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Use of pendimethalin and trifluralin on rice/brachiaria intercroping system

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Abstract

Rice is commonly used in degraded pasture area renovation. In this process, the rice is set up simultaneously with the forage plants, which increases the difficulty to control post-emerged weeds. Thus, this study aimed to evaluate rice crop development intercropped with *Urochloa* under the herbicides pendimethalin and trifluralin application. The experimental design used was a 2x3 factorial composed of 1) absence or 2) presence of the herbicides pre-plant incorporated (PPI) x 1) control (no additional herbicides); 2) pendimethalin and 3) trifluralin. For the intercrop with rice, two forage grass were used, *Urochloa ruziziensis* and *U. brizantha*. The rice was sowed on the same day as the application of the herbicide. The control level determination was performed by counting the remaining weeds. In the rice crop, were evaluated: tiller number, viable panicle, and grain yield. In the forage grass, was evaluated shoot dry mass yield. An interaction between herbicide application and incorporation was observed. On weed the joyweed (*Alternanthera tenella*) control was affected by treatments, under herbicide incorporation, the weed was better controlled. Thus, the improved control provided better conditions for shoot dry weight biomass production. The highest rice yield was observed under intercrop with *U. ruziziensi* and pendimethalin application. The trifluralin incorporation decreased the shoot biomass of the forage grass plants. The use of pre-emergence herbicides provide weed control and increased rice yield without reducing the grass dry weight and not affecting the intercropping system.

Keywords: herbicides; weeds; *Alternanthera* tenella; crop-livestock system.

Desenvolvimento de arroz em consorcio com braquiária sob efeito de pendimethalin e trifluralina

A cultura do arroz é frequentemente utilizada na reforma de pastagens degradadas. Nesse processo a implantação do arroz ocorre concomitantemente com as forrageiras, fato que dificulta o controle de plantas daninhas em pós emergência. Assim sendo, o objetivo deste trabalho foi avaliar o desempenho da cultura de arroz em consorcio com *Urochloa* sob o efeito da aplicação do herbicidas pendimethalin e trifluralin incorporados ou não ao solo. O delineamento experimental foi um fatorial 2x3. O primeiro fator foi composto pela incorporação ou não dos herbicidas PPI (Pré-plantio incorporado) e três tratamentos, sendo o 1) controle (sem uso de herbicida) 2) pendimethalin 3) trifluralin. Foi o usado em consorcio com o arroz duas forrageiras a *Urochloa ruziziensis* e *Urochloa brizantha*. A semeadura do arroz, cultivar BRS Sertaneja, foi realizada no mesmo dia da aplicação dos herbicidas. A determinação do nível de controle foi realizada contando-se as plantas daninhas remanescentes. Na cultura do arroz as avaliações realizadas foram perfilhos e panículas viáveis e produtividade de grãos. As forrageiras foram avaliadas pela produção de biomassa seca da parte aérea. Os dados apresentaram distribuição normal, e, portanto, submetidos à análise de variância e teste F com probabilidade de 5%, quando significativo foram comparados ao teste de Tukey a 5% de probabilidade. O controle do apaga-fogo (*Alternanthera tenella*) com Pendimethalin e Trifluralin com incorporação foi superior a 90%. O controle das plantas daninhas favoreceu a produção de biomassa seca da parte aérea. A produtividade do arroz foi obtida no consórcio com *Urochloa ruziziensis*.com aplicação do herbicida Pendimenthalin sem incorporação.

Palavras-chave: herbicidas; plantas daninhas; Alternanthera tenella; sistema Integração lavoura-pecuária.

