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Agronomic performance of kidney bean and castor bean cultivars in intercropping and monocropping systems under weed competition

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Abstract

Castor bean is becoming a major industrial crop in Brazil. Weed management is a castor bean large-scale production issue due to lack of registered herbicides in Brazil. It was hypothesized that intercrops with kidney bean and castor bean could not only provide nitrogen to castor, but reduce weed pressure and, consequently, reduce herbicide purchase costs. This research aimed to determine weed community influence on kidney bean and castor bean intercropping and monocropping cultivars agronomic traits under soil and climate conditions of the Southeast region of the State of Goiás, Brazil. The experimental design was a randomized block design with factorial arrangement of 3 × 2 × 2 + 10, with three replications. The treatments consisted of three bean cultivars with different growth types (Pérola = type II/III; Pontal = type III; Estilo = type I) and two castor cultivars with different sizes (Guarani = medium and Paraguaçu = tall), combined with two types of weed handling: manually weeded area (without weeds infestation throughout the cultivar cycle) and unweeded area (with weeds infestation throughout the cultivar cycle) in intercropping, in addition to involved crops monocropping treatments, with and without weeding. Weed infestation during the cropping cycle caused a yield decrease of around 32% and 67% for bean and castor, respectively. Pontal, Pérola and Estilo kidney bean cultivars, and Guarani and Paraguaçu castor bean cultivars showed potential for intercropping. The use of kidney bean intercropping with castor bean under weed handling was more efficient than monocropping of both, regardless of researched genetic materials. The intercropping system enabled bean and castor yield of around 1.328 Mg ha^{-1} and 1.827 Mg ha^{-1}, respectively, in areas that were kept free from weed competition, regardless of cultivar.

Keywords: Intercropping; *Phaseolus vulgaris*; *Ricinus communis*; weeds; competition; yield.
Abbreviations: DAE_days after emergence, LER_Land equivalent ratio, C.V._ coefficient of variation.

Introduction

Intercropping consists of more than one crop growing in the same area, where plants coexist throughout the whole period or at least during a part of their cycle (Ferreira et al., 2014). In a resource-limited area, vegetables intercropping may not only improve crop productivity, through resources efficient utilization, but may also control weeds, pests and soil erosion, besides enhancing soil fertility (Jensen et al., 2010).
Kidney bean is the main protein source of classes with limited economic power, especially in some countries of South-Central America (FAO, 2013). Kidney bean, as wrll as other vegetables, can add N to the soil via N fixation. Kidney bean is often regarded as a suitable companion crop in intercropping systems due to its non-aggressive and short growth cycle (Dawo et al., 2009). Castor bean is a plant of African origin which is tolerant to adverse climatic conditions of tropical countries, such as India, China, Brazil and Mozambique, which are responsible for 96% of the world production (Severino and Auld, 2014). Castor bean seeds are rich in oil content with various industrial and medicinal uses, such as in biodiesel production (Ogunniyi, 2006; Silva et al., 2006). Growers often sell the seeds to the chemical industry and incorporate the residue to the soil to improve soil carbon (Podgaiski et al., 2010), but it is also used in the phytoremediation of soils contaminated with heavy metals and agricultural pesticides (Olivares et al., 2013). Castor oil has more than 700 applications in the most diverse sectors, and is used in the manufacturing of lubricants, cosmetics, medicines and chemical applications. In addition, it has also been proposed as a potential source of biodiesel due to the high oil content of its seeds, which confirms its socioeconomic importance. (Silva et al., 2006).
Although castor bean cultivation is considered by the Brazilian federal government as the main source for biodiesel production, it faces difficulties in the adoption of available technologies due to low availability of genetic material on the market associated with the lack of registered herbicides for weed control. Heat, whose chemical composition is: N '{2–chloro– 4–fluoro–5–[1,2,1,3,6–tetrahydro–3–methyl–2,6–dioxo–4 (trifluoromethyl)pyrimidin–1–yl]benzoyl}–N–isopropyl–N–methyl–sulfamide, is the only registered herbicide in Brazil that can be used to control weeds in castor bean (MAPA, 2014), having difficulty in controlling weeds.
Weed interference in the referred crops can happen through direct forms, by competition for growth resources (water, light, CO_2 and nutrients), allelopathy promotion, harvest interference and cultivation practices hampering, or by an

