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Article

WEED MANAGEMENT IN BEANS USING SUBDOSES OF FLUAZIFOP-P-BUTYL + FOMESAFEN

Manejo de Plantas Daninhas na Cultura do Feijão com Subdoses de Fluazifop-P-Butil + Fomesafen

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ABSTRACT - The objective of this work was to evaluate the effect of reduced doses of the commercial mixture composed of fluazifop-p-butil + fomesafen, applied for the management of common weeds in beans. The experiment was conducted in a completely randomized block design, with a 5x2+1 factorial arrangement and with four replications. In factor A, there were five percentual doses (100, 87.5, 75.0, 62.5 and 0.0%), in relation to the recommended commercial dose (2 L ha^{-1}) of fluazifop-p-butil + fomesafen, which corresponded to 2.00; 1.75; 1.50; 1.25 and 0.00 L ha^{-1}. Factor B was composed by two development stages of black beans (three and eight trefoils) and weeds: black-jack (two to four and four to eight leaves) and southern crabgrass (two leaves to one tiller and one to four tillers) with one weeded control treatment. The variables evaluated for the control of black-jack and southern crabgrass were: herbicide phytotoxicity to the crop, number of pods per plant, number of grains per pod, 1,000 grain weight and grain yield of the crop. The results demonstrated that the use of fluazifop-p-butil + fomesafen, at all evaluated doses evaluated and application periods, caused low phytotoxicity to the crop, less than 12%. The use of reduced doses of this herbicide presents efficient control of black-jack and southern crabgrass, mainly at the initial development stages of these weed species. The economic threshold dosage of fluazifop-p-butil + fomesafen to control these weeds was 1.23 L ha^{-1}.

Keywords: *Phaseolus vulgaris, Bidens pilosa, Digitaria ciliares.*

RESUMO - Objetivou-se com este trabalho avaliar o efeito de doses reduzidas da mistura comercial composta de fluazifop-p-butil + fomesafen, aplicada para o manejo de plantas daninhas infestantes de lavouras de feijão. O experimento foi conduzido em condições de campo, no delineamento de blocos casualizados, em esquema fatorial 5x2+1, com quatro repetições. No fator A alocaram-se cinco doses percentuais (100; 87,5; 75,0; 62,5; e 0,0%), em relação à dose comercial recomendada (2 L ha^{-1}), da mistura comercial do herbicida fluazifop-p-butil + fomesafen, o que correspondeu a 2,00; 1,75; 1,50; 1,25; e 0,00 L ha^{-1}. Já o fator B foi composto por dois estádios de desenvolvimentos do feijão do tipo preto (três e oito trifólios) e das plantas daninhas picão-preto (duas a quatro e quatro a oito folhas) e milhã (duas folhas a um perfilho e um a quatro perfilhos) e mais uma testemunha capinada. As variáveis avaliadas foram controle do picão-preto e da milhã, fitotoxicidade à cultura, número de vagens por planta, número de grãos por vagem, massa de mil grãos e produtividade de grãos da cultura. Os resultados demonstraram que a utilização do fluazifop-p-butil + fomesafen, em todas as doses avaliadas e épocas de aplicação, provocou baixa fitotoxicidade à cultura, sendo inferior a 12%. A utilização de doses reduzidas deste herbicida apresenta controle

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eficiente do picão-preto e da milhã, principalmente em estádios iniciais do desenvolvimento dessas plantas daninhas. A dose econômica ótima de fluazifop-p-butil + fomesafen para controle de picão-preto e milhã foi de 1,23 L ha^{-1}.

Palavras-chave: *Phaseolus vulgaris, Bidens pilosa, Digitaria ciliaris.*

INTRODUCTION

Black beans (Phaseolus vulgaris) stand out as one of the most important crops for Brazilian food; the country is the largest producer and consumer in the world. Brazil produces around 3.4 million tons annually, with the state of Rio Grande do Sul accounting for 33% of the national production (Conab, 2016). However, despite its importance for the human consumption and in the income composition of family farms, the productivity and quality of black beans, obtained mostly from crops in southern Brazil, are far below those verified in experimental areas and within producers who adopt high technological levels.

Among the main factors associated with low productivity and quality of bean grains, which were verified in most southern Brazilian crops, there is an inefficient weed control, which can cause variable losses from 25% to 67% in grain yield, if no management method is adopted (Teixeira et al., 2009; Vidal et al., 2010; Borchartt et al., 2011; Fontes et al., 2013).

In this regard, the bean-infesting weed species that stand out among the most harmful are the black-jack (Bidens pilosa) and the southern crabgrass (Digitaria ciliaris). The losses caused by these species are due in particular to the high competitive ability with the crop, the production capacity and the dissemination of propagules, and the occurrence of dormancy among seeds, which can remain viable in the soil for several years (Kissman and Groth, 1999; Vidal et al., 2010).

In this context, weed management practices are necessary to reduce losses to bean crops; the chemical method, through the use of herbicides, is the most used due to its practicality, efficiency, lower use of labor and lower cost, compared to other control methods. However, when carried out through the application of herbicides, it can cause negative effects both for the crop and the agroecosystems (Tironi et al., 2012; Fontes et al., 2013).

Based on the growing demand for a sustainable use of agroecosystems, the alternative is reducing the applied herbicide doses, using the concept of optimal timing and dosage (OTD). The OTD, conceptually, is expressed by a satisfactory control of weeds, which can be obtained using herbicide doses below the ones normally recommended on product labels (Rizzardi and Fleck, 2004), considering the relation between herbicide doses and plant development stage, environmental conditions, soil chemical and physical characteristics, in order to obtain control efficiency (Barros et al., 2005; Trezzi et al., 2010).

In bean crops, ACCase-inhibiting herbicides such as clethodim, fluazifop-p-butyl and sethoxydim, are the most commonly used to control monocot weeds, especially because they are selective to dicot crops. As for the post-emergence control of dicots, only a few herbicides are highly selective; fomesafen is the most used, but it may cause high rates of phytotoxicity to the crop (Rodrigues and Almeida, 2011; Oliveira et al., 2013; Cieslik et al., 2014).

Considering the aforementioned, together with the demand for a sustainable use of herbicides, providing an efficient control of monocot and dicot weeds without interfering in the development and growth of beans, there is a need for studies that contemplate the dose reduction of products used on the field. Thus, the objective of this work was to evaluate the effect of reduced doses of the commercial mixture composed of fluazifop-p-butyl + fomesafen, applied for the management of bean-infesting common weeds.

