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Effectiveness and interaction of the association of Flumioxazin and Pyroxasulfone in the control of Guinea grass (*Panicum maximum*)

Eficácia e interação da associação de Flumioxazin e Pyroxasulfone para controle de capim-colonião (Panicum maximum)

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ABSTRACT

The infestation of difficult-to-control weeds in a crop has direct negative effects on growth and development as they compete for water, light, and nutrients, in addition to hindering the harvest, and in the specific case of sugarcane they can reduce the longevity of the field. Normally, formulated mixture of herbicides, applied in pre-emergence conditions, is used to achieve a greater weed spectrum, longer residual effect, and lower costs. However, a mixture of two molecules can cause diverse effects, such as antagonism, synergism, or additives effects; therefore, it is important to know the interaction involved in each mixture used. In this way, this work has been developed to assess possible interactions of the association of the herbicides flumioxazin and pyroxasulfone applied in pre-emergence conditions, as well as assessing the effectiveness of the mixture control in Guinea grass (*Panicum maximum*). The study was conducted in greenhouse conditions in 5 L plastic pots, and the treatments consisted of a 4 x 4 factorial design: four flumioxazin doses (0, 50, 100, and 200 g ha^{-1}) and four pyroxasulfone doses (0, 50, 100, and 200 g ha^{-1}). The experimental design was the randomized block, with percentage control and residual dry mass evaluations at 35 days after application (DAA). The interaction data were analyzed using the Colby's model, and the control effectiveness data were analyzed using the F-test, followed by Tukey test, when significant. The effectiveness of the association between the herbicides flumioxazin and pyroxasulfone on Guinea grass was proven when applied in pre-emergence conditions with averages above 90% of control. The interaction between the herbicides flumioxazin and pyroxasulfone has been considered additive by Colby's model.

KEYWORDS: management; sugarcane; synergism; antagonism; additive.

RESUMO

A infestação de plantas daninhas de difícil controle em uma cultura exerce efeitos negativos diretos no seu crescimento e desenvolvimento, competindo por água, luz e nutrientes, além de dificultar a colheita e, no caso específico da cana-de-açúcar, pode reduzir a longevidade do canavial. Normalmente, a mistura formulada de herbicidas em condições de pré-emergência é utilizada na cultura de cana-de-açúcar, para se alcançar maior espectro de ação, longo efeito residual e redução de custos. No entanto, uma mistura de duas moléculas pode resultar em efeitos sinérgicos, antagônicos ou aditivos, portanto, é importante conhecer a interação envolvida em cada mistura utilizada. Desta forma, este trabalho foi desenvolvido com o objetivo de avaliar possíveis interações da associação dos herbicidas flumioxazin e pyroxasulfone aplicados em condições de pré-emergência, bem como avaliar a eficácia de controle da mistura em capim-colonião (*Panicum maximum*). O experimento foi realizado em condição de casa-de-vegetação em vasos plásticos com capacidade de 5 L, e os tratamentos constaram de esquema fatorial 4 x 4, quatro doses do herbicida flumioxazin (0, 50, 100 e 200 g ha^{-1}) e quatro doses do herbicida pyroxasulfone (0, 50, 100 e 200 g ha^{-1}). Adotou-se o esquema experimental de blocos ao acaso, com avaliações percentuais de controle, e massa seca residual aos 35 dias após a aplicação (DAA). Os dados da interação foram analisados utilizando-se o modelo de Colby, e os dados de eficácia de controle foram analisados por meio do teste F e do teste de Tukey. A eficácia da associação entre os herbicidas flumioxazin e pyroxasulfone sobre o capim-colonião foi comprovada na aplicação em condições de pré-emergência, com médias acima de 90% de controle. A interação dos herbicidas flumioxazin e pyroxasulfone foi considerada aditiva pelo modelo de Colby.

PALAVRAS-CHAVE: manejo; cana-de-açúcar; sinergismo; antagonismo; aditivo.

INTRODUCTION

The edaphoclimatic potential of Brazil is a favorable condition for the agricultural production of several crops, such as sugarcane (*Saccharum* spp.). However, there are a number of factors that can affect crop yield. Weed infestation is one of the main factors, which can reduce sugarcane productivity by up to 80% (AZANIA et al. 2002) and significantly increase production costs by competing for water, light, and nutrients, in addition to hindering harvest and reducing the quality of the harvested product (SANTOS et al. 2011, ARALDI et al. 2015).