indirect form, by hosting plagues and diseases (Epperlein et al., 2014). Weeds pose as a serious problem for cultivation due to the low competitiveness of kidney bean, mainly the upright and low-branched genotypes of type I and II, with growth habits being less competitive (Teixeira et al., 2008). On the other hand, type III genotypes, which are the most cultivated, promote a higher soil covering (Blair et al., 2013), thus having higher competitive power against weeds. In this sense, the bean plant growing of type III can reduce the problems with weeds in intercropping system. According to Salgado et al. (2007), depending on factors related to the environment and weed community conditions, the bean yield decrease can reach 80%. However, intercropping use may reduce the problems with weeds, as seen in the study by Midega et al. (2014), in which control effectiveness of *Striga hermonthica* parasitic weed in a cultivation area of corn intercropped with six species of leguminous plants, including crotalaria (*Crotalaria ochroleuca*), cowpea (*Vigna unguiculata*), kidney bean (*Phaseolus vulgaris*), greengram (*Vigna radiata*), groundnut (*Arachis hypogaea*) and greenleaf desmodium (*Desmodium intortum*) in relation to a corn monocropping area was verified. This study aimed at determining the influence of the weed community on the agronomic traits of intercropping and monocropping cultivars of kidney bean and castor bean under the soil and climate conditions of the Southeast region of the State of Goiás, Brazil.

Results and Discussion

Kidney bean intercropped with castor and monocropping

The analyzed agronomic traits kidney beans intercropped with castor bean and in monocropping were significantly influenced by the presence or absence of weed competition (with and without weeding). On the other hand, castor cultivars on intercropping had no influence on the agronomic traits of beans. Kidney bean plants final stand was influenced only in intercropping system and under weed competition during the whole crop cycle. Nevertheless, the plant population final average of the three studied cultivars was of around 10 plants per meter (3A), being, therefore, close to the normally recommended value for beans, which is 12 plants per meter. It should be noted that even with this plant population per area value being lower than the recommended value, the kidney bean plant has the capacity to compensate the existing empty spaces. Thus, the final stand had no influence on the other evaluated agronomic traits. Pérola and Estilo cultivars showed a higher reduction in the number of pods than the Pontal cultivar in the treatments under competition with the weed community, when compared with weeded treatments (Fig. 3B). The lower competitive ability of these cultivars with weed is related to the fact that Pérola and Estilo cultivars belong to the growth types II/III, while the Pontal cultivar belongs to type III, with higher competitive potential thanks to its larger ramifications and prostrate canopy architecture, making microclimate conditions unfavorable to weeds growth and development (Blair et al., 2013). It must be emphasized that pods number is the component that is most closely related to kidney bean seed yield (Nemli et al., 2013), which is thus most susceptible to environment conditions, such as weed competition.

