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Weed management with post-emergent herbicides in intercropped castor and common bean cultivation

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Abstract

The objective of this work was to evaluate the possibility of using herbicides registered for the cultivation of beans in castor crop when intercropped with beans and the influence of weeds in the crops. A randomized block design was used in a 2 x 4 + 1 factorial scheme with three replications. The herbicides chosen were: (A) fluazifop-p-butyl + fomesafen (125 + 125 g ai L^{-1}) and (B) bentazon + imazamox (600 + 28 g ai L^{-1}). They were applied in four different dosages (0.5; 1.0; 2.0 and 4.0 L ha^{-1}) of the commercial product, plus a control as no weed management. The number of racemes per plant, number of berries per raceme, weight of one hundred grains and castor yield were evaluated. In the bean crop, the number of pods per plant, number of grains per pod, weight of one hundred grains and grain yield were evaluated. Weed competition reduced crop yields by 65.5% for castor beans and 71.87% for beans when intercropped. The results suggest that intercropping of beans with castor is viable and weed management can be carried out with the herbicides evaluated in this study, respect to the doses. The herbicides demonstrate selectivity for BRS Paraguaçu castor crop, showing higher productivity at doses of 612.25 g ai ha^{-1} and 1506.4 g ai ha^{-1} of the herbicides fluazifop-p-butyl + fomesafen and bentazon + imazamox, respectively.

Keywords: *Phaseolus vulgaris; Ricinus communis*; intercropping; weed competition.

Introduction

Castor bean (*Ricinus communis L.*) is an oilseed of significant socioeconomic value, with products and by-products used in the ricino-chemical industry and agriculture, enabling its use as a biofuel due to the oil that is extracted from its seeds (Almeida et al., 2007; Ribeiro et al., 2009). The castor plant has a C3 photosynthetic cycle, a metabolism that is characterized by slow initial growth and low ability to compete with other species (Beltrão et al., 2006; Azevedo et al., 2007). Moreover, the spacing used for cultivation, generally wider, makes the crop susceptible to weeds, which in general, have greater competitive capacity.

The literature has demonstrated the feasibility of using crops intercropped with castor bean, especially common beans without causing losses in its productivity (Jesen et al., 2010; Teixeira et al., 2012; Cardoso et al., 2013; Pereira et al., 2015; Lisboa et al., 2018). However, normally weed control in crops is carried out by mechanical weeding, mainly due to the low availability of herbicides registered for this purpose, which makes cultivation difficult due to dependence on labor.

Beans (*Phaseolus vulgaris* L.) is one of the most important constituent foodstuffs of the Brazilian diet, as it is an excellent source of protein, carbohydrates and has high levels of iron (Borém and Carneiro, 2015). In addition, it has great socioeconomic importance due to the large amount of labor demanded in its cultivation (Salgado et al., 2012), especially in family farming. Together with rice, it is the basis of the nutrition of the Brazilian people, especially of the lower income classes, where it becomes the main source of protein.

In Brazil, beans are cultivated throughout the year, in the "water" seasons (November to January), in the "dry" season (February to April) and irrigated (May to July). The first cultivation crop is responsible for the greater volume of grain of this legume produced (Conab, 2021), practiced in small rural properties under an intercropping system, mostly under low technological level.

Despite the socioeconomic importance of castor bean, it has been considered a weed for other crops resulting in a lack of interestment in research for selective herbicides to the crop (Vitorino et al., 2012). One of the major obstacles to expand cultivation of castor bean in both monoculture and intercropping is the issue of weed management, due to the lack of registered selective herbicides to the crop, mainly post-emergence to control dicotyledonous weeds. There are only two herbicides currently registered for use in castor crops, cletodim (annual grasses) and saflufenacil (non-selective) to control species such as viola rope (*Ipomoea grandifolia*) and bull's weed (*Tridax procumbens*) in post-emergence, both recommended for monoculture system (Brasil, 2021).