MATERIAL AND METHODS

The experiment was conducted under field conditions, in the municipality of Quatro Irmãos - Rio Grande do Sul state, in the agricultural year 2012/13. The soil of the experimental area is classified as eutrophic Ta Haplic Cambisol (Embrapa, 2013). The adopted cultivation method was the no-tillage system on black oat straw, desiccating the area with glyphosate (1,080 g ha^{-1}) before sowing the crop. Maintenance fertilization was performed according to physical-chemical analyses, following the technical recommendations for black beans (ROLAS, 2004).

Each experimental unit (plot) was composed of an area of 14.1 m^2 (2.82 x 5.0 m), sown in six lines, 5 m long and spaced 0.47 m. The sowing density of the black bean cultivar, IPR Tuiuiu, was 15 viable seeds m^{-1}, or 250,000 ha^{-1} seeds, corresponding to an approximate population of 25 plants m^{-2}.

The experimental design was a randomized block one, with a factorial arrangement of 5x2+1 and four replications. Treatments were constituted by five percentage doses in relation to the commercial one (Table 1), two application periods, considering two development stages of bean and weed culture: black-jack and southern crabgrass (Table 2), plus one weeded control treatment. A commercially formulated herbicide, composed of a mixture of fluazifop-p-butyl + fomesafen (125 + 125 g L^{-1} of active ingredient), was used due to its potential to control monocots and dicots, without persisting in soil and/or water (Rodrigues and Almeida, 2011).

The application of the treatments was performed with a precision backpack CO_2 pressurized sprayer, equipped with four DG 110.02 fan-type nozzles, under a constant pressure of 2.0 kgf cm^{-2} and a displacement velocity of 3.6 km ha^{-1}, with a flow of 200 L ha^{-1} of herbicide spraying mixture. The mean densities of black-jack and southern crabgrass in the experimental area were 44 and 15 plants m^{-2}, respectively. The climatic conditions during the experiment are shown in Figure 1.

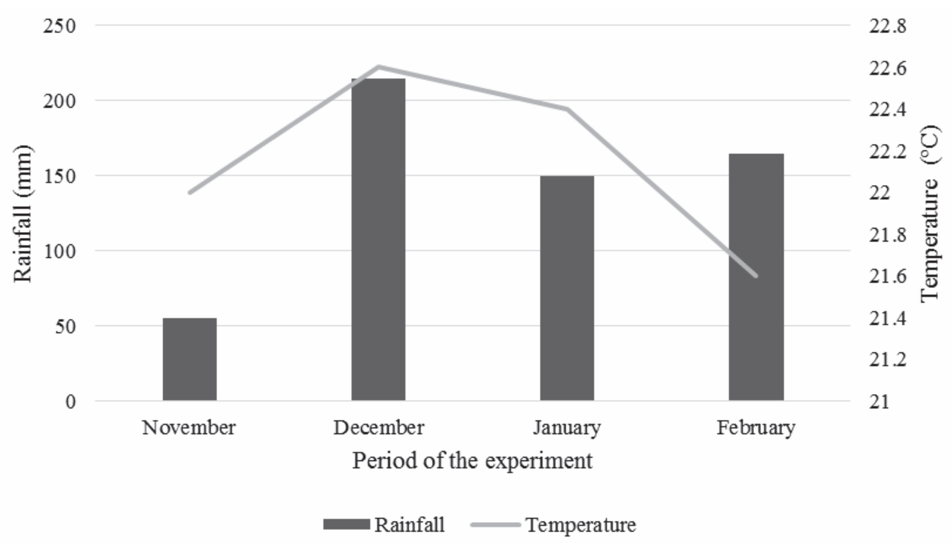
Table 1 - Doses of the commercial mixture of fluazifop-p-butyl + fomesafen herbicides used in the experiment

Herbicide dose (%)	Herbicide dose(1) (L ha^{-1})	Active ingredient (g ha^{-1})
100.0	2.00(2)	250.00 + 250.00
87.5	1.75	218.75 + 218.75
75.0	1.50	187.50 + 187.50
62.5	1.25	156.25 + 156.25
0.0	0.00	0.00

(1) Fusiflex® (fluazifop-p-butil + fomesafen – 125 + 125 g L^{-1}); (2) Commercial dose.

Table 2 - Application period of the treatments based on the development stages of black beans and black-jack and southern crabgrass weeds

Period	Development stage		
	Beans	Black-jack	Southern crabgrass
1	3 trefoils	2 to 4 leaves	2 leaves to 1 tiller
2	8 trefoils	4 to 8 leaves	1 to 4 tiller



Source: INMET (2016).

Figure 1 - Precipitation (mm) and average monthly temperature at the place of installation of the experiment, between November 2012 and February 2013.

Weed control and phytotoxicity variables were evaluated 14, 28 and 35 days after the application of the treatments (DAT), through visual observations. To do so, a percentage scale was used, in which zero corresponded to no control effect on black-jack and southern crabgrass or black bean injury, and 100% corresponded to weed and/or crop death (SBCPD, 1995).

During the pre-harvest, the number of pods per plant was quantified using the average of five plants per plot, collected within the usable area, counting the number of grains per pod of these samples, which were incorporated into the productivity sample.

Bean grain yield was obtained by harvesting plants in a usable area of 5.64 m^2 within each experimental unit, when the moisture content of grains reached approximately 18% (measured with moisture meter). After weighing the grains, their moisture content was determined and, subsequently, the grain mass was corrected to 13% of moisture and extrapolated as kg ha^{-1}. Subsequently, the 1,000 grain weight was determined by counting 250 grains per experimental unit, weighed on an analytical scale; the mean result was multiplied by 4 and expressed as g.

The grain yield losses of bean crops, for each treatment, were calculated in relation to weed control, without the presence of weeds, expressed as kg ha^{-1} or dollars ha^{-1} (US$), using the average productivity of each treatment in both evaluation periods.

The economic threshold dosage (ETD) was the one at which the productivity loss curve, as US$ ha^{-1}, intercepted the control cost (Rizzardi and Fleck, 2004; Tironi et al., 2012). For these authors, ETD is the herbicide dose at which the monetary loss of productivity equals the control cost provided by the use of the dose on the label of the herbicide, adding the application cost. The control cost ranged from US$ 68.31 to 104.17 ha^{-1} for the lowest and highest herbicide dose, respectively, considering the cost of fluazifop-p-butyl + fomesafen to control weeds in post-emergence and the cost of the application.

The obtained data for the evaluated variables were submitted to analysis of variance by F test and, when significant, the effects of the herbicide application periods were compared by Tukey's test. Dosage effects were submitted to regression analysis; the models were chosen based on statistical significance (F test), determination coefficient and biological significance of the model. All tests were conducted at $p \leq 0.05$.