The other yield components, number of seeds per pod and hundred seed weight, were only influenced by the cultivars, although being genetic traits that are little influenced by environment factors. Estilo and Pérola cultivars showed the highest decrease in the number of seeds per pod, regardless of weed handling (Fig. 3C). The elimination of the weed community produced heavier seeds for all researched cultivars, while the lightest seeds were found in the treatments that kept weeds in competition with kidney bean plants during the whole cycle (Fig. 3D). The highest averages of the number of seeds per pod and hundred seed weight were verified for the Pontal cultivar, with respective values of 5.0 and 27 grams in the weeded plots. On the other hand, the lowest averages of yield components, number of seeds per pod and hundred seed weight were verified in the Pérola kidney bean cultivar under weed competition. Such results confirm the importance of keeping kidney bean cultivation free from weed competition, regardless of cropping system. For beans in monocropping, only the number of pods per plant component was influenced by the weed handling system; with the highest averages being obtained in the environment that was free from weed competition for the three evaluated cultivars (Fig. 4A). Taking into account the number of seeds per pod and hundred seed weight, kidney bean genotypes had a distinct behavior, with the highest averages being observed for the Pontal cultivar. The Pérola and Estilo cultivars have not differed statistically, both with and without weed competition (Figs. 4B and C). The significant effect on the number of pods per plant may be attributed to the influence of cultivation medium factors, whereas the number of seeds per pod and hundred seed weight are predominantly influenced by the genetic part. Kidney bean cultivars seed yield differed between treatments. The highest bean yield averages were obtained in the weeded areas, both in intercropping (Fig. 5A) and in monocropping (Fig. 5B) regardless of studied genetic materials. On the other hand, the lowest yield was obtained in the areas where kidney beans were intercropped with castor beans and in the bean monocropping area, without weeding. Such results confirm the hypothesis that, regardless of the cropping system, it is important to keep crops free from weed competition to get higher yield levels. In the specific case of the kidney bean plant, yield loss due to weed competition was higher than for castor bean, reaching a decrease rate of 32% in comparison to the weeded areas in both crop systems. However, this decrease rate was lower than the rate normally found in studies about beans under weed competition, which is close to 80% (Salgado et al., 2007). Such difference may be related to factors of the crop itself, of the medium conditions and of the weed community prevailing in the area. However, in the intercropping system, weeds influence was softened due to the shading caused by the castor plant, since kidney bean yield difference in this system was lower than in monocropping, which produced higher differences. Although kidney bean seed yield was lower in the intercropping system than in the monocropping, it was higher than the monocropping kidney bean seed yield national average, which was of 910 kg ha^{-1} in 2012/2013 (CONAB, 2014). Therefore, intercropping can guarantee good profit for farmers who use intercropping kidney beans and castor beans.

***Castor bean intercropped with Kidney bean in* monocropping**

Castor bean agronomic traits, such as number of racemes per plant and seed yield were influenced by cultivars and weed handling in intercropping and in monoculture. Number of capsules per raceme and hundred seed weight were influenced by weed handling in intercropping and in monoculture. Neither cultivars nor weed management had significant influence on plant height, stem diameter and stand. The number of racemes per castor bean plant was

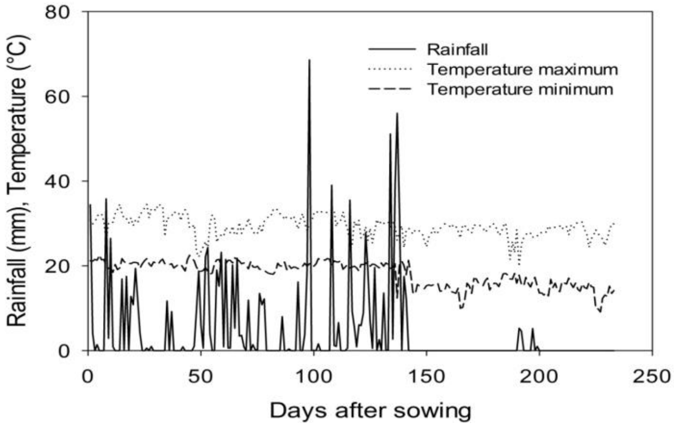

Fig 1. Field daily climate data during the intercropping/monocropping cycle of kidney bean and castor bean plants, referred to the maximum temperature and minimum temperature in degrees Celsius (°C), and rainfall in millimeters (mm) for Ipameri (State of Goiás, Brazil). Source: NATIONAL INSTITUTE OF METEOROLOGY – INMET, BRAZIL.

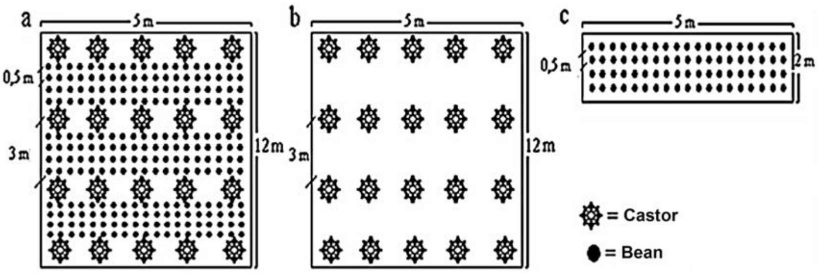

Fig 2. Schematic picture of intercropping between castor bean and kidney bean between lines (a), castor bean (b) and kidney bean (c).