Currently, in the bean crop, the main method used to manage weeds is chemical control, with the use of both pre- and post-emergent herbicides (Manabe et al., 2015). This

crop has a large availability of herbicides, allowing the management of the main weeds of the crop. However, these products are exclusively for the monoculture system.
Therefore, this study was carried out with the objective of evaluating a possible selectivity of herbicides registered for the crop of beans under intercropping with castor bean, thus enabling the management of weeds in the post-emergence system.

Results

Castor crop development

There was a significant interaction between the effect of herbicides and the doses evaluated on all agronomic components of castor bean (Supplementary Table 2). The production of racemes per plant was influenced both by the application of herbicides and by the doses applied. In the control treatment, which lived throughout the cycle in competition with the weed, a reduction of 55.82% of this characteristic was observed. This is demonstrating the high influence of the effects of the medium on this production component.
The highest average obtained through regression analysis was 10.98 racemes plant^{-1}, with the application of the herbicide fluazifop-p-butyl + fomesafen in dose of 825 g ai ha^{-1} (Figure 1A). With the use of the herbicide bentazon + imazamox the highest average production of racemes per plant was obtained with the use of 1283.33 g ai ha^{-1}, reaching 9.59 racemes plant^{-1} (Figure 1B).
Regarding the number of berries per raceme, the application of the herbicides showed interaction between the doses evaluated, for the herbicide fluazifop-p-butyl + fomesafen, with the highest production of berries per raceme observed in the dosage of 549.17 g ai ha^{-1}, obtaining 36.90 berries per raceme (Figure 2A), while in the plots treated with the herbicide bentazon + imazamox in the dosage of 1745 g ai ha^{-1} 52.23 berries per raceme were obtained in the castor bean crop (Figure 2B).
Although the weight of one hundred grains is a characteristic of high genetic heritability, but in the present study it presented an interaction between the herbicides evaluated and the doses used. In the areas treated with fluazifop-p-butyl + fomesafen (Figure 3A) the highest observed value was 65.59 g with the use of 579.45 g ai ha^{-1}. The herbicide bentazon + imazamox (Figure 3B) showed higher values for this characteristic, reaching 70.70 g when 1287.50 g ai ha^{-1} was applied.
Regarding grain productivity, the highest levels of productivity were 1511.9 kg ha^{-1} and 1595.7 kg ha^{-1} observed in treatments with the herbicides fluazifop-p-butyl + fomesafen (612.25 g ha^{-1}) and bentazon + imazamox (1506.4 g ha^{-1}), respectively (Figure 4).

Bean crop development

Although the herbicides evaluated were registered for the beans in monoculture, the agronomic characteristics of the crop were evaluated, since some doses used are much higher than those registered for the crop. The results obtained show that there was a significant effect of the doses applied on the number of grains per pod and in the weight of one hundred grains of beans. For the characteristics of number of pods per plant and grain yield, a significant interaction was observed between the herbicides and the doses evaluated (Supplementary Table 3).
The number of pods per plant in the intercropped system showed significant interaction for the herbicides and doses evaluated. The highest values obtained for this characteristic were 10.45 for the herbicide fluazifop-p-butyl + fomesafen with the application of 547.5 g ai ha^{-1} (Figure 5A) and 12.19 pods per plant with the application of herbicide bentazon + imazamox at a dose of 1683.33 g ai ha^{-1} (Figure 5B).
Regarding the number of grains per pod in common bean crop, the results show that there was a significant interaction only for the evaluated doses, not differing in relation to the herbicides evaluated. For this characteristic, the highest value obtained by regression analysis was 3.94 grains per pod with the application of 1.97 L cp ha^{-1} of the evaluated herbicides, corresponding to 493.6 and 1239.92 g ai ha^{-1} of the fluazifop-p-butyl + fomesafen and bentazon + imazamox herbicides, respectively (Figure 6A). For this characteristic, no major reductions were observed in relation to the plots in the bush (witnesses).
The weight of one hundred grains is a characteristic that is slightly influenced by the environment because it is an intrinsic characteristic of the species with high heritability. This characteristic showed significant interaction for the evaluated doses. The highest value obtained was 29.19 g with the application of 2.17 L pc ha^{-1}, corresponding to 543.8 and 1357.34 g ai ha^{-1} of the herbicides fluazifop-p-butyl + fomesafen and bentazon + imazamox, respectively (Figure 6B).
The grain yield of beans in the intercropped system was influenced by the interaction of herbicides with the doses evaluated in the experiment. The highest yields found were 1323.14 and 1793.55 kg ha^{-1} for the herbicides, fluazifop-p-butyl + fomesafen (600 g ai ha^{-1}), bentazon + imazamox (1450.08 g ai ha^{-1}), (Figure 7A and 7B), respectively.

