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Management of top-dressed nitrogen fertilization in the common bean/castor intercropping system

Rafael Batista Ferreira[1], Itamar Rosa Teixeira[2*], Elton Fialho dos Reis[1], Alessandro Guerra da Silva[2], Gisele Carneiro da Silva[3]

[1]State University of Goiás, Unity of Anápolis, 75001-970, Anapólis-GO, Brazil
[2] University of Rio Verde, Department of Agronomy, 75901