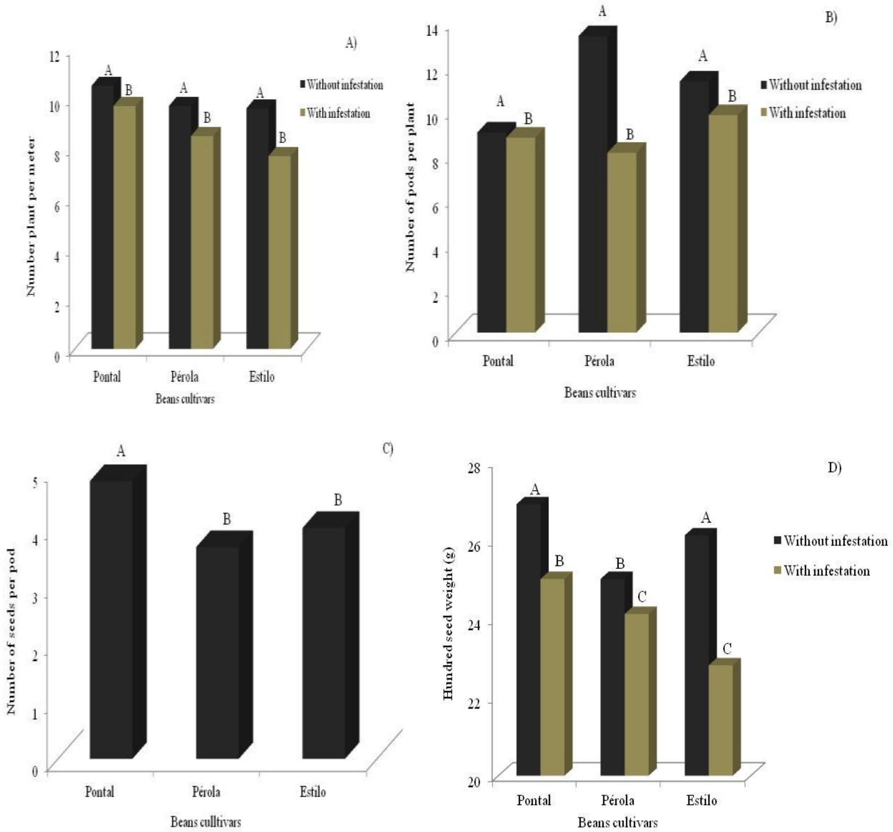

Fig 3. Final stand - C.V. (%): 18.7 - (A), number of pods per plant - C.V. (%): 22.5 (B), number of seeds per pod - C.V. (%): 11.6 (C) and hundred seed weight - CV (%): 7.8 (D) of common bean plant intercropping with castor bean, with and without weed competition.

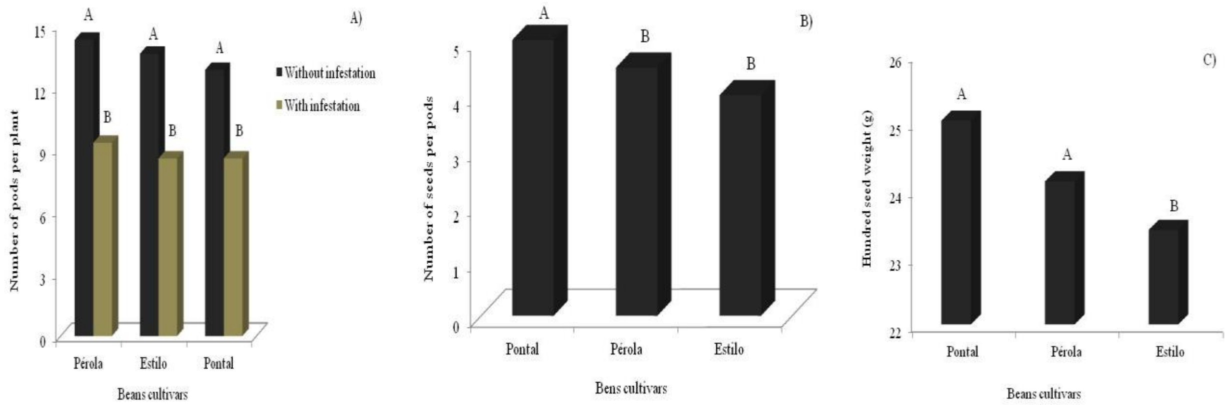

Fig 4. Number of pods per plant - CV (%): 33.8 (A), number of seeds per pod - CV (%): 11.7 (B) and hundred seed weight - CV (%): 7.9 (C) of kidney bean plant in monocropping , with and without weed competition.