Introduction

Rice cultivation in Brazil might be performed in lowlands and upland. Most upland rice cultivation in Brazil is found in the Mato Grosso state, totaling 112.3 thousand hectares in the 2019/2020 harvest (CONAB, 2021). The choice for upland rice cultivation can be beneficial for the crop-livestock intercrop system, also known as "Barreirão" system. This system is a technology used for the renovation of degraded pasture areas by performing pasture and annual crop intercropping (TORRES *et al*., 2018). Diverse systems are more resilient to climatic changes, environmental stressful conditions, and can improve soil health, nutrient cycling, and nutrient use and efficiency (BAPTISTELLA *et al*., 2020). The upland rice and forage grass intercropping is an important strategy to increase agriculture sustainability in the tropical region, increasing food production and soil use by area unit (CRUSCIOL *et al*., 2021).

To set up intercropping system, some agricultural practices must be adopted, aiming to improve the development of both crops cultivated simultaneously. In the "Barreirão" system that can be performed in the no-tillage system as well as in the conventional, the grass sowing can be performed simultaneously with the rice, or after rice emergence (PORTES *et al*., 2000; OLIVEIRA *et al*., 2009). Even with no-tillage system consolidation, rice is cultivated mostly in the conventional system, especially in the renovation of degraded pasture situations.

The rice-pasture intercropping could impair rice yield, thus, the pasture crop must be managed properly to mitigate pasture and rice competition (CARVALHO *et al*., 2011) and to avoid the shoot biomass decrease of brachiaria plants (OLIVEIRA *et al*., 2014). This decrease might be caused by rice and grass competition, or also by herbicides used to control weeds in rice areas, which can also impair pasture (CARVALHO *et al*., 2011).

The management and control of weeds in the intercropping system might consider both plants being cultivated, thus, selective herbicides for both plants must be used (IKEDA *et al*., 2007; BORGHI *et al*., 2008).

Preemergence and pre-plant incorporation (PPI) herbicides application is a technique regularly used in rice crops, herbicides such as pendimethalin and trifluralin are commonly used on rice crops, due to their great selectivity for rice (CARVALHO *et al*., 2000), and due to its efficiency against a monocot weed plants, and some dicotyledonous (RODRIGUES; ALMEIDA, 2011) such as *Alternanthera tenella*, with excellent control levels when applied under pre-emergence (CANOSSA *et al*., 2007). However, not much is known about these herbicides in rice-pasture intercropping cultivation.

Pendimethalin and trifluralin are herbicides that act inhibiting cell division. Are applied at pre-emergence to control monocot. The main selectivity mechanism is the seed depth, which must be below the product in the soil layers (RODRIGUES; ALMEIDA, 2011).

Thus, this study hypothesizes that the method of herbicide use might improve weed plants control without impairing both rice and pasture grass intercropping.

The lack of information regarding herbicide selectivity in rice-pasture intercropping is frequent, and consistent results are required regarding this subject. Thus this study aimed to evaluate rice performance intercropped with *Urochloa* under pre-emergence herbicides application.

Material and Methods

The experiment was carried out in the Nova Xavantina, Brazil (14º54'41''S, 52º34'63''W, altitude 580 m). The climate is classified as Aw according to Köppen, characterized by warm and rainy summer and dry winter. The meteorological data collected throughout the experiment are presented in figure 1.

The experiment was set up in an area previously cultivated with soybean in no tillage system for over 10 years. The soil was a dystrophic red latosol. The chemical and physical analisys performed in the 0-20cm depth presented the following results pH ($CaCl_2$) = 5.2; P = 6.0 mg dm^{-3} (Mehlich); K^+ = 43.0 mg dm^{-3}; Ca^{+2} = 2.1 $cmol_c$ dm^{-3}; Mg^{+2} = 1.2 $cmol_c$ dm^{-3}; Al^{+3} = 0.0 $cmol_c$ dm^{-3}; V% = 51; CEC = 8.1 $cmol_c$ dm^{-3}; OM = 33.7 g dm^{-3}; S = 9.5 mg dm^{-3}; Fe = 61.0 mg dm^{-3}; B = 0.56 mg dm^{-3}; Mn = 53 mg dm^{-3}; Zn = 3.7 mg dm^{-3}; Cu = 0.7 mg dm^{-3}; clay content = 530 g kg^{-1}.