Discussion

Cordeiro et al. (2019) Evaluated the interference of intercropping with *Urochloa ruziziensis* under the castor bean crop and reported a 15% reduction in raceme production per plant. Under no or poor managed filed conditions, weeds can reduce racemes in the castor bean crop by 50% of the production. This characteristic is the one that is most related to the productivity of this castor bean cultivar (Pereira et al., 2015). These results corroborate those observed in the present study, where a reduction of racemes per plant reached approximately 56% without the use of herbicides to manage as weeds, demonstrating the importance of carrying out the initial control of weeds in the crop, especially in the early stages of development.
Living with weeds during the entire crop cycle reduced the production of berries by up to 59.3% per raceme in relation to the areas that had the best weed control. These results are superior to those found in the literature in experiments with castor bean crop that cite values close to 25 berries per raceme (Moreira et al., 2012; Silva et al., 2015). Although this characteristic is highly dependent on the number of female flowers in the plants, this result demonstrates that it can be influenced by variations in the environment and by the management techniques adopted. This is important since this production component, together with the number of racemes per plant, are apparently the most closely linked to the productivity of castor beans.
Under weeds competition, the weight of one hundred grains and other evaluated characteristics were reduced by 67%.

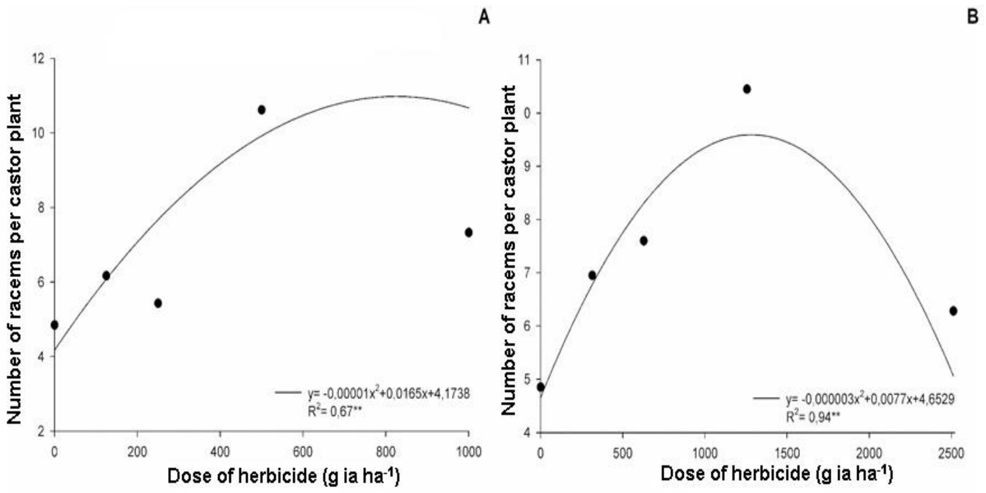

Figure 1. Number of racemes per castor bean plant intercropped with beans, submitted to different doses of the fluazifop-p-butyl + fomesafen herbicides (A); bentazon + imazamox (B), in Ipameri – GO, Brazil, 2013/2014 and 2014/2015.