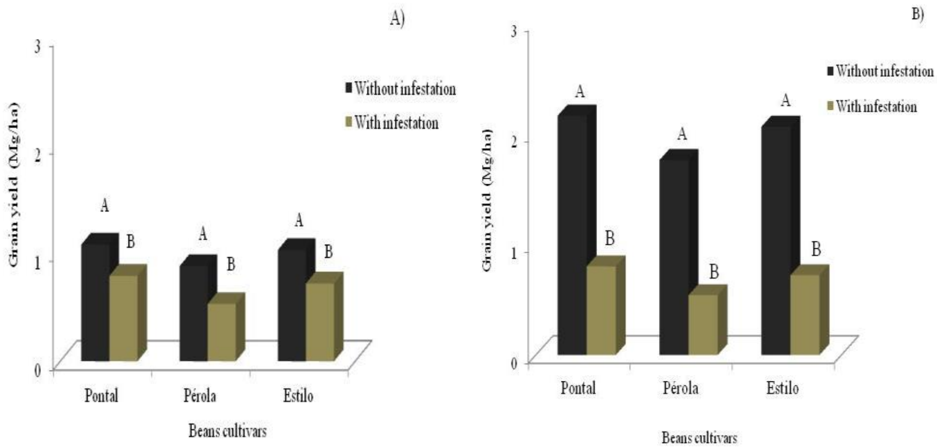

Fig 5. Grain yield of beans intercropping with castor bean- C.V. (%): 30.1 (a) and in monocropping - C.V. (%): 9.6 (b), with and without weed competition.

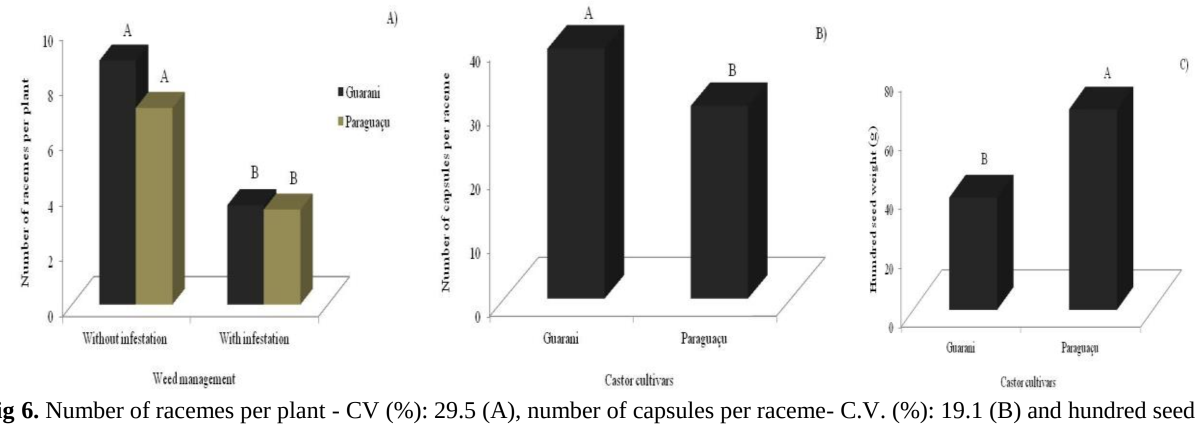

Fig 6. Number of racemes per plant - CV (%): 29.5 (A), number of capsules per raceme- C.V. (%): 19.1 (B) and hundred seed weight - CV (%): 18.8 (C) of castor bean intercropping with kidney bean, with and without weed competition.