RESULTS AND DISCUSSION

The results showed that, generally speaking, there was an interaction between the studied factors, herbicide doses and application period of both crop and weed. As for the phitotoxicity of beans according to the development stage of the culture in relation to the applied dose of the mixture (Table 3), it is possible to verify that there was no significant result in the evaluation 28 days after the application of the treatments (DAT). For the evaluations performed at 14 and 35 DAT, it was verified that the development stage of the culture influenced the response variable; during both periods, a higher percentage of phytotoxicity was observed at the most advanced development stage of the crop, with eight trefoils, for the 1.25, 1.50, 1.75 and 2.00 L ha^{-1} doses.

Similarly to what was found in this research, Oliveira et al. (2013) do not recommend the application of fomesafen, regardless of the application period (15 or 28 days after emergence), because this herbicide causes high phytotoxicity to cowpea crops, compared to oxadiazon (1,000 g ha^{-1}), fluazifop-p-butyl (375 g ha^{-1}) and phenoxaprop-p-ethyl + clethodim (37.5 + 37.5 g ha^{-1}). It is also worth mentioning that the greatest injury symptoms were verified as the dose of the commercial mixture composed of fluazifop-p-butyl + fomesafen increased (Table 1; Figure 2).

However, the phytotoxic effect was generally low, not exceeding 11.8% at 14 DAT and 4.3% at 35 DAT; both were verified for the highest dose of the mixture tested (Table 3; Figure 2). This demonstrates that black-bean IPR Tuiuiú cultivars present selectivity to the fluazifop-p-butyl + fomesafen mixture. Different results were obtained by Fontes et al. (2013) who, when applying the same herbicide mixture, found a 31% phytotoxicity at 28 DAT in cowpea plants; this was credited to fomesafen, since the isolated application of fluazifop-p-butylpractically did not affect the plants of culture.

Table 3 - Phytotoxicity (%) to black beans IPR Tuiuiu cultivar according to the development stages of the crop and the doses of the commercially formulated herbicide mixture, composed of fluazifop-p-butyl + fomesafen

Herbicide dose (L ha^{-1})	Application period	Phytotoxicity (%)		
		14 DAT[(1)]	28 DAT	35 DAT
0.00	3 trefoils	0.0 a[(2)]	0.0 a	0.0 a
	8 trefoils	0.0 a	0.0 a	0.0 a
1.25	3 trefoils	1.8 b	1.0 a	0.0 b
	8 trefoils	4.8 a	1.0 a	1.0 a
1.50	3 trefoils	2.8 b	2.5 a	0.3 b
	8 trefoils	7.0 a	1.8 a	1.8 a
1.75	3 trefoils	4.3 b	4.3 a	0.5 b
	8 trefoils	9.5 a	2.8 a	2.8 a
2.00	3 trefoils	4.3 b	5.5 a	1.0 b
	8 trefoils	11.8 a	4.3 a	4.3 a
Weeded contr.	3 trefoils	0.0 a	0.0 a	0.0 a
	8 trefoils	0.0 a	0.0 a	0.0 a
General mean		3.83	1.91	0.95
VC (%)		32.86	59.64	50.48

(1) Days after the application of treatments; (2) Means followed by the same letters, within each dose, in the column do not differ among themselves by Tukey's test at 5% probability.

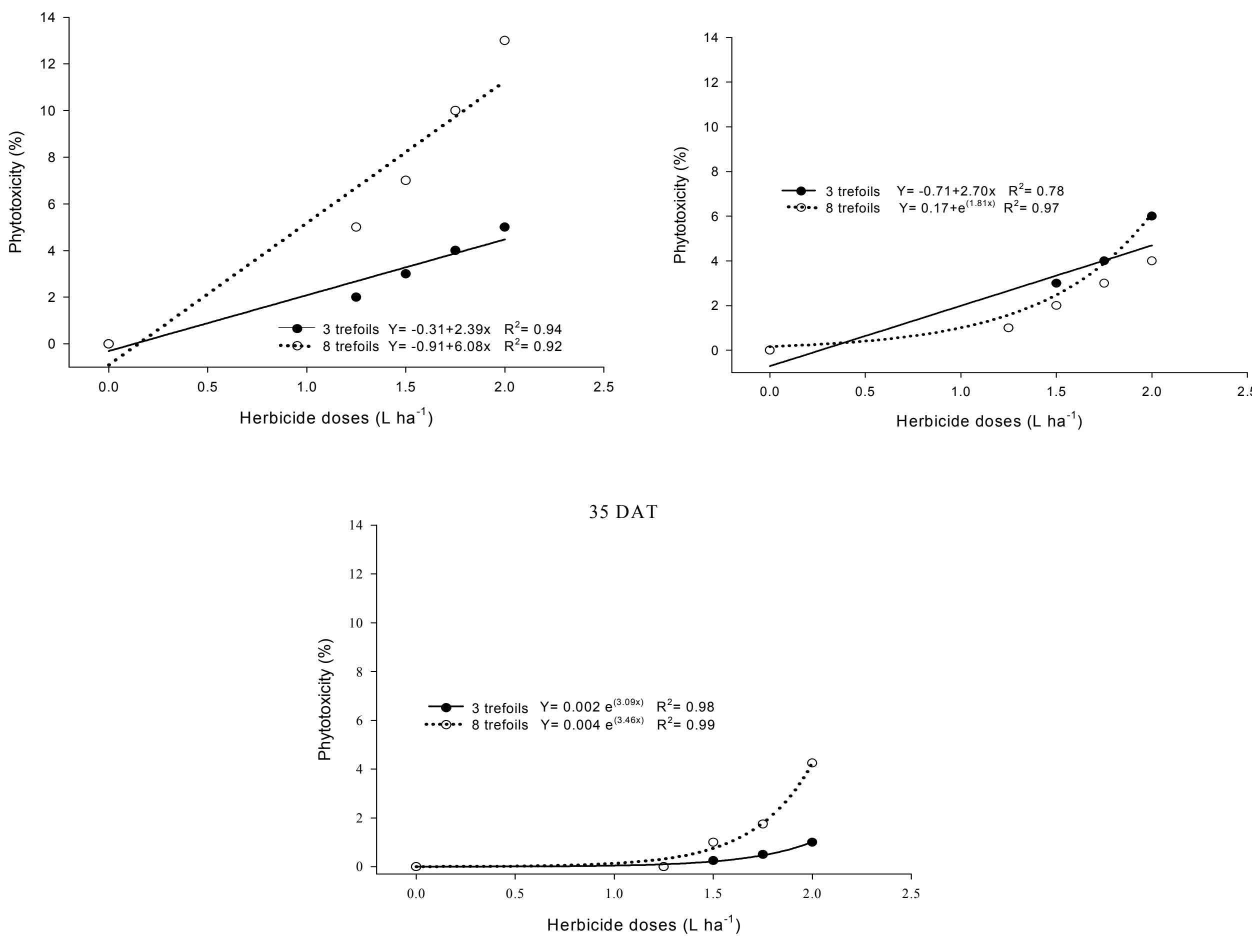


Figure 2 - Phytotoxicity (%) to black beans IPR Tuiuiu cultivar at 14, 28 and 35 days after the application of the treatments (DAT) according to doses of the commercially formulated mixture, composed of fluazifop-p-butyl + fomesafen, and to the development stages of the culture.