The experiment design used was a 2 x 3 factorial, composed by: 1) absence and 2) presence of pre-plant incorporated herbicides x 1) control (no additional herbicide use); 2) pendimethalin 900 g a.i ha^{-1}; 3) trifluralin 667.5 g a.i ha^{-1}. For the rice intercropping, two distinct grass plants were used, *U. ruziziensis e U.*

brizantha according to "Barreirão" system (OLIVEIRA *et al.*, 1996). The experimental plot dimension was 16m² (4 x 4m) with a useful area of 9m² (3 x 3m).

The herbicides were applied on pre-emergence of weed and at PPI considering the crop sowing. The applications were performed using a CO_2 pressure backpack sprayer working at constant pressure, coupled to a bar containing four-wide flat spray tips XR-110.20, the pulverization was set to deliver 200 L ha^{-1}. The application was performed under the following environmental conditions: mean temperature of 28 ºC, relative air humidity of 80%, and wind speed between 3 and 8 km h^{-1}. The herbicide incorporation in the soil (including control), in the plot in which it was required, was performed by leveling the harrow soon after the application of the herbicide, the incorporation depth used was 0.10 m.

The rice was cultivated in the conventional system. The sowing was performed on 11/29/2008, the same day of herbicide application, using the cultivar BRS Sertaneja. The sowing was performed using a sowing/fertilizing machine. Sowing density was 70 kg seed ha^{-1}, and the space between sowing lines was 0.25 m. The sowing fertilization was performed using 250 kg ha^{-1} of 08-28-16 distributed in the sowing line. At 25 days after emergence (DAE) was applied 50 kg N ha^{-1} .

The pasture grass *U. ruziziensis* and *U. brizantha* cv Marandu sowing were performed 25 DAE of rice. The sowing was carried out at 0.03m depth in a perpendicular direction regarding the rice lines, at a sowing amount of 9 kg seed ha^{-1} with a pure live seed of 64%, equivalent to seed density of 576 pure live seed points ha^{-1} of the pasture grass.

The control evaluation was carried out following the methodology proposed by the European Weed Research Community (EWRC, 2014), in which a grade scale was used to assign grades according to visually observed damage caused by herbicide application. Grade 1 was assigned to plants with no phytotoxicity symptoms and grade 9 to dead plants. The evaluation was carried out 7 and 14 days after herbicide application.

The only weed evaluated was *A. tenella* (joyweed), due to its high infestation at the local of the experiment. The infestation data was converted to control percentage, considering 0% control in the treatment without any herbicide incorporation.

Rice crop development was evaluated by viable tiller number at 50 DAE of rice and viable panicle number at 70 DAE of rice. The evaluations were performed considering 2 m in the center of 2 random lines sampled in the useful area of each plot.

Rice grain yield was determined by harvesting 2 m in the center of the 4^{th} and 5^{th} lines (1m²) of each plot. After weighting, the grain yield was converted to 13% moisture, and the grain yield was estimated in kg ha^{-1}.

The pasture grass *U. ruziziensis* and *U. brizanta* cv Marandu were evaluated by shoot dry yield. The harvest was performed 120 days after sowing (DAS) of the pasture. The sampling was carried out twice in each plot, in each sampling, collecting all the biomass was within a 0.25m² square. After collection, the shoot fresh material was dried on the stove with forced air ventilation, at 70 ^{o}C until reached constant weight. The data was expressed in kg ha^{-1}.

The data presented normal distribution, and thus, was submitted to variance analysis and F test at 5% probability. The variables that presented significant results were submitted to the Tukey test at 5% probability.

Results and Discussion

The herbicide incorporation affected *A. tenella* control in the upland rice intercropping with pasture grass in both evaluation times. Thus, an interaction was observed between herbicide application and incorporation practice (Table 1). At 7 days after application (DAA) joyweed control was superior under pendimethalin application with and without incorporation, and under trifluralin application with incorporation.

Table 1. Control (%) of *A. tenella* (joyweed), in upland rice intercropping, due to absence or presence of pre-emergence herbicides application, incorporated or not in the. Nova Xavantina, Brazil, 2009.