higher in weeded areas than in unweeded areas in intercropping, not considering the studied cultivars. When plots were weeded, the number of racemes per plant in Guarani and Paraguaçu cultivars were 9.7 and 8.0, respectively. A 50% reduction in number of racemes per plant was observed for both cultivars when weed control has not occurred (Fig. 6A). The number of capsules per raceme average of the Guarani cultivar in intercropping was higher than that of the Paraguaçu cultivar (Fig. 6B), regardless of weed management. There were significant differences between hundred seed weight of the two cultivars in intercropping. Paraguaçu produced heavier grains, with average hundred seed weight of 79g, while the hundred seed weight of the Guarani cultivar was of 43g (Fig. 6C). The results of castor bean monocropping are in line with those of kidney beans intercropping, where the highest averages of

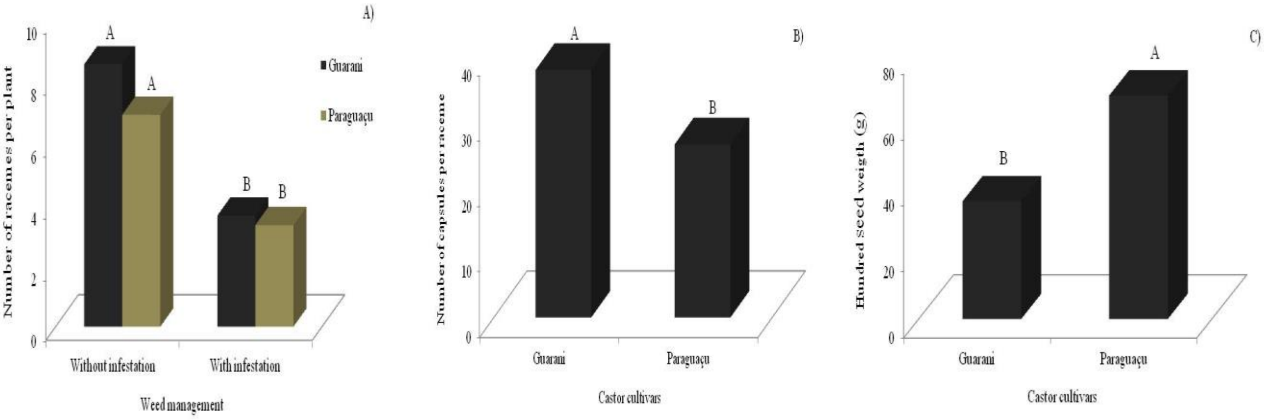

Fig 7. Number of racemes per plant - CV (%): 22.7 (A), number of capsules per raceme - C.V. (%): 14.9 (B) and hundred seed weight - CV (%): 9.8 (C) of castor bean in monocropping, with and without weed competition.

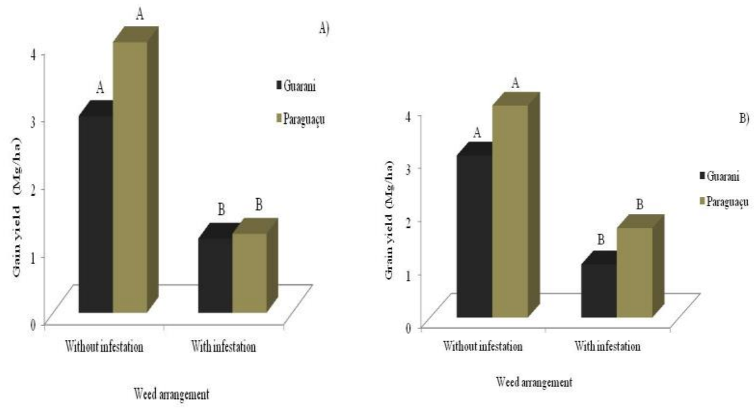

Fig 8. Grain yield of castor bean intercropping with common bean - C.V. (%): 16.8 (A) and in monocropping - C.V. (%): 15.8 (B), with and without weed competition.