Also, in relation to the phytotoxicity evaluated on beans, it is possible to observe that, as the doses of fluazifop-p-butyl + fomesafen were increased, there was a greater percentage of phytotoxicity in the evaluated periods, according to the development stage of the culture (Figure 2). Cieslik et al. (2014) also verified that the increase in the applied doses of fomesafen on beans provided an increase in the phytotoxicity of the crop, especially when the herbicide was applied during the hottest hours of the day, between 11 am and 4 pm. It should be noted that the phytotoxicity percentage was mitigated by the development of the crop, a fact that indicates the recovery of beans from the injuries caused by the herbicide mixture. Oliveira et al. (2013) also observed phytotoxicity reduction caused by fluazifop-p-butyl on cowpea plants during the crop cycle; 34% was the maximum value observed in the first evaluation, and 12% was the minimum in the second evaluation. This behavior is possibly associated to the emission of new leaves, absence of new symptoms caused by the herbicide, or even to the fact that the plant has the potential to metabolize the product (Silva et al., 2011).

Results demonstrated a statistical significance in the control of black-jack, when comparing the weed stages within each dose of fluazifop-p-butyl + fomesafen, only when 1.25 L ha^{-1} were applied at 14 DAT (Table 4). The highest control efficiency of the black-jack was in the 2 to 4 leaf stage; however, even at the most advanced stage (4 to 8 leaves), control was close to 80%. As for the other doses, at 14 DAT, 100% control of black-jack was verified, regardless of the development stage at which the treatment was applied. At 28 and 35 DAT, black-jack control did not show significant differences between the evaluated stages for any of the tested doses, presenting control above 93.8%. Thus, it can be observed that, with 62.5% of the recommended commercial dose of fluazifop-p-butyl + fomesafen, it is possible to obtain a satisfactory control of black-jack. Similar results demonstrated the efficiency of reduced doses to control a mixed population of black-jack and sida when applying 75% of the recommended dose of acifluorfen + bentazon (Rizzardi and Fleck, 2004). It is worth mentioning that even if a certain herbicide, applied at lower doses than the recommended ones, does not cause complete weed death, it can suppress its growth, and this effect will negatively affect its competitive ability with the crop (Murphy and Lindquist, 2002).

When comparing the effect of the incremented doses of fluazifop-p-butyl + fomesafen, it was observed that black-jack control was 100% in the three evaluated periods (14, 28 and 35 DAT) with the application of 1.75 L ha^{-1} of the commercial mixture (Figure 3). The lowest control was observed when using the lowest dose of fluazifop-p-butyl + fomesafen at 14 and 35 DAT, when the weed is at the most advanced development stage, with 4 to 8 leaves. Rizzardi and Fleck (2004),

Table 4 - Control (%) of black-jack (*Bidens pilosa*) according to the weed development stages and doses of the commercially formulated mixture, composed of fluazifop-p-butyl + fomesafen in black beans

Herbicide dose (g ha^{-1})	Weed stage	Black-jack control (%)		
		14 DAT[(1)]	28 DAT	35 DAT
0.00	2 to 4 leaves	0.0 a[(2)]	0.0 a	0.0 a
	4 to 8 leaves	0.0 a	0.0 a	0.0 a
1.25	2 to 4 leaves	100.0 a	100.0 a	100.0 a
	4 to 8 leaves	79.3 b	100.0 a	94.5 a
1.50	2 to 4 leaves	100.0 a	100.0 a	100.0 a
	4 to 8 leaves	100.0 a	100.0 a	93.8 a
1.75	2 to 4 leaves	100.0 a	100.0 a	100.0 a
	4 to 8 leaves	100.0 a	100.0 a	100.0 a
2.00	2 to 4 leaves	100.0 a	100.0 a	100.0 a
	4 to 8 leaves	100.0 a	100.0 a	100.0 a
Weeded contr.	2 to 4 leaves	100.0 a	100.0 a	100.0 a
	4 to 8 leaves	100.0 a	100.0 a	100.0 a
General mean		64.94	66.50	65.69
VC (%)		6.76	0.26	6.80

(1) Days after the application of treatments; (2) Means followed by the same letters in the column do not differ from each other by Tukey's test at 5% probability.