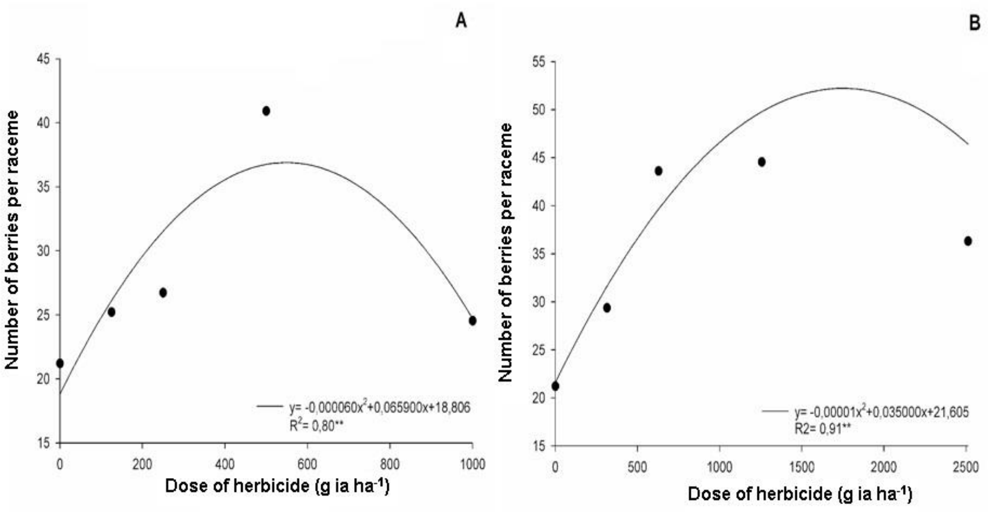

Figure 2. Number of berries per raceme in castor crop intercropped with beans submitted to fluazifop-p-butyl + fomesafen (A) and bentazon + imazamox (B), in Ipameri – GO, Brazil, 2013/2014 and 2014/2015.

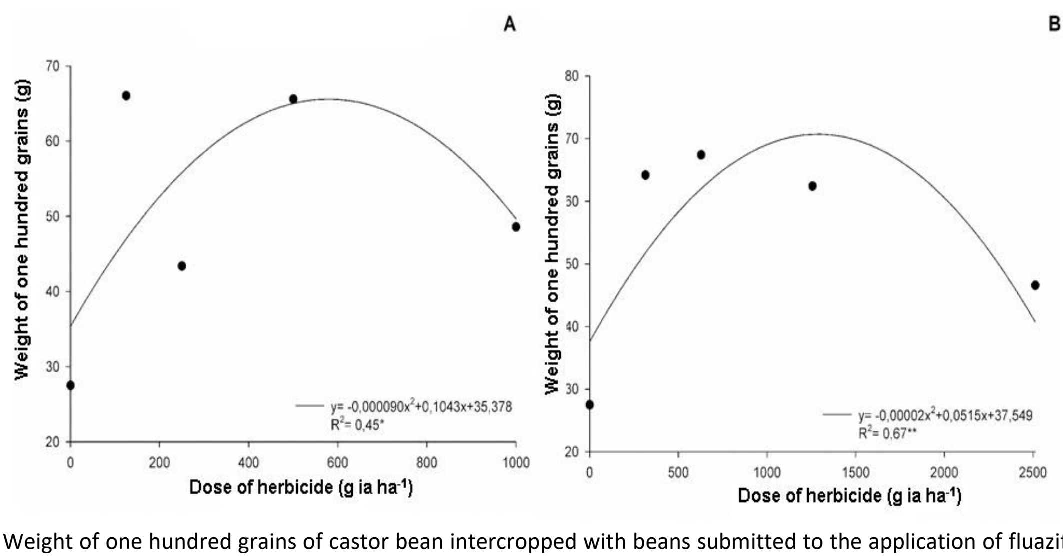

Figure 3. Weight of one hundred grains of castor bean intercropped with beans submitted to the application of fluazifop-p-butyl + fomesafen (A) and bentazon + imazamox (B), in Ipameri – GO, Brazil, 2013/2014 and 2014/2015.