number of racemes per plant were found in weeded areas, with statistically different values between the Guarani and Paraguaçu cultivars (Fig. 7A). The Guarani cultivar produced more capsules per raceme than the Paraguaçu cultivar, both with and without weed competition (Fig. 7B). The Paraguaçu cultivar produced larger and heavier seeds than the Guarani cultivar (Fig. 7C), regardless of the system of weed handling, which had no significant influence on this trait. The results of castor bean intercropping with beans or in monocropping confirm, at least in part, that castor bean is sensible to weed interferences, especially in the initial phases, when its development is slow. It must be highlighted that, apparently, the number of racemes per plant was castor bean agronomic trait that was most directly related to crop yield. The highest yield for castor bean was recorded from weeded plots (1.827 kg ha^{-1}) when intercropped with kidney beans (Fig. 8A), which was of 1.923 kg ha^{-1} for castor bean monoculture (Fig. 8B), disregarding castor cultivars. Thus, it may be observed that castor bean is influenced by weed competition, both intercropping with kidney bean and in monoculture. Coexistence with the weed community promoted a strong castor bean yield decrease, with percentages of 67% to 69%, in intercropping and monoculture, respectively, when compared to plots without weed competition, regardless of planted cultivars (Fig. 8A and B). Moreover, it can be concluded that castor cultivation in the Southeast region of the State of Goiás showed high yield, regardless of cultivar and cropping system, which resulted in a surpass of up to four times the yield of this oil-producing plant in the State of Bahia - 646 kg ha^{-1}, which is the largest producer in Brazil, and getting the same average as for the State of São Paulo – 1.848 kg ha^{-1}, which has the highest average in Brazil (CONAB, 2014).

Materials and Methods

Experimental site

The experiment was conducted between November 2012 and August 2013 at the experimental farm of Goiás State University, Ipameri (17º43'S and 48º10''W). The municipality elevation is of 772 m and the regional climate is classified as humid Cwa-mesothermal, with an average annual rainfall of 1278 mm and temperature of 24ºC (75 F) (INMET, 2014). The climate data of the period in which the crops were cultivated are presented in Fig. 1. Soil samples were collected from the top 20 cm of the experimental site. Soil had the pH of 6.1; P (cmol$_c$ dm^{-3}) = 2.1; K^+ (cmol$_c$ dm^{-3}) = 72; Ca^{2+} (cmol$_c$ dm^{-3}) = 4.5; Mg^{2+} (cmol$_c$ dm^{-3}) = 1.5; Al^{3+} (cmol$_c$ dm^{-3}) = 0.1; H^++Al^{3+} (cmol$_c$ dm^{-3}) = 5.5; V (%) = 61; B (mg dm^{-3}) = 0.3; Cu (mg dm^{-3}) = 1.8; Fe (mg dm^{-3}) = 175.0; Mn (mg dm^{-3}) = 16.5; Zn (mg dm^{-3}) = 3.7; organic matter (g kg^{-1}) = 1.7; sand (g kg^{-1}) = 315; silt (g kg^{-1}) = 153 and clay (g kg^{-1}) = 532.

Experimental design and treatments

The experimental design was of randomized block design with factorial arrangement of 3 x 2 x 2 + 10, with three replications. The treatments consisted of three kidney bean cultivars with different growth types (Pérola = type II/III; Pontal = type III; Estilo = type I) and two castor bean cultivars with different sizes (Guarani = medium and Paraguaçu = tall), combined with two types of weeds handling: manually weeded area (without weeds infestation throughout the cultivar cycle) and unweeded area (with weeds infestation throughout the cultivar cycle) in intercropping, in addition to involved crops monocropping treatments, with and without weeding. In the weed control treatment, weeds were controlled every 15 days in the weeded plots, until complete canopy closure.