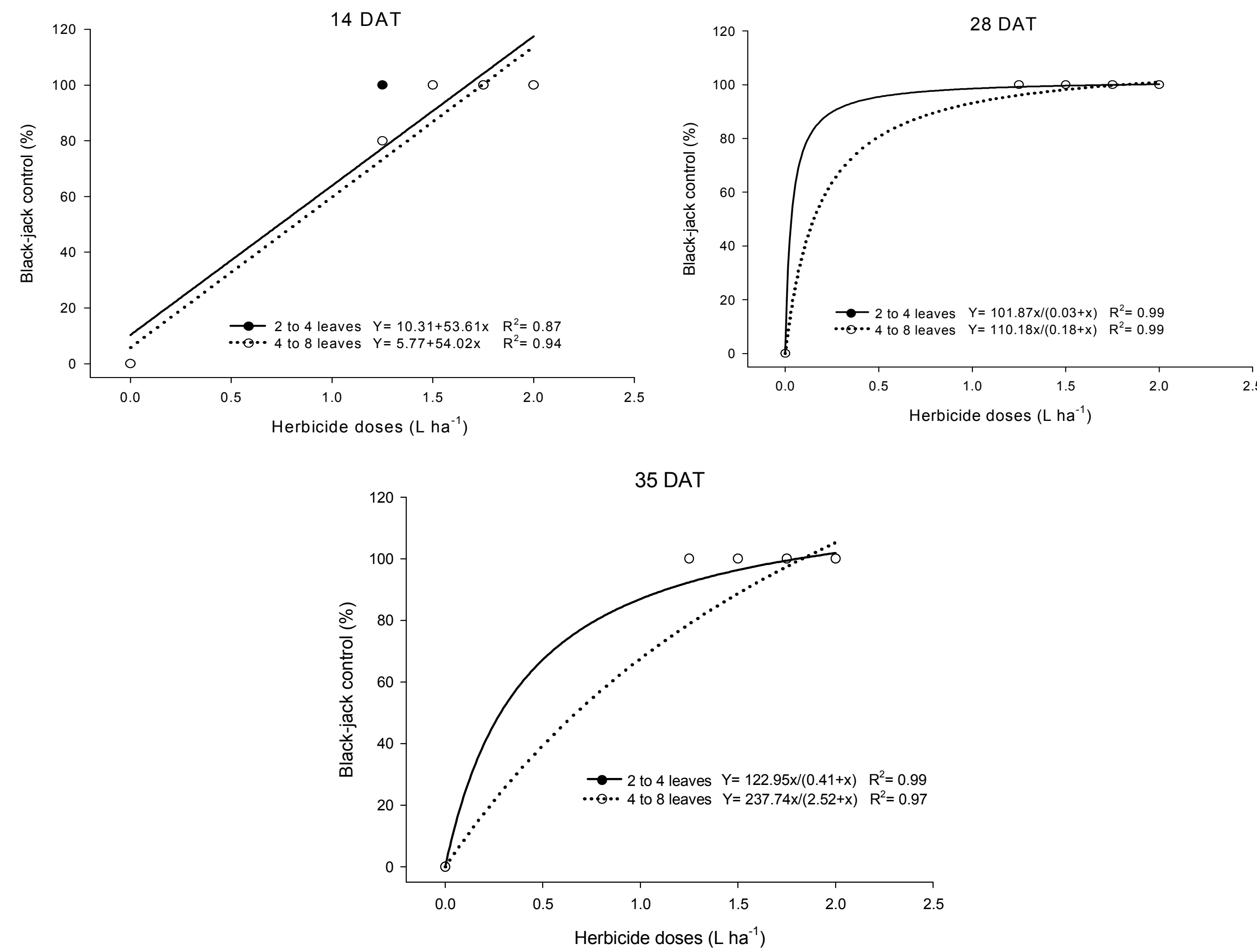


Figure 3 - Black-jack (*Bidens pilosa*) control (%), infesting black-bean IPR Tuiuiu cultivar 14, 28 and 35 days after the application (DAT) of doses of the commercially formulated mixture, composed of fluazifop-p-butyl + fomesafen, and stages of weed development.

when working with acifluorfen + bentazon, found a higher control degree at 7 DAT, when weeds were at lower development stages (2 and 4 leaves); this corroborates the results of this study. Some studies have pointed out that lower doses of herbicides usually cause a better control effect when applied on younger weeds (Dieleman et al., 1996; Rizzardi and Fleck, 2004; Tironi et al., 2012).

Results concerning the control of southern crabgrass show differences between the development stages within each applied dose, only for the use of 1.25 L ha^{-1}, in the evaluations at 14 and 28 DAT. In this case, weed control was higher when plants were at the 2 leaf to 1 tiller stage (Table 5). Within the other doses, development stages and evaluation periods, no significant difference were verified in the control of southern crabgrass; it was higher than 88% (Table 5).

When comparing southern crabgrass control, it was possible to observe that it was higher than 96% applying 0.8, 1.63 and 1.63 L ha^{-1} of the mixture, respectively, at 14, 28 and 35 DAT, at the stage from 2 leaves to 1 tiller, and applying 1.75, 1.60 and 1.69 L ha^{-1} of the mixture, respectively, at 14, 28 and 35 DAT at the stage of 1 to 4 tillers (Figure 4). The weed stage becomes essential for a good herbicide efficiency, especially for fomesafen, when applied on cowpea, for the management of fireplant, black-jack, Benghal dayflower and clover (Mancuso et al., 2016).

The analysis of the number of pods per plant shows that the use of percentage doses of 62.5% and 75.0%, corresponding to 1.25 and 1.50 L ha^{-1} respectively, causes a reduction in the variable only when fluazifop-p-butyl + fomesafen were applied when beans were at a more advanced development stage (8 trefoils). As for the other tested doses, there was no significant difference, regardless of the application period of the herbicide (Table 6 and Figure 5A). Corroborating the results of this study, Mancuso et al. (2016) did not observe any change in the number of pods per

Table 5 - Control (%) of southern crabgrass (*Digitaria ciliaris*) according to the stages of weed development and doses of the commercially formulated mixture, composed of fluazifop-p-butyl + fomesafen

Herbicide dose (g ha^{-1})	Weed stage	Southern crabgrass control (%)		
		14 DAT[1]	28 DAT	35 DAT
0.00	2 leaves to 1 tiller	0.0 a[2]	0.0 a	0,0 a
	1 to 4 tillers	0.0 a	0.0 a	0,0 a
1.25	2 leaves to 1 tiller	100.0 a	100.0 a	100,0 a
	1 to 4 tillers	81.3 b	89.5 b	89,5 a
1.50	2 leaves to 1 tiller	91.3 a	100.0 a	100,0 a
	1 to 4 tillers	88.8 a	100.0 a	100,0 a
1.75	2 leaves to 1 tiller	98.3 a	100.0 a	100,0 a
	1 to 4 tillers	100.0 a	100.0 a	100,0 a
2.00	2 leaves to 1 tiller	99.5 a	100.0 a	100,0 a
	1 to 4 tillers	100.0 a	100.0 a	94,5 a
Weeded control	2 leaves to 1 tiller	100.0 a	100.0 a	100,0 a
	1 to 4 tillers	100.0 a	100.0 a	100,0 a
General mean		63.25	66.63	65.33
VC (%)		10.38	4.87	6.41

[1] Days after the application of treatments; [2] Means followed by the same letters, within each dose, in the column do not differ among themselves by Tukey's test at 5% probability.