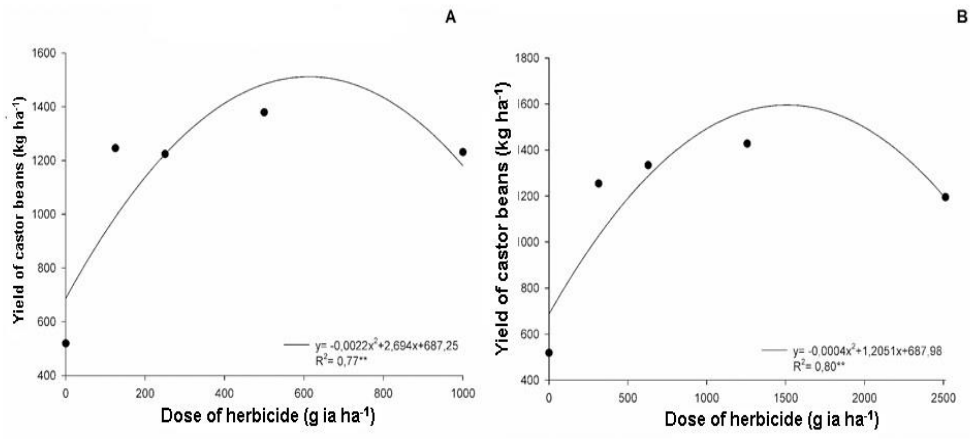

Figure 4. Yield of castor beans in intercropping with beans submitted to fluazifop-p-butyl + fomesafen (A) and bentazon + imazamox (B) in Ipameri – GO, Brazil, 2013/2014 and 2014/2015.

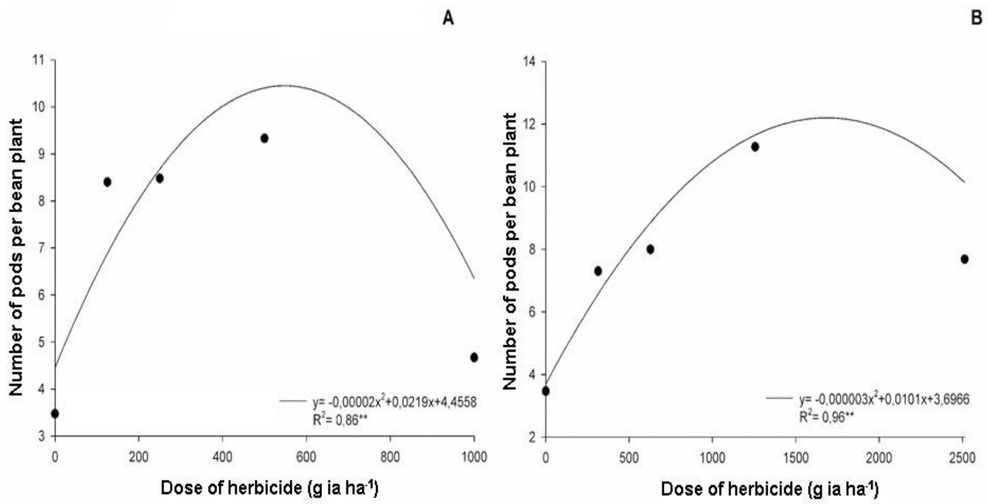

Figure 5. Number of pods per bean plant intercropped with castor bean, submitted to different doses of the herbicides fluazifop-p-butyl + fomesafen (A); bentazon + imazamox (B), in Ipameri – GO, Brazil, 2013/2014 and 2014/2015.