Herbicide	*B. ruziziensis*				*B. brizantha* cv Marandu			
	07 DAA*		14 DAA*		07 DAA*		14 DAA*	
	Incorporation				Incorporation			
	Yes	No	Yes	No	Yes	No	Yes	No
Control	0.0 Ab	0.0 Ac	0.0 Ab	0.0 Ab	0.0 Ab	0.0 Ac	0,0 Ab	0,0 Ac
Pendimethalin	92.00 Aa	95.50 Aa	85.0Aa	92.00 Aa	95.00 Aa	97.50 Aa	85,00 Aa	90,00 Aa
Trifluralin	87.50 Aa	16.25 Bb	75.0 Aa	2.50 Bb	92.50 Aa	20.00 Bb	80,00 Aa	10,00 Bb
CV (%)	14.06		15.69		14.06		8.61	

Mean followed by the same uppercase letter in the column and same lowercase letter on the line, for each evaluation time, do not differ statistically according to Tukey (5%). DAA = Days after application. CV. Coefficient of variation.

The trifluralin application (667.5 g a.i. ha^{-1}) without incorporation presented inefficient joyweed control in both 7 DAA and 14 DAA. Not incorporating the product in the soil might lead to active principle loss, thus, when the weed germinates the product might not be available to be uptake by the weed roots, and then the control is inefficient. The herbicide trifluralin, when exposed to the sun, might lose the active principle due to volatilization and photodecomposition, since it has a high sensibility to ultraviolet radiation, which is responsible for photodegradation (CAMPOS *et al*., 2017). On the other hand, low water conductivity might occur in soils with high levels of clay, as the one in the present study, which might impair the herbicide diffusion (TAIZ; ZEIGER, 2013), thus when not incorporated the herbicide might not be dissolved by soil colloids and not be able to reach the weed seeds depth. In this condition, is recommended to apply higher doses, in addition, to incorporating the trifluralin herbicide. Pendimethalin is less volatile, thus, is efficient in weed control even without incorporation (MARCHI *et al*., 2008).

Pendimethalin was more flexible in joyweed control (Table 1). This herbicide presented higher efficiency even without incorporation and kept its residual effect, inhibiting new plants' germination until the 14DAA evaluation. The pendimethalin resilience in the soil is relatively long (KARASALI *et al*., 2016), mainly on low pH soils (CHEN *et al*., 2018). In the present study, the pH of 5.2 improved the herbicide efficiency up until the second evaluation date (14 DAA).

For the viable number of rice tillers evaluated ate 50 DAE, it was no observed effect on the pasture grass, however, the herbicides application and application methods affected it. In the absence of herbicide application (control), the viable number of tillers decreased, it occurs both with and without incorporation (Table 2). Weeds might impair the production components of crops (REDDY, 2018) leading to a decrease in yield and food quality (RAJ *et al*., 2017).

The observed results indicate the pre-emergence herbicides pendimethalin (900 g a.i. ha^{-1}) and trifluralin (667.5 g a.i. ha^{-1}) selectivity to rice cultivar BRS Sertaneja, even under soil incorporation. This suggests that on the studies doses, both pendimethalin and trifluralin are good options to control weeds in the initial stages of the development of rice crop. If weeds are not controlled correctly, plant tillering might be impaired, decreasing the final number of viable tillers (Table 2). The use of herbicides at the right moment does not impair crop development and can control weeds, allowing the rice crop to develop properly. These results corroborate Nunes *et al*. (2018) that observed a satisfactory effect of pendimethalin to control weeds on soybean, resulting in a yield increase.

The number of viable panicles at 70 DAE was affected by both factors studies both isolated and interacting with each other. The number of viable panicles was higher in the intercropping with *U. brizantha* compared to *U. ruziziensis* under trifluralin application with and without incorporation (Table 3). The lower number of viable panicles under trifluralin application and intercropping with com *U. ruziziensis* might be related to the herbicide inefficiency to control weeds, mainly, when incorporation in the soil was not performed (Table 1). The results of viable panicles number reflected the results observed for viable tiller number.