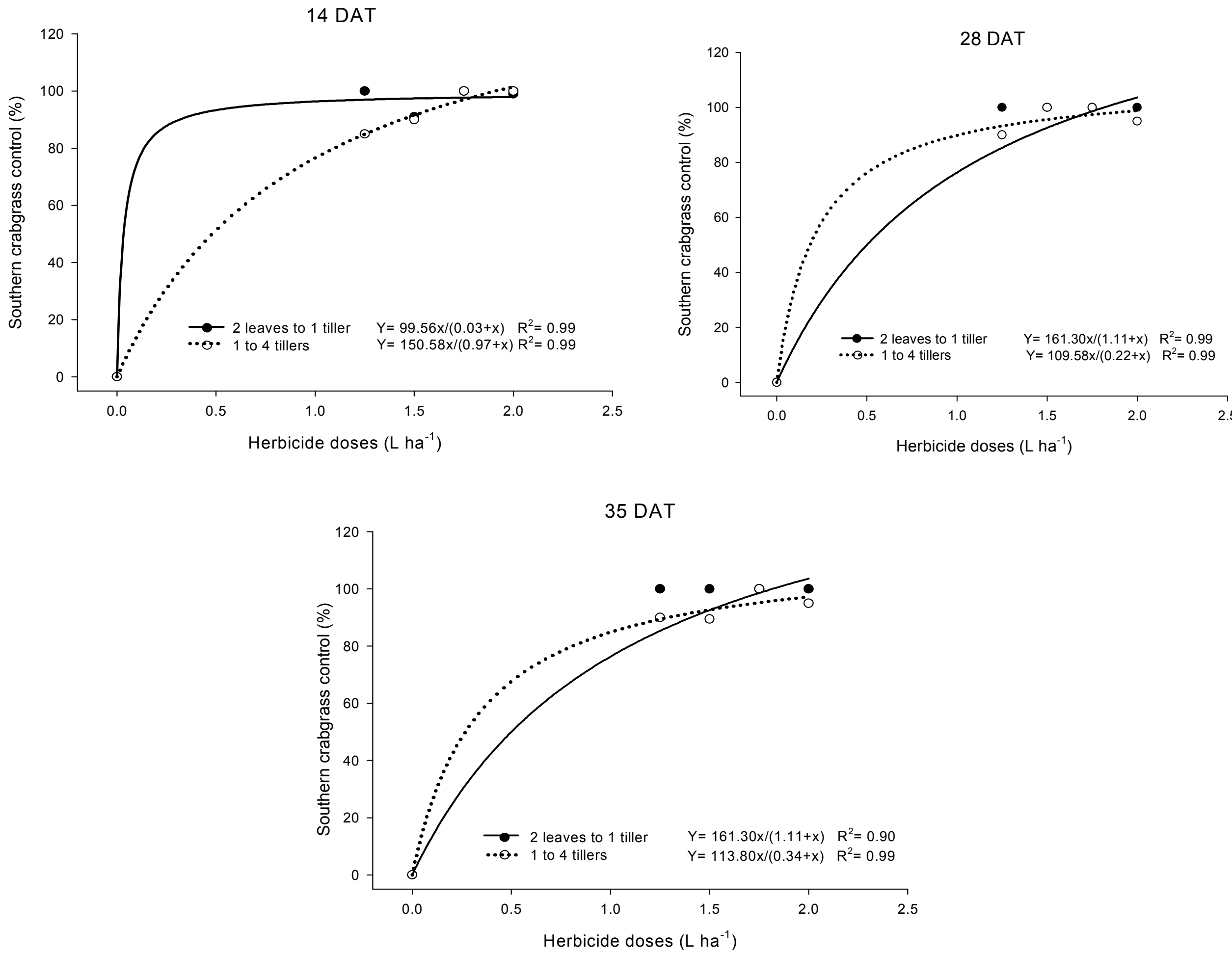


Figure 4 - Control (%) of southern crabgrass (*Digitaria ciliaris*) infesting black beans IPR Tuiuiu cultivar, 14, 28 and 35 days after the application (DAT) of doses of the commercially formulated mixture, composed of fluazifop-p-butyl + fomesafen, and stages of weed development.

Table 6 - Number of pods per plant, number of grains per pods, 1,000-grain weight (g) and grain yield (kg ha-1) of black beans cultivar IPR Tuiuiú according to the development stages of the crop and to doses of the commercially formulated mixture, composed of fluazifop-p-butyl + fomesafen

Herbicide dose (L ha-1)	Herbicide application period	N. of pods per plant	N. of grains per pod	1,000-grain weight (g)	Grain yield (kg ha-1)
0	3 trefoils	9.73 a[1]	22.99 a	178.47 a	1942.44 a
	8 trefoils	7.80 a	18.53 b	177.71 a	1759.41 b
1.25	3 trefoils	10.70 a	22.70 a	189.44 a	2124.61 a
	8 trefoils	8.40 b	17.67 b	185.76 a	2113.33 a
1.50	3 trefoils	12.33 a	18.03 a	184.82 a	2303.52 a
	8 trefoils	9.93 b	15.47 a	178.92 a	1811.55 b
1.75	3 trefoils	11.80 a	17.96 a	185.10 a	2184.88 a
	8 trefoils	10.27 a	15.72 a	182.55 a	1697.54 b
2.00	3 trefoils	11.25 a	19.13 a	189.43 a	2213.68 a
	8 trefoils	10.47 a	18.25 a	184.34 a	1975.00 b
Test. capinada	3 trefoils	10.50 a	18.09 a	188.61 a	2104.26 a
	8 trefoils	9.80 a	16.91 a	183.53 a	1988.89 b
General mean		10.25	18.45	184.06	2018.26
VC (%)		13.56	13.71	2.26	4.42

[1] Means followed by the same letters, within each dose, in the column do not differ among themselves by Tukey's test at 5% probability.

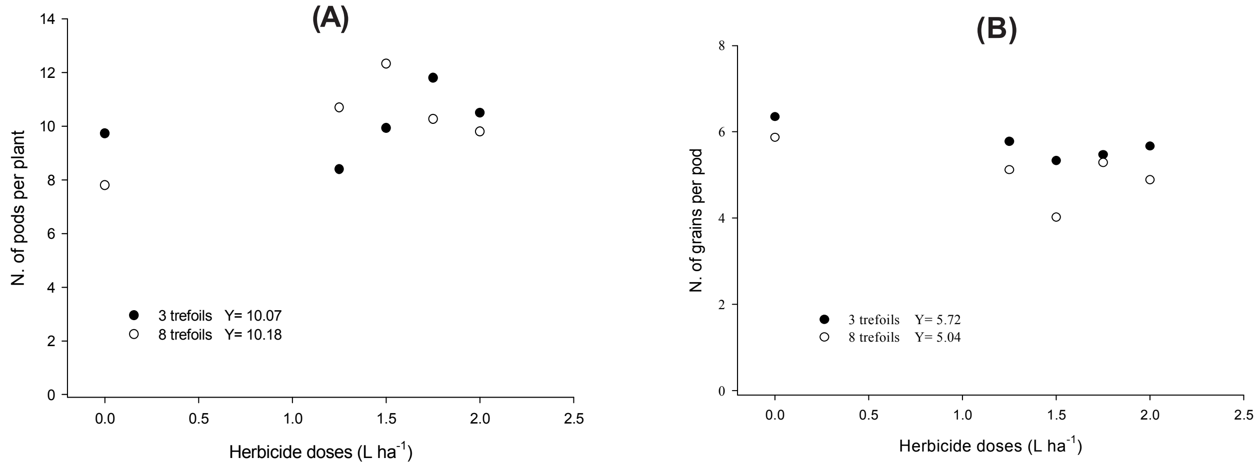


Figure 5 - Number of pods per plant (A) and number of grains per pod (B) of black beans cultivar IPR Tuiuiú after the application of commercially formulated doses of fluazifop-p-butyl + fomesafen and development stages of the culture.

plant when evaluating the use of herbicides (bentazon, fomesafen and diclosulam) at the initial (first pair of leaves) and late (three true leaves) stages in two cowpea cultivars.