Guinea grass (*Panicum maximum*) is a prominent weed in sugarcane areas; it is a perennial species with a strong and vigorous root system, propagating both through seeds and vegetatively, and it is considered a difficult weed to control in sugarcane fields (KISSMANN & GROTH 1997, SILVA et al. 2018). For example, in areas with Guinea grass infestations, productivity can decrease more than 50% (KUVA et al. 1999) while the combined infestation of Guinea grass and signal grass (*Brachiaria decumbens*) have reduced crop yield by 40% (KUVA et al. 2003).

For weed management in sugarcane, the most used method is the herbicide application in pre-emergence conditions (HERNANDEZ et al. 2001), as it ensures a prolonged residual effect and control effectiveness during the critical period of competition with the crop (CARBONARI et al. 2010). The adoption of this type of application is mainly a consequence of the greater spacing adopted, approximately 1.50 m between the lines, focused on mechanized harvesting, which extends the time required for the crop to close its canopy; in addition, the same production unit (sugar and alcohol plant) often manages very large areas, thus the use of pre-emergent products is essential for the unit's logistics.

However, for the success of the application, it is important to consider that the crop is planted (plant cane) or cut (ratoon cane) at different times during the year (seasons of low and high precipitation), which results in different environmental management conditions throughout the year (SANTOS et al. 2011). This variation provides suitable environments for the development of a large number of weed species.

In this way, herbicides must have a broad spectrum of control to suit the requirements of the crop and, in this aspect, herbicide associations become important to improve application efficiency and reduce production costs (SANTOS et al. 2011).

It is known that the combination of herbicides with different mechanisms of action can result in synergistic, antagonistic, or additive effects (COLBY 1967). Associations that result in synergistic or additive effects are of interest, as they allow an increase in the spectrum of action and the use of lower doses, which represents a reduction in production costs. On the other hand, associations that result in antagonistic effects negatively influence the performance of herbicides, and they may result in incompatibility or require an increase in the dose and/or separate application of herbicides, in this way increasing production costs (KRUSE et al. 2001, TREZZI et al. 2007, TREZZI et al. 2016).

Thus, this work has been developed with the objective of assessing the efficacy and the interaction of the association of flumioxazin + pyroxasulfone in different combinations of doses, being the mixture applied in pre-emergence conditions of Guinea grass.

MATERIAL AND METHODS

The work was carried out in a greenhouse of the Plant Production Department of the Luiz de Queiroz College of Agriculture, University of São Paulo, in Piracicaba, SP, Brazil (22º 42' 32” S, 47º 37' 43” W, and 550 m altitude), during the year 2019.

The experiment was carried out following a randomized block design, in which each plot consisted of a 5 L pot. The treatments consisted of a 4 x 4 factorial design, considering four doses of the herbicide flumioxazin (0, 50, 100, and 200 g ha^{-1}) and four doses of the herbicide pyroxasulfone (0, 50, 100, and 200 g ha^{-1}), which resulted in 16 treatments with four replications.

Initially, the pots were filled with Dystrophic Red Latosol (Oxisol) from a previously sieved arable layer. This soil was collected from an area with no history of herbicide use and was characterized in the ESALQ/USP soil laboratory in relation to its chemical and physical characteristics.: pH ($CaCl_2$) 5.3; O.M. 18 g dm^{-3}; SB 41.8 $mmol_c$ dm^{-3}; CEC 66.8 $mmol_c$ dm^{-3}; 54% sand, 41% clay, and 5% silt.

The Guinea grass seeds were purchased from the company Agro Cosmos (Cosmos Agrícolas Produção e Serviços Rurais Ltda.) located in the municipality of Engenheiro Coelho/SP/Brazil. They were sown in the proportion of 0.3 g of seeds per pot. Soon after sowing, spraying was carried out in total Guinea grass pre-emergence. For this purpose, a precision backpack sprayer, pressurized by CO_2, was used coupled to a TeeJet XR 110.02 nozzle, positioned 0.50 m from the targets, with a relative spray liquid consumption of 200 L ha^{-1}. Subsequently, all plots were maintained with irrigation of 4 mm day^{-1}.

Then, the percentage control of Guinea grass was evaluated at 35 days after application (DAA), as well as residual dry mass at 35 DAA. For the percentage control evaluations, a visual control score was assigned ranging from 0% in the case of absence of symptoms caused by herbicides and 100% for plant death, according to the method proposed by the Brazilian Society for the Science of Weeds (SBCPD 1995). The residual dry mass was obtained from the harvesting of the remaining plant material in the plots with subsequent drying in an oven at 70 °C for 72 hours. The percentage of decrease in residual dry mass (Rm), in relation to the control, was calculated following Equation 1:

$$Rm = 100 - \frac{(\text{Residual dry mass x 100})}{\text{Residual dry mass of the control}} \quad (1)$$

In which the residual dry mass of the control was the mean of the values obtained in the absence of herbicide application. All the data obtained for the control and decrease in mass were submitted to the F-test followed by the Tukey test, both with 5% significance.

