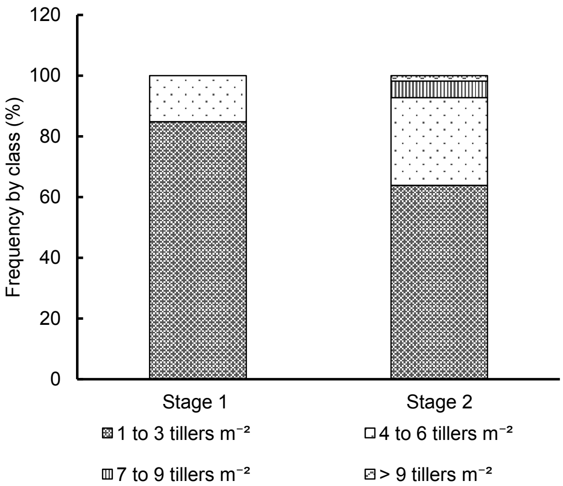

Figure 2. Classes' frequency of number of tillers m^{-2} in two forage stages at the application moment.

Significant interaction between herbicides and application stages was not reported on ruzigrass plants, therefore, only the herbicide factor data was showed. The highest value of forage intoxication was observed to nicosulfuron+atrazine (10+1200 g ha^{-1}), about 50%. The other treatments composed the group of intermediate intoxication (between 15 and 47%) except atrazine (1200 g ha^{-1}) that did not provide enough significantly forage intoxication (>3%) (Table 2).

Table 2. Forage intoxication at 28 days after treatment (DAT) in two stages of application (S1 and S2) in field experiment.

Herbicide treatments (g ha^{-1})	Plant intoxication at 28 DAT
Nicosulfuron (5)	30.62 f
Nicosulfuron (10)	33.43 g
Nicosulfuron+atrazine (5+1200)	47.18 h
Nicosulfuron+atrazine (10+1200)	54.06 i
Mesotrione (48)	15.62 b
Mesotrione (60)	17.50 c
Mesotrione+atrazine (48+1200)	25.31 d
Mesotrione+atrazine (60+1200)	26.87 e
Atrazine (1200)	2.50 a
CV (%)	17.26

Means followed by the same low letters in columns are not different by Scott-Knott test ($p<0.05$).

The sub-dose herbicide applications to nicosulfuron+atrazine (8+1500 g ha^{-1}) suppressed greater than 50% of palisade grass (*Urochloa brizantha*) biomass in the off-season period (Jakelaitis et al., 2005). Mesotrione was reported to cause lesser plant intoxication in ruzigrass than nicosulfuron (Anésio et al., 2017; Sousa et al., 2018; Costa et al., 2020). Ceccon et al. (2010) also verified the high capacity of injury recover of ruzigrass after mesotrion+atrazine (60+880 g ha^{-1}) application in two development stages (14 and 24 days after emergency). In relation to tembotrione, higher plant intoxication has been reported in *Urochloa* species, limiting its use in intercropping systems (Adegas et al., 2011).

Comparing IWH with other treatments, nicosulfuron (5 or 10 g ha^{-1}), nicosulfuron+atrazine (5 or 10+1200 g ha^{-1}) and mesotrione+atrazine (48 or 60 + 1200 g ha^{-1}) caused negative effect on the numbers of tiller m^{-2} for S1, whereas only nicosulfuron herbicide (10 g ha^{-1}) reduced the number of tillers m^{-2} of forage at S2 (Table 3). The yield average of the experiment was low (2545.6 kg ha^{-1}) compared to the grain yield harvested by growers in the same region during the field experiment. According to Conab (2018), the yield average of corn (second season) in the years 2016/2017 was 5.564 kg ha^{-1}. However, a long dry period and absence of irrigation during the corn season were factors that affected strongly the production (Figure 1). In this situation, specifically, plant competition between intercropping species could be accentuated due to the limited sources as water and nutrients from soil (Manabe et al., 2014). We must emphasize that, besides the forage had been sown in inter rows of corn, the machine disc incorporation provided forage establishment close to the corn rows, resulting in an increased plant competition between the two species. Thus, our results show the importance of herbicide management for forage suppression to avoid corn yield losses and to enjoy all benefits of corn and ruzigrass intercropping.

Corn/ruzigrass intercropping resulted corn yield losses of 25% compared to SC vs IWH (Table 4). Mesotrione (48 g ha^{-1}) and mesotrione+atrazine (48+1200 g ha^{-1}) application on S2 also reduced the corn grain yield than SC, with values of 21.8 and 26%, respectively (Table 4). Thus, these herbicide treatments did not provide sufficient forage suppression, causing interference on corn yield. The other herbicide treatments applied at S1 and S2, suppressed the forage growth, with reduced interference of forage and ensuring higher corn yield, with grain yield similar to SC (Table 4). Ceccon et al. (2010), Garcia et al. (2012) and Almeida et al. (2018) observed that corn intercropping with ruzigrass did not affect corn yield.