The number of grains per pod was not affected when the doses of 1.50, 1.75 and 2.00 L ha-1 of the commercial fluazifop-p-butyl + fomesafen mixture were applied on the weeded control (Table 6) . However, there was a reduction in the number of grains per pod when using the dose of 1.25 L ha-1 only for the second application period of this herbicide; there was also a reduction at dose 0, for the same period of application (8 trefoils). This reduction in the number of grains per pod when using the 1.25 L ha-1 dose of the herbicide may be associated with the fact that the later application of lower doses of fluazifop-p-butyl + fomesafen did not cause 100% control of black-jack and southern crabgrass (Tables 4 and 5). Even if a few plants remained in the area due to the fact that these species present high competition with beans due to the resources of the environment, they interfere negatively on the variable, especially when beans require a great amount of water, light and nutrients. This also reflected in a lower grain yield (Table 6).

When evaluating the effect of the doses on the number of grains per bean pod, no data adjustments were observed to the tested models, and the averages obtained for the two application stages of the herbicide were very similar (Figure 5B). Lamego et al. (2011), when evaluating the effect of doses of alachlor and s-metolachlor on the number of grains per pod of Juriti Branco beans, did not find significant differences between the tested doses and the herbicides; this corroborates the results of this work.

As for the 1,000 grain weight variable, no difference was observed, regardless of the herbicide application period and the doses at issue (Table 6 and Figure 6A). The use of fomesafen, applied at early or late stages of cowpea (Mancuso et al., 2016) and of alachlor and s-metolachlor doses on carioca beans (Lamego et al., 2011) did not affect the 1,000 grain weight, which is in line with what was observed in this research.

The application period of the herbicide influenced the grain yield at all tested doses, except for 1.25 L ha^{-1} (Table 6). This reduction is probably due to the greater competition time that occurred between beans and weeds, since, similarly, a decrease in productivity was observed when weeding the weeds at a later development stage of the crop. Weed interference during the bean cycle can significantly reduce grain yield. These variations may also occur according to cultivars, weed species, place where the experiment is conducted, adopted management adopted, among other factors (Teixeira et al., 2009; Fontes et al., 2013). According to Borchartt et al. (2011), the critical period of interference prevention in beans is from 4 to 18 days after the emergence of the crop, so that there is no negative effect of weed competition on grain yield. These authors also report that losses of up to 35.78% in bean grain yield can occur if the coexistence with weeds persists during the entire crop cycle and no control measures are adopted.

There was an increase in bean grain yield with the increase in the fluazifop-p-butyl + fomesafen dose, during the application performed when the crop presented three trefoils; this increase is linear. This effect was not observed in the later application (eight trefoils), having an average yield of 1,873.62 kg ha^{-1} (Figure 6B). The application of higher doses of fluazifop-p-butyl + fomesafen during the young stages of weeds provided a control close to 100%, thus keeping beans free from the competition with black-jack and southern crabgrass, which favored a greater crop grain yield. In addition to this, when applying herbicides at early stages of the bean, there is time for the crop to recover from phytotoxicity symptoms, compared to later applications. Carvalho et al. (2012) reported that the use of reduced doses of fluazifop-p-butyl provided an increase in bean productivity, since higher doses of this herbicide resulted in more phytotoxicity for the crop, which failed to overcome the effects of the injuries in time to have a higher production.

The grain yield of black bean cultivar IPR Tuiuiu was compared between the treatments that used the lowest (1.25 L ha^{-1}) and the highest dose (2.00 L ha^{-1}) of the commercially formulated fluazifop-p-butyl + fomesafen, together with the control treatments, weeded and infested during both application periods (Table 7). Results showed that treatments involving the highest and

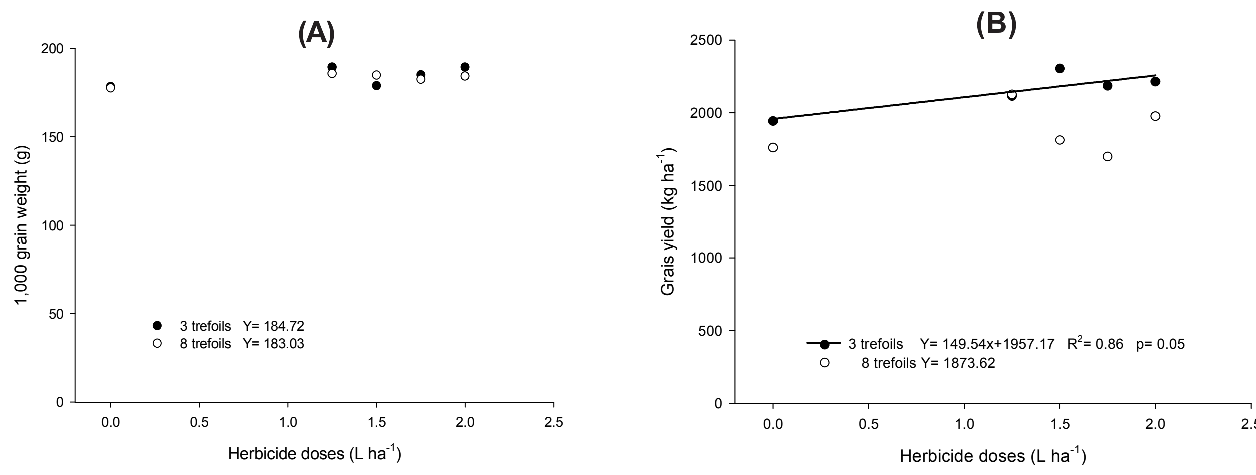


Figure 6 - 1,000 grain weight (A) and grain yield (B) of black beans cultivar IPR Tuiuiu after the application of commercially formulated doses of fluazifop-p-butyl + fomesafen and development stages of the crop.

lowest doses and weed control did not differ statistically from each other, being higher than the infested control sample with 17.93% and 13.31% grain yield, respectively, during period 1 and 2 (Table 7). Depending on weed community, sowing season, cultivar characteristics and test site, productivity can be even lower, reaching 67% (Teixeira et al., 2009). Thus, the control of bean-infesting weeds is one of the obligatory practices to obtain high grain yields.