For the interaction data of the associations, both the control and the decrease in dry mass were analyzed according to the model proposed by COLBY (1967), as well as other literatures that also assess the interaction of herbicide associations (GOULART et al. 2012, BARROSO et al. 2014, TREZZI et al. 2016, ANDRADE et al. 2018).

This method consists of calculating a theoretical value of control effectiveness (expected value) as a result of mixing two molecules from Equation 2:

$$E = 100 - \frac{(100 - X) * (100 - Y)}{100} \quad (2)$$

Where: *X* is the percentage of growth inhibition (observed control) by flumioxazin at the single dose *x*; *Y* is the percentage of growth inhibition (observed control) by pyroxasulfone at the single dose *y*; and *E* is the expected control percentage (expected effectiveness) of the herbicide mixture at the same dose (x + y) (COLBY 1967). Thus, considering the observed control data, the expected data are calculated so that the comparison of observed and expected values can be performed using the t-test, with 5% significance.

A mixture will be considered synergistic at a given dose when its observed effectiveness is significantly greater than the expected effectiveness of isolated applications of each herbicide; it will be considered additive when the observed efficacy is similar to the expected efficacy; and it will be considered antagonistic when the observed efficacy is statistically lower than the expected efficacy of the mixture.

RESULTS AND DISCUSSION

Considering the control provided by the herbicide flumioxazin alone at 35 DAA, the control of Guinea grass remained above 80% at all doses, and the control progressed in response to the increase in the dose. However, the rate of 200 g ha^{-1} was the only one to promote a statistically superior control for the species in the isolated doses (97.5%) (Table 1).

Table 1. Percent control[1] of Guinea grass (*Panicum maximum*) after application of different doses of the herbicides flumioxazin and pyroxasulfone, alone or in association, in the pre-emergence condition, evaluated at 35 DAA. Piracicaba, SP, Brazil, 2020.

Flumioxazin (g ha^{-1})	Pyroxasulfone (g ha^{-1}) 0	50	100	200
	Control assessment at 35 days after application MSD$_{5\%}$ = 6.64			
0	0.0 C b	95.0 AB a	98.7 A a	100.0 A a
50	82.5 B c	90.0 B b	100.0 A a	100.0 A a
100	85.0 B b	97.5 A a	100.0 A a	100.0 A a
200	97.5 A a	100.0 A a	100.0 A a	100.0 A a
	CV = 3.90	F_{int} = 158.885*	F_{flu} = 172.264*	F_{pyr} = 339.206*

[1]Means followed by the same letters, capital letters in the columns and lowercase in the lines, do not differ from each other according to Tukey test, with 5% of significance; *Significant F-test at 5% probability.

Although the herbicide flumioxazin was initially considered as a latifolicide, studies show its effectiveness on some grasses when applied in pre-emergence, as is the case of Guinea grass, at a rate of 125 g ha^{-1} (RODRIGUES & ALMEIDA 2018), which has been recorded in our experiment with increased dose. Similar results by CARBONARI et al. (2010) evidence the effectiveness of flumioxazin in grass species, in which the pre-emergence application of 150 g ha^{-1} has promoted 100% control of the species *Brachiaria decumbens* (signal grass) and *Digitaria horizontalis* (crab grass).

On the other hand, the herbicide pyroxasulfone is a graminicide with a spectrum of action on some dicotyledons, a fact that can be seen in all isolated doses of pyroxasulfone, in which the control was statistically equal and always remained above 90% (Table 1).

Similar results have been obtained by MARCUSSI et al. (2018a) who, in a study of the efficacy and selectivity of pyroxasulfone in the sugarcane crop, have obtained, in addition to the selectivity for the crop, effective control of the weeds *P. maximum*, *B. decumbens*, *D. horizontalis*, and *Rottboellia exaltata* in doses from 150 g ha^{-1}. Other results of effective control in grasses have also been reported by KNEZEVIC et al. (2009) and OLSON et al. (2011).

When compared in association, there were nine possible dose combinations, all of which remained above 90% (Table 1). In these cases, the increase in herbicide doses also increased the levels of Guinea grass control.

In conjunction with these results, MOROTA et al. (2018) have verified that the weed management system in soybean with the association of glyphosate (1440 g ha^{-1} in pre-sowing + 720 g ha^{-1} in post-emergence), pyroxasulfone (100 g ha^{-1} in pre-sowing), and flumioxazin (60 g ha^{-1} in pre-sowing) provided 100% control for *Eleusine indica* (goosegrass) and 91% for *Digitaria insularis* (sourgrass) at 45 days after sowing. Similarly, MARCUSSI et al. (2018b) have observed the mixture's effectiveness at a dose of 150 g ha^{-1} of each molecule for the control of *D. insularis* in citrus crop.