Rice yield with pasture grass intercropping was affected by pre-emergence herbicide application in both pastures (Table 3). Under the right management of herbicides and pasture, better yield results were observed. The higher yield was observed under pendimethalin application, in intercropping with *U. ruziziensis* which provided better control of joyweed (Table 1). The highest rice yield intercropped with *U. ruziziensis* could be explained by a lower competition with rice, which means, ah lower shoot biomass production (Table 4). Another important aspect that might improve rice yield is the growing habit. *U. ruziziensis* growth habit is more prostrated than *U. brizantha*, (COSTA *et al*., 2012).

In the intercropping with *B. ruziziensis*, pendimethalin application, with and without soil incorporation provided an increase in rice, compared to control treatment, while the trifluralin application provided similar results to control treatment. These results are an indirect effect of the pre-emergence herbicide application, resulting in the control of weed plants during the vegetative stage of rice in the intercropping. On pendimethalin treatments with and without incorporation, and on trifluralin treatment with incorporation, in which the weed control was efficient (Table 1). The weed competition with upland rice might lead to severe yield losses (SILVA, 2006), thus the lack of weed control and the wrong use of herbicides might impair rice yield. In the intercropping with *U. brizantha* rice yield was higher under trifluralin application with and without incorporation, and under pendimethalin application without incorporation, compared to the other treatments.

The shoot dry weight yield for pasture grass at 120 DAS was affected by the different species used and by the pre-emergence herbicides with and without incorporation (Table 4). Shoot dry weight yield for *U. ruziziensis* was higher under trifluralin application incorporated and pendimethalin application. These results are an indirect effect of the application of herbicides in weed control. The control provided by these treatments was able to mitigate the competition of joyweed with the forage grass while providing a low phytotoxic effect on the pasture, thus standing out the effect of joyweed competition on pasture growth and development, as well as the potential for competition between the pastures with the weed.

The low potential to control weeds on trifluralin treatment without incorporation (Table 1) led to a decrease in shoot dry weight for pasture grass, leading to similar results to control treatment and explain the weed interference. However, regarding the capacity to compete with joyweed, a difference between both pasture grass was observed. *U. brizantha* presented a higher shoot dry weight yield than *U. ruziziensis* (Table 5) under treatments in which the herbicides were inefficient to control joyweed (Table 1).

The pendimethalin herbicide application with soil incorporation decreased shoot dry weight yield of *U. brizantha* by around 40% compared to treatments without herbicides. Trifluralin did not cause this effect on *U. brizantha* leading to similar shoot dry weight yield in treatment with and without soil incorporation. Although trifluralin can control *U. brizantha* (ALVES, 2002) this effect might be related to the timing between herbicide application and forage grass sowing, and in the present study, this time was 25 days, which might decrease the phytotoxic effect of trifluralin on *U. brizantha.* It was clear according to the evaluations that the control provided by trifluralin herbicide decreased over time (Table 1), which might reinforce this hypothesis.

There is a direct relation between *A. tenella* (joyweed) control and forage and rice plants development and yield. The weed *A. tenella* has a great capacity to cover the soil, inhibiting other plants development. This might lead to crops decrease in yield and growth (MAROTTO, 2002) due to competition for light, water, and nutrients.

The herbicide doses in the intercropping and crop-livestock system used to inhibit the growth of *U. brizanta* are higher than the one utilized for *U. ruziziensis*, showing thus the higher sensibility of this grass to herbicides.

The alternative of intercropping upland rice with *Brachiraria* presented viable results in the Nova Xavantina region. The crop-livestock system has been a great means to renovate pasture areas and improve the soil in the region, the herbicide pendimethalin provides the necessary control leading to a field free of weeds that potentially can impair the crops yield.