The mechanisms of growth suppression in grass species by mesotrione, tembotrione, nicosulfuron, and atrazine are totally related to the mode of action of these herbicides. Mesotrione and tembotrione inhibits the 4-hydroxyphenylpyruvate dyoxigenase (HPPD), a precursory enzyme of carotenoids biosynthesis (Mitchell et al., 2001). Besides affecting only emerging leaves, the metabolization of HPPD inhibitors by plants has been responsible for herbicide tolerance (Mitchell et al., 2001). Nicosulfuron inhibits the acetolactate synthase (ALS) breaking essential amino acids production valine, leucine and isoleucine (Garcia et al., 2017). The reduced amino acid production break the plant growing, causing the forage suppression when low doses are applied and it can be reverted by continuous herbicide metabolism, mainly by P450 monooxygenases activity (Liu et al., 2018).

Table 3. Contrasts of number of tillers m^{-2} between intercropping without herbicide (IWH) and herbicides treatments applied to suppress the ruzigrass in two phenological stages.

Contrast			Number of tillers m^{-2}		
Coefficient ⊕	*vs*	Coefficients (g ha^{-1}) Θ	⊕	Θ	Difference
IWH	*vs*	SSG	103.4	285.3	**-181.9**
Stage 1					
IWH	*vs*	Nicosulfuron (5)	103.4	67.2	**36.2**
IWH	*vs*	Nicosulfuron (10)	103.4	51.7	**51.7**
IWH	*vs*	Nicosulfuron+atrazine (5+1200)	103.4	59.7	**43.7**
IWH	*vs*	Nicosulfuron+atrazine (10+1200)	103.4	51.4	**52.0**
IWH	*vs*	Mesotrione (48)	103.4	87.4	16
IWH	*vs*	Mesotrione (60)	103.4	90.2	13.2
IWH	*vs*	Mesotrione+atrazine (48+1200)	103.4	65.6	**37.8**
IWH	*vs*	Mesotrione+atrazine (60+1200)	103.4	61.4	**42.0**
IWH	*vs*	Atrazine (1200)	103.4	91.9	11.5
Stage 2					
IWH	*vs*	Nicosulfuron (5)	103.4	79.1	24.3
IWH	*vs*	Nicosulfuron (10)	103.4	63.3	**40.1**
IWH	*vs*	Nicosulfuron+atrazine (5+1200)	103.4	76.8	26.6
IWH	*vs*	Nicosulfuron+atrazine (10+1200)	103.4	76	27.4
IWH	*vs*	Mesotrione (48)	103.4	82.4	21.0
IWH	*vs*	Mesotrione (60)	103.4	91.2	12.2
IWH	*vs*	Mesotrione+atrazine (48+1200)	103.4	91.1	12.3
IWH	*vs*	Mesotrione+atrazine (60+1200)	103.4	87.2	16.2
IWH	*vs*	Atrazine (1200)	103.4	95.6	7.8

Values in bold had significant difference by contrast estimative ($p<0.05$). SSG: single ruzigrass.

Table 4. Contrasts of corn yield between single corn (SC) and herbicides treatments applied to suppress the ruzigrass in two phenological stages.

Contrast			Corn yield (kg ha^{-1})		
Coefficient ⊕	*vs*	Coefficients (g ha^{-1}) Θ	⊕	Θ	Difference
SC	*vs*	IWH	2880	2157.4	**722.5**
Stage 1					
SC	*vs*	Nicosulfuron (5)	2880	2584	296
SC	*vs*	Nicosulfuron (10)	2880	2906.8	-26.8
SC	*vs*	Nicosulfuron+atrazine (5+1200)	2880	2562.2	317.8
SC	*vs*	Nicosulfuron+atrazine (10+1200)	2880	2810.2	69.8
SC	*vs*	Mesotrione (48)	2880	2687.6	192.3
SC	*vs*	Mesotrione (60)	2880	2811.1	68.9
SC	*vs*	Mesotrione+atrazine (48+1200)	2880	2660.9	219.1
SC	*vs*	Mesotrione+atrazine (60+1200)	2880	2945.1	-65.1
SC	*vs*	Atrazine (1200)	2880	2678	202
Stage 2					
SC	*vs*	Nicosulfuron (5)	2880	2547	333
SC	*vs*	Nicosulfuron (10)	2880	2381.2	498.8
SC	*vs*	Nicosulfuron+atrazine (5+1200)	2880	2654.8	225.2
SC	*vs*	Nicosulfuron+atrazine (10+1200)	2880	2519.2	360.7
SC	*vs*	Mesotrione (48)	2880	2252.2	**627.8**
SC	*vs*	Mesotrione (60)	2880	2277.9	602.1
SC	*vs*	Mesotrione+atrazine (48+1200)	2880	2132.4	**747.6**
SC	*vs*	Mesotrione+atrazine (60+1200)	2880	2205.9	674.1
SC	*vs*	Atrazine (1200)	2880	2205.5	674.5

Values in bold had significant difference by contrast estimative ($p<0.05$). IWH: intercropping without herbicide.