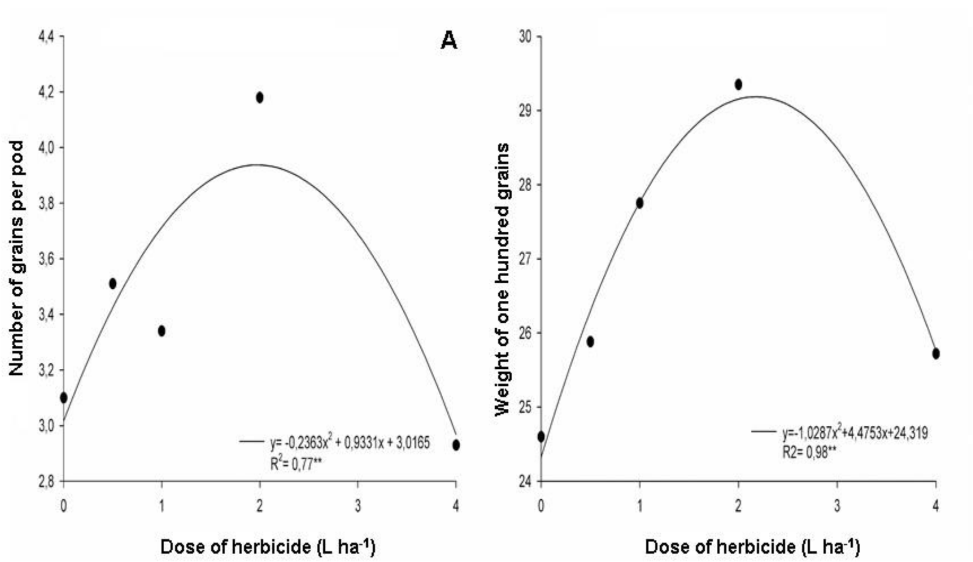

Figure 6. Number of grains per pod (A) and weight of one hundred grains (B) of beans intercropped with castor bean, submitted to different doses of post-emergent herbicides, in Ipameri – GO, Brazil, 2013/2014 and 2014/2015.

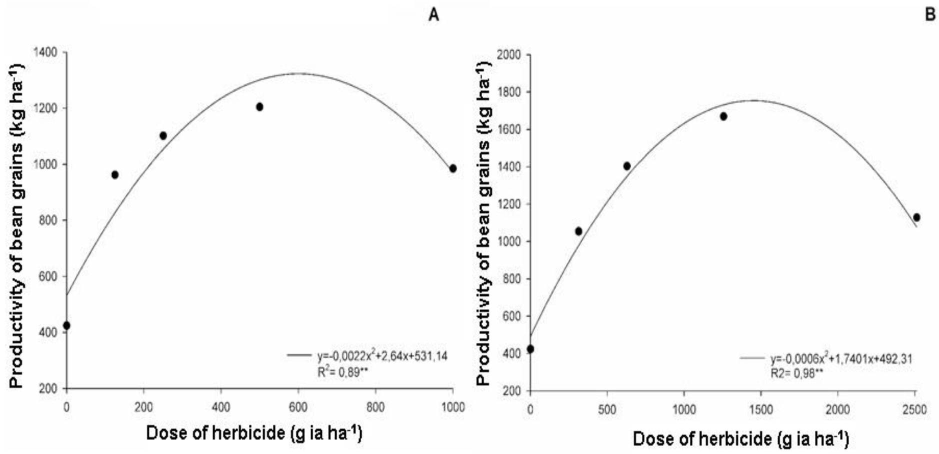

Figure 7. Productivity of bean grains intercropped with castor bean, submitted to different doses of the herbicides fluazifop-p-butyl + fomesafen (A) and bentazon + imazamox (B), in post emergence, in Ipameri – GO, Brazil, 2013/2014 and 2014/2015.

This lower value obtained with the application of the herbicide fluazifop-p-butyl + fomesafen, is possibly due to the fact that the herbicide fluazifop-p-butyl is an inhibitor of acetyl coenzyme-A carboxylase (ACCase) (Cieslik et al., 2017), whose primary mode of action is the inhibition of fatty acid synthesis, regulating the lipid biosynthesis that makes up castor seeds. Alves et al. (2015) assessed that in addition to the production of racemes per plant, population density and grain weight are important characteristics for defining castor bean yield.