Table 2. Number of viable rice tillers evaluated at 50 DAE* and number of viable rice panicles evaluated at 70 DAE, in each intercropping, according to the presence or absence of pre-emergence herbicides applied with and without soil incorporation. Nova Xavantina, Brazil, 2009.

Herbicides	**50 DAE***					**70 DAE**				
	U. ruziziensis		***U. brizantha***		Média	***U. ruziziensis***		***U. brizantha***		**Média**
	Incorporation					**Incorporation**				
	Yes	**No**	**Yes**	**No**		**Yes**	**No**	**Yes**	**No**	
Control	27.75 ^{ns}	30.75	29.87	28.37	29,12 b	24,25 ^{ns}	27,25	26,37	23,37	24,87 b
Pendimethalin	32.5	34.87	36.37	35.37	35,87 a	26,75	29,37	29,12	29,25	29,18 a
Trifluralin	33.5	31.75	33.75	34.87	34,31 a	24,37	27,5	30,62	33	31,81 a
Mean			33.33	32.87		25,56	28,04	28,7	28,54	
CV (%)	11.91			9.94		12.67		11.53		

Mean followed by the same uppercase letter in the column and same lowercase letter on the line, for each evaluation time, do not differ statistically according to Tukey (5%). DAE = Days after the emergence of rice crop. CV. Coefficient of variation.

Table 3. Rice yield (kg ha^{-1}), in each intercropping, according to the presence or absence of pre-emergence herbicides applied with and without soil incorporation. Nova Xavantina, Brazil, 2009.

Herbicide	**Evaluated intercropping**					
	Rice with *B. ruziziensis*			**Rice whit *B. brizantha***		
	Incorporated	**No incorporated**	**mean**	**Incorporated**	**No incorporated**	**mean**
Control	2175	2193	2184 b	2180	2145	2162 b
Pendimethalin	3097	3569	3328 a	2643	2952	2797 a
Trifluralin	2310	2475	2392 b	2896	2767	2832 a
Mean	2528	2743		2573	2621	
CV (%)		16.06			7.68	

Mean followed by the same uppercase letter in the column and same lowercase letter on the line, for each evaluation time, do not differ statistically according to Tukey (5%). CV. Coefficient of variation.

Table 4. Shoot dry weight of pasture grass at 120 DAS (kg ha^{-1}), in each intercropping, according to the presence or absence of pre-emergence herbicides applied with and without soil incorporation. Nova Xavantina, Brazil, 2009.

Herbicide	Evaluated intercropping			
	Rice with *B. ruziziensis*		Rice whit *B. brizantha*	
	Incorporated	No incorporated	Incorporated	No incorporated
Control	1965.00 Ab	2080.00 Ab	3557.25 Ab	3057.00 Ab
Pendimethalin	4240.00 Aa	4520.00 Aa	3753.70 Bb	4691.70 Aa
Trifluralin	5189.00 Aa	2540.00 Bb	5304.10 Aa	3201.60 Bb
CV (%)	26.8		32.27	

Herbicide	Evaluated intercropping			
	Rice with *B. ruziziensis*		Rice whit *B. brizantha*	
	Incorporated	No incorporated	Incorporated	No incorporated
Control	1965.00 Ab	2080.00 Ab	3557.25 Ab	3057.00 Ab
Pendimethalin	4240.00 Aa	4520.00 Aa	3753.70 Bb	4691.70 Aa
Trifluralin	5189.00 Aa	2540.00 Bb	5304.10 Aa	3201.60 Bb
CV (%)	26.8		32.27	

Mean followed by the same uppercase letter in the column and same lowercase letter on the line, for each evaluation time, do not differ statistically according to Tukey (5%). DAS = Days after sowing of pasture. CV. Coefficient of variation.

Conclusions

The control of joyweed (*A. tenella*) is more dependent on the herbicide incorporation into the soil.

Weed control improved forage grass shoot dry weight yield.

Pendimethalin showed better control on *A. tenella* and do not affect *U. ruziziensis* development.

The best rice yield was observed in the intercropping with *U. ruziziensis* under pendimethalin application without soil incorporation.

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