Culture management practices

Soil preparation was conventional, with one plowing and two harrowing cycles, with subsequent furrow opening for sowing. Basic fertilization was performed with the respective dosages of 320 kg ha^{-1} for kidney bean and 400 kg ha^{-1} for castor bean, using the 05-25-15 formula, both in intercropping and monoculture. Castor bean and kidney bean were sown simultaneously and manually in the furrows on 25/11/2012. Twenty five percent extra seeds were used and plant thinning was carried out at 10 days after emergence (DAE), with the aim of reaching castor and bean density of 1 and 12 plants per meter, respectively. Pérola, Pontal and Estilo castor bean cultivars had their normal cycles, i.e., varying between 85 and 95 days. The Pérola cultivar has a production potential of 3.903 Mg ha^{-1}. Its plant architecture is semi-erect, not suited for mechanical harvesting, although this is the process in practice. The Pontal cultivar has a production potential of 4.271 Mg ha^{-1}. Its plant architecture is prostrate, which is not suited for mechanical harvesting because of its intense lodging. The Estilo cultivar has a production potential of 4.011 kg ha^{-1}. Its plant architecture is upright, which is suited for mechanical harvesting (EMBRAPA, 2013). The Paraguaçu castor bean cultivar has a production potential that is higher than 1.200 Mg ha^{-1} for capsules. Its plant architecture is tall, its fruits are semi-dehiscent and the cycle varies between 230 and 250 days. The Guarani cultivar has a production potential of 2.500 Mg ha^{-1}. Its plant architecture is medium, its fruit is indehiscent and the cycle is of 180 days (EMBRAPA, 2014). Castor plots intercropping consisted of four rows of 5.0 m length, spaced 3.0 m apart. The space between the castor bean lines was allocated to four kidney bean rows, spaced 0.5 m apart. Castor bean monoculture plots consisted of four lines of five m, spaced 3.0 m apart; for kidney bean, four plant rows of five m length, spaced 0.5 apart were used (Fig. 2). Both in intercropping and monoculture, the two central lines of each plot were considered as harvest area (Fig. 2). 25 days after emergence (DAE), both crops had topdressing fertilizations with urea at a dose of 30 kg ha^{-1} and 40 kg ha^{-1} of N in a continuous band along the planting lines for kidney bean and castor bean, respectively. Leafcutter ant control was conducted with fipronil-based granulated baits in both cultures. The handling of the pea leafminer (*Liriomyza huidobrensis*) in the kidney bean and castor bean cultures was carried out with abamectin at a dose of 0.5 L ha^{-1}. The silverleaf whitefly (*Bemisia tabaci*) in the kidney bean was controlled with acetamiprid-based products at a dose of 0.3 kg ha^{-1}, thiametoxam at a dose of 0.2 kg ha^{-1} and pyriproxifen at a dose of 0.25 L ha^{-1}. The cucurbit beetle (*Diabrotica speciosa*) in the kidney bean was controlled with deltamethrin at a dose of 0.03 L per 100 liters of water. Prevention of white mold (*Sclerotinia sclerotiorum*) in the kidney bean was carried out through thiopahanate-methyl at a dose of 1 kg ha^{-1}, and of anthracnose (*Colletotrichum lindemuthianum*) and (*Phaeoisariopsis griseola)* through protioconazol + trifloxystrobin, at a dose of 0.5 L ha^{-1}. There was some incidence of *(Amphobotrys ricini*) in the castor bean, but with low severity, and the attack was concentrated at the end of the cycle, therefore not requiring chemical control.

Evaluated traits

Kidney bean plants were harvested on 02/25/2013, and harvested plants were threshed to determinate seed yield, taking into account 13% moisture content. Plot stand and grain yield components were also determined, such as the number of pods per plant, the number of seeds per pod and hundred seed weight. The components were determined using 10 plants taken randomly from the plots harvested area. Castor harvesting began on 05/14/2013 and ended on 07/15/2013, being divided into three harvests. In the usable area, the capsule yield and the plant's components were quantified: number of racemes per plant, number of capsules per raceme and hundred seed weight, plant height, stem diameter and stand.

Statistical analysis

Kidney bean and castor bean agronomic traits data were submitted to the analysis of variance with F-test, and the averages of the treatments were compared with the Tukey test, at 5% probability. The SAEG version 9.0 software was used to carry out the statistical analyses (Ferreira, 2011).

Conclusions

Weed infestation during the cropping cycle caused a yield decrease of around 32% and 67% for kidney bean and castor bean in intercropping, respectively. Pontal, Pérola and Estilo kidney bean cultivars, and Guarani and Paraguaçu castor bean cultivars showed potential for intercropping. The use of kidney bean intercropping with castor bean under weed handling was more efficient than monocropping for both, regardless of researched genetic materials. Intercropping enabled kidney bean and castor bean yield of around 1.328 kg ha^{-1} and 1.827 kg ha^{-1}, respectively, in areas that are free of weed competition, for all cultivars.

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