Regarding grain yield, the higher productivity obtained with the use of herbicides, probably because the weeds in the area of cultivation in intercropping present a high occurrence of grassy and eudicotyledonous species (Santos et al., 2017). This result is justified because the products are broad-spectrum control agents for the two types of invaders.

In general, the weed competition with the castor crop reduced the productivity levels of the crop by 65.5% in relation to the treatment that showed the best productivity, confirming the importance of weed control in the castor crop (Pereira et al., 2015), especially in the initial stages, when plants are most susceptible to competition.

The yields obtained in this research show that the southeastern region of Goiás has the potential for the cultivation of castor beans obtaining high yields, presenting average yields higher than double the national average in Brazil, which for the 2020/2021 harvest was 582 kg ha^{-1} (Conab, 2021).

The weed competition during the experiment caused a reduction of 65.7% in the number of pods per plant in the bean crop. The increase in the expression of this characteristic in areas treated with post-emergent herbicides, possibly results from the control carried out on the infesting flora. It is important to note that the number of pods per plant is the component that has a direct relationship with the grain yield of beans. The results show that this characteristic is influenced by the conditions of the crop environment, such as the influence of weed competition. These results corroborate with Teixeira et al. (2009) and Barroso et al., (2010) who showed a reduction in the production of pods by the crop in competition with weeds.

In general, living with weeds during the entire cultivation cycle resulted in a 15.69% reduction in the weight of beans, compared to the dose with the greatest expression of this characteristic. This behavior was also observed by Glowacka et al. (2018) evaluating the effect of weed competition on the agronomic characteristics of common bean. The crop productivity is related to the number of pods per plant, grains per pod and grain weight (Pereira et al., 2015; Gomes et al., 2017; Glowacka et al., 2018; Coelho et al., 2021).

The behavior observed in the grain yield was similar to those observed for the characteristic of the number of pods per plant, confirming a significant relationship between these variables. The grain yield in the system intercropped in the plots that lived with weeds during the entire conduction of the crop decreased by 71.87%. The increases in productivity observed with the application of the herbicides are possibly due to the fact that herbicides evaluated were mixtures with effective weed control for both grasses and eudicotyledons. This situation was present in the experimental area, which had a high incidence of species such as *Cenchrus echinatus L*. and *Euphorbia heterophylla L.* (Santos et al., 2017).

The yields obtained in this experiment are lower than the yield potential of the analyzed cultivar, which can reach up to 3,900 kg ha^{-1}. Possibly, this behavior is due to intercropping of the bean crop with the castor bean. The reduced bean productivity when intercropped is reported in the literature (Costa and Silva, 2008; Teixeira et al., 2011; Teixeira et al., 2012) that demonstrated reductions in bean productivity between 40 and 80% when intercropped with other crops ranging. It is worth mentioning that the yields obtained in the present crop, even in conditions of intercropping with another crop, using post-emergent herbicides exceeded the level of the national average the Brazil of bean productivity, which in the 2020/2021 harvest was 977 kg ha^{-1} (Conab, 2021).

Materials and Methods

Characterization of the field

The experiments were conducted in the agricultural years 2013/2014 and 2014/2015, in the experimental area of the State University of Goiás, Campus de Ipameri, GO, Brazil, located at the geographical coordinates 17º43 'south latitude and 48º09' 'west longitude, and altitude of 820 m. The regional climate is classified as Cwa-Mesothermic Humid, with precipitation and the average annual temperature of 1750 mm and 25ºC, respectively. The climatic data referring to the period of conduction of the experiments are shown in Supplementary Figure 1.

The soil of the experimental area is classified as a dystrophic Red Latosol (eq. Oxisol). The results of the physico-chemical analysis of the 0-20 cm layer are shown in Supplementary Table 1.

Experimental design and treatments

A randomized block design was used in a 2 x 4 + 1 factorial scheme with three replications. The treatments consisted of the combination of two post-emergent herbicides applied: (A) fluzifop-p-butyl + fomesafen (125 + 125 g ai L^{-1}) and (B) bentazon + imazamox (600 + 28 g ai L^{-1}), in four dosages (0.5; 1.0; 2.0 and 4.0 L ha^{-1}) of the respective commercial products, plus a control portion (conducted under weed competition).