When compared by the percentage of decrease in dry mass, the data corroborate this (Table 2), in which the lower efficacy observed in the two treatments with isolated applications of flumioxazin may be a consequence of the use of low doses. However, the use of reduced doses is important to assess each molecule's contribution to increasing the level of control of the species, since high doses result in full efficacy of the products.

Table 2. Percentage of decrease in dry mass[1] of Guinea grass (*Panicum maximum*) after application of different doses of the herbicides flumioxazin and pyroxasulfone, alone or in association, in the pre-emergence condition, evaluated at 35 DAA. Piracicaba, SP, Brazil, 2020.

Flumioxazin (g ha^{-1})	Pyroxasulfone (g ha^{-1})			
	0	50	100	200
Percentage of decrease in dry mass at 35 days after application DMD$_{5\%}$ = 10.25				
0	0.0 C b	98.0 A a	100.0 A a	100.0 A a
50	69.8 B b	96.1 A a	100.0 A a	100.0 A a
100	67.6 B b	100.0 A a	100.0 A a	100.0 A a
200	100.0 A a	100.0 A a	100.0 A a	100.0 A a
CV = 6.08	F_{int} = 58.992*	F_{flu} = 61.035*	F_{pyr} = 220.156*	

[1]Means followed by the same letters, capital letters in the columns and lowercase in the lines, do not differ from each other according to Tukey test, with 5% of significance; *Significant F-test at 5% probability.

In this case, it is possible to notice that both molecules contribute to a greater control of Guinea grass, and pyroxasulfone is more pronounced starting from the lowest dose studied. For the tested combinations, 100% control at 35 DAA was achieved with doses starting from 50 g ha^{-1} of pyroxasulfone + 200 g ha^{-1} of flumioxazin or 100 g ha^{-1} of pyroxasulfone + 50 g ha^{-1} of flumioxazin.

As for the interaction type of the mixture, Colby's model was applied to the data of percentage of control and percentage of decrease in mass; however, for the latter variable, all combinations were considered additive, thus the data will not be presented.

For the percentage of control, the addition of 50 g ha^{-1} of flumioxazin to the solution of 50 g ha^{-1} of pyroxasulfone resulted in a decrease in the percentage of control when compared to the isolated application of 50 g ha^{-1} of pyroxasulfone, in this way resulting in an antagonistic mixture of the products. However, from a practical point of view, this antagonism is not representative, since the control obtained with the mixture was 90% and, according to FRANS et al. (1986), the minimum acceptable control effectiveness for an herbicide treatment is 80% (Table 3).

Table 3. Interaction analysis of the association of flumioxazin and pyroxasulfone evaluated at 35 DAA. $DMD_{5\%}$ = 5.016. Piracicaba, SP, Brazil, 2020.

Flumioxazin (g ha^{-1})	Pyroxasulfone (g ha^{-1})								
	50			100			200		
	Obs.[1]	Exp.[2]	Int.[3]	Obs.[1]	Exp.[2]	Int.[3]	Obs.[1]	Exp.[2]	Int.[3]
50	90.0	99.3	-	100.0	99.8	=	100.0	100.0	=
100	97.5	99.1	=	100.0	99.8	=	100.0	100.0	=
200	100.0	100.0	=	100.0	100.0	=	100.0	100.0	=

[1]Observed values; [2]Expected values; [3]Interaction analysis, considering the t-test applied at 5% significance, where (+) refers to the synergistic mixture, (=) refers to the additive mixture, and (-) refers to the antagonistic mixture.

No evidence relates the antagonism to the association of these molecules since each molecule acts in different mechanisms of action, and there was no physical incompatibility of the spray solution; furthermore, there are reports in the literature that emphasize the effectiveness of these associated herbicides on dicotyledonous species (MARCUSSI et al. 2018b, DOTRAY et al. 2018, BEAM et al. 2019). No negative or positive effect of the herbicide mixture has been identified for the other combinations tested. This resulted in an additive interaction of the molecules, so that the controls obtained were already those expected with the application of each isolated molecule according to the proposed model.

CONCLUSION

The effectiveness of the association between the herbicides flumioxazin and pyroxasulfone on the weed Guinea grass (*Panicum maximum*) has been confirmed with applications in pre-emergence conditions with means greater than 90% of control.

The interaction of the herbicides flumioxazin and pyroxasulfone has been considered additive by the Colby's model.

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