Table 7 - Productivity (kg ha^{-1}) of black bean grains cultivar IPR Tuiuiú according to the management method of black-jack and southern crabgrass in different control periods

Treatment	Weed control	
	Period 1	Period 2
	Black-jack - 2 to 4 leaves Southern crabgrass - 2 leaves to 1 tiller	Black-jack - 4 to 8 leaves Southern crabgrass - 1 to 4 tillers
Infested control treatment	1759.41 bA[(2)]	1759.41 bA
Herbicides[(1)] – 1,25 L ha^{-1}	2113.33 aA	2124.61 aA
Herbicides[(1)] – 2,00 L ha^{-1}	2213.68 aA	1975.00 aB
Weeded control treatment	2104.26 aA	1988.89 aA
General mean	2004.82	
VC (%)	4.23	

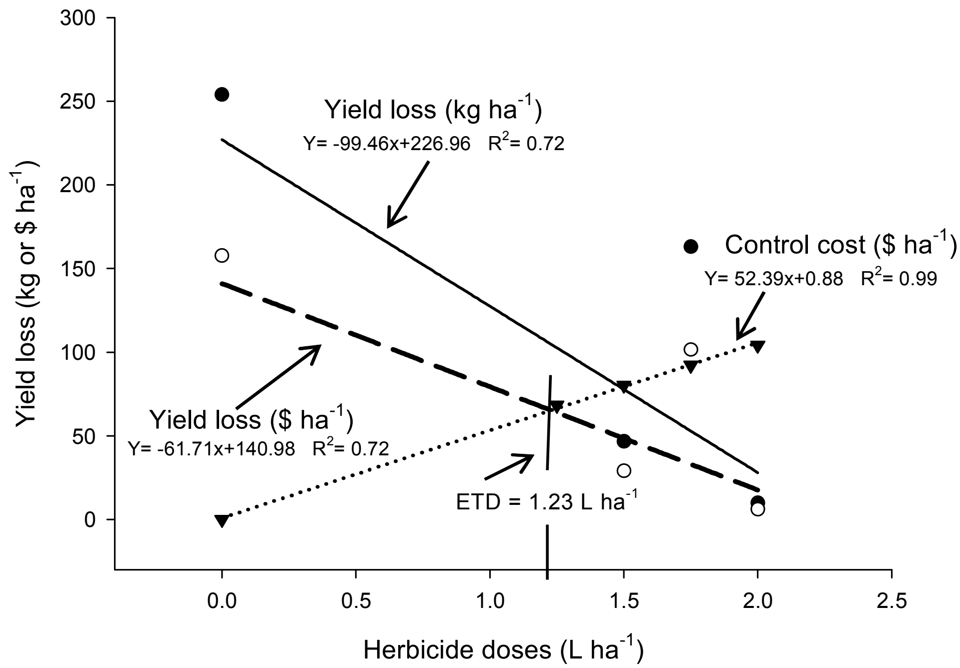
[(1)] Commercially formulated mixture of fluazifop-p-butyl + fomesafen (Fusiflex®); [(2)] Averages followed by the same letters, lowercase letters in the column and upper case in the line, do not differ by Tukey's test at p≤0.05.

When analyzing the effect of the application period for the treatments, it can be verified that there were significant differences only for the highest dose of the herbicide (2.0 L ha^{-1}); there was a reduction in grain yield by 10.78% in period 2 in relation to period 1 (Table 7). This can be partially explained by the greater phytotoxicity observed in beans at 35 DAT (Table 3) using a higher dose and at the later application period, compared to the other doses applied. Furthermore, it is possible to consider that, comparing the treatments with the lowest (1.25 L ha^{-1}) and highest dose (2.00 L ha^{-1}) of the herbicide under study, the non-occurrence of a significant difference in productivity for both periods; this allows the use of a reduced dose of fluazifop-p-butyl + fomesafen, without compromising the bean crop productivity.

Assuming the average values of grain yield and application periods of the herbicide fluazifop-p-butyl + fomesafen, the calculation of the economic threshold dosage (ETD) was performed. To do so, grain yield was converted, decreasing the values of each treatment based on the productivity of the weeded control treatment, which did not receive the application of herbicides. In general, a higher grain (kg ha^{-1}) and economical (US$ ha^{-1}) yield were observed with the increase in the herbicide dose (Figure 7).

In calculating economic losses, the amount paid for a black bean sack at the marketing season was used, at US$ 37.38 (R$ 120.00, considering the dollar exchange rate at R$ 3.21). For a higher economic return, the herbicide dose at which it was possible to obtain profit maximization was calculated, calculating the economic threshold dosage - ETD (Rizzardi and Fleck, 2004). According to Dieleman et al. (1996), the decision on the best dose to be used can be successfully used in the development of an integrated weed management program to achieve efficient control, low cost and lower environmental impact.

Results showed that the economic threshold dosage for weed control was 61.5% (1.23 L ha^{-1}) of the commercially formulated fluazifop-p-butyl + fomesafen recommended dose, applied on the control treatment when plants had 2 to 4 and 4 to 8 leaves, for black-jack, and two leaves to 1 tiller and one to four tillers, for southern crabgrass (Figure 7). These results partially corroborate the ones found by other authors in soybean cultures, when studying sida and black-jack control, with a 75% reduction of the label doses of the commercially formulated mixture of acifluorfen + bentazon (Rizzardi and Fleck, 2004); of wheat, with a lower use than the one producers had been applying at diclofop-methyl + fenoxaprop-p-ethyl + mephenepyr-diethyl, to control *Lolium rigidum* (Barros et al., 2005); and sugarcane, with up to a 50% reduction in herbicide doses (diuron + hexazinone) + MSMA when used on young *Brachiaria brizantha* plants (Tironi et al., 2012).



ETD = dose of the herbicide in which the monetary loss of the income equals the control cost.

Figure 7 - Yield loss of black beans cultivar IPR Tuiuiu according to the dose of fluazifop-p-butyl + fomesafen and the economic threshold dosage to control black-jack (*Bidens pilosa*) and southern crabgrass (*Digitaria ciliaris*).

Considering the aforementioned, it can be concluded that the use of fluazifop-p-butyl + fomesafen at all doses and application periods caused low phytotoxicity to the bean culture in general, being lower than 5.5% and 11.8%, with three and eight trefoils, respectively. As for the control of black-jack and southern crabgrass weeds, it was observed that, generally speaking, treatments that received the herbicide mixture presented control near 100% in period 1 and higher than 80% in period 2. The economic threshold dosage of fluazifop-p-butyl + fomesafen to control of black-jack and southern crabgrass was 61.5% (1.23 L ha^{-1}) of the commercial mixture recommended dose, with efficient control of these weeds, especially at young development stages.

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