Plant material

The cultivar of Pérola beans from the Carioca group was used from semi-erect to prostrate position of indeterminate growth habit and type II / III and cycle between 85 and 90 days (Embrapa, 2021b). The castor cultivar used was BRS Paraguaçu, with tall plant architecture (± 1.60m), with semi-fresh fruits and seeds with an oil content of 48%, with a cycle ranging from 230 to 250 days (Embrapa, 2021a).

Conduction of study

The experimental units consisted of plots in an intercropping system consisting of four lines of beans between the lines of the castor with 5.0 m long and 3.0 m wide in the lines of beans the spacing of 0.5 m between lines was adopted.

The soil preparation was carried out in a conventional manner, with plowing and two harrows, as well as basic fertilization carried out according to the soil analysis and recommendation by Cfsemg (1999), using 400 kg ha^{-1} of the formulated 04-30-16 (NPK). Castings of castor and beans were carried out simultaneously and manually, on 11/25 and 11/20, respectively, in the 2013/2014 and 2014/2015 seasons. At sowing, 25% more seeds were used, and 10 days after emergence (DAE) the plants were thinned to reach castor bean and bean densities of 1 and 12 plants per meter, respectively. At 25 DAE of the bean crop, the covering fertilization was performed with 40 kg ha^{-1} of nitrogen (urea), along the crop lines. Phytosanitary treatments were carried out according to the needs of the crops.

The herbicides were applied at 22 DAE of the crops, when the weeds reached the initial stage of development, with three to four leaves in grasses and two leaves for broad-leaved species. The backpack sprayer pressurized with CO_2 was used, calibrated to apply 200 L ha^{-1} of syrup, containing adhesive spreader Assist at a concentration of 0.5% of the syrup volume. To prevent drift, plastic tarps were used on the sides of the plots at the time of application.

Traits measured

Bean harvest was carried out on 02/19/2014 and 02/16/2015 in 2014 and 2015, respectively. Initially, 10 plants were harvested in the plot's useful area to determine yield components (number of pods per plant, number of grains per pod and weight of 100 grains). Subsequently, the remaining plants of the plot were harvested and tracked to determine grain yield, taking into account 13% moisture. The analysis of the bean production components was necessary, since the evaluated doses are much higher than those registered for use in the crop. The castor bean harvest was carried out in May of the aforementioned years, making the transfer in the subsequent months until July. In castor bean, the components were quantified (number of racemes per plant, number of berries per raceme and weight of 100 grains). Berry productivity was obtained by harvesting and trailing the rest of the plants in the plot's useful area, considering 10% moisture in the grains.

Statistical analysis

The data referring to the agronomic components of the castor bean and common bean crops in the intercropping systems in the two harvests were initially submitted to individual variance analysis. Subsequently, joint analysis of variance was performed on the common characteristics of both experiments based on Banzatto and Kronka (2006). When appropriate, a Scott-Knott test at 5% probability was used to discriminate the effects of crops and herbicides, and regression analysis to discriminate the effect of doses. All data were submitted to analysis using the statistical software Sisvar 5.3 (Ferreira, 2010).

Conclusion

The intercropping of castor beans with beans is a good management alternative, especially for family farming. This cultivation system is interesting because it allows the diversification of income on the property, in addition to the better use of the soil during the year. For the management of weeds in intercropping, the fluazifop-p-butyl + fomesafen and bentazon + imazamox herbicides are efficient for the intercropping of castor and beans. Weed competition causes losses in productivity up to 65.5% in the crop of beaver and 71.87% in the crop of beans when intercropped. The herbicides demonstrate selectivity for BRS Paraguaçu castor crop, with higher productivity under doses of 612.25 g ai ha^{-1} and 1506.4 g ai ha^{-1} of the fluazifop-p-butyl + fomesafen and bentazon + imazamox herbicides, respectively.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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