The low suppression rate by atrazine probably is due to the formation of an atrazine–glutathione conjugate as already documented for several grass species (Shimabukuro et al., 1970; Lamoureux et al., 1973). Though molecule of atrazine can affect photosystem II pathway because of metabolism, the major effect is usually found in small plants or in pre-emergence applications (Chand et al., 2016) explaining the high selectivity for ruzigrass in the present research.

Prior to soybean sowing (94 DAH), the forage had been able to recover its development in treatments composed by mesotrione (48 and 60 g ha⁻¹) and atrazine (1200 g ha⁻¹) for S1 (Table 5). In these situations, forage plants provided similar amounts of biomass in comparison to IWH (>2,179 kg dry biomass ha⁻¹). For S2, the forage regrowth was more significant for S1 than S2, including including mesotrione (48 and 60 g ha⁻¹), mesotrione+atrazine (48 or 60+1200 g ha⁻¹), and atrazine (1200 g ha⁻¹) (Table 5).

Table 5. Contrasts of ruzigrass dry biomass between intercropping without herbicide (IWH) and herbicides treatments in off-season period at 94 days after corn harvest (DAH).

Contrast			94 DAH		
			Ruzigrass dry biomass (kg ha^{-1})		
Coefficient ⊕	*vs*	Coefficients (g ha^{-1}) Θ	⊕	Θ	Difference
IWH	*vs*	SSG	2623.75	4675.5	**-2051.75**
Stage 1					
IWH	*vs*	Nicosulfuron (5)	2623.75	1872.25	**751.5**
IWH	*vs*	Nicosulfuron (10)	2623.75	1406	**1217.75**
IWH	*vs*	Nicosulfuron+atrazine (5+1200)	2623.75	1432.75	**1191**
IWH	*vs*	Nicosulfuron+atrazine (10+1200)	2623.75	1500.25	**1123.5**
IWH	*vs*	Mesotrione (48)	2623.75	2179.5	444.25
IWH	*vs*	Mesotrione (60)	2623.75	2191.5	432.25
IWH	*vs*	Mesotrione+atrazine (48+1200)	2623.75	1973.75	**650**
IWH	*vs*	Mesotrione+atrazine (60+1200)	2623.75	1813	**810.75**
IWH	*vs*	Atrazine (1200)	2623.75	2265.5	358.25
Stage 2					
IWH	*vs*	Nicosulfuron (5)	2623.75	1860.75	**763**
IWH	*vs*	Nicosulfuron (10)	2623.75	1677.25	**946.5**
IWH	*vs*	Nicosulfuron+atrazine (5+1200)	2623.75	1889.25	**734.5**
IWH	*vs*	Nicosulfuron+atrazine (10+1200)	2623.75	1613.5	**1010.25**
IWH	*vs*	Mesotrione (48)	2623.75	2409.25	214.5
IWH	*vs*	Mesotrione (60)	2623.75	2287.5	336.25
IWH	*vs*	Mesotrione+atrazine (48+1200)	2623.75	2495.75	128
IWH	*vs*	Mesotrione+atrazine (60+1200)	2623.75	2392.25	231.5
IWH	*vs*	Atrazine (1200)	2623.75	2372.75	251.5

Values in bold had significant difference by contrast estimative ($p<0.05$). SSG: single ruzigrass.

The most treatments that did not result in forage suppression after corn harvest and prior to soybean sowing were observed for S2 (Table 5). Therefore, when the application is later, there are more risks of forage interference on corn, as observed with mesotrione (48 g ha⁻¹) and mesotrione+atrazine (48+1200 g ha⁻¹), limiting the options of herbicide treatments. This discussion suggests a flexibility to choose the moment of the application, making a decision based on corn yield or ruzigrass.

An often question from farmers that produce corn and forage intercropping is what the sub-dose herbicides efficiency for weed control are. Adegas et al. (2011) found control levels up to 83% with mesotrione+atrazine (60+800 g ha⁻¹) or nicosulfuron+atrazine (16+800 g ha⁻¹) in a weed community composed by *Ageratun conyzoidis*, *Amaranthus hybridus*, *Commelina benghalensis*, *Digitaria horizontalis*, *Raphanus raphanistrum* and *Richardia brasiliensis*. However, the weed community in the field must be relevant criteria for herbicide choice. More studies must be conducted to evaluate the weed control with sub-dose treatments in other weed species normally found in Brazilian environments, as well as evaluating corn and forage yield in different sites and years.

Then, aiming at forage formation to increase straw mulching for no-tillage or provide food for livestock, the most interesting option should be applying herbicide treatments on ruzigrass with more than three tillers (S2).

4. Conclusion

It is possible to rank mesotrione (48 or 60 g ha⁻¹) and atrazine (1200 g ha⁻¹) in S1 (up to three-tillers); and mesotrione (60 g ha⁻¹), mesotrione+atrazine (60+1200 g ha⁻¹) and atrazine (1200 g ha⁻¹) in S2 (one-six tillers per plant) as efficient treatments that provide ruzigrass suppression avoiding corn yield losses and do not prejudice forage biomass during off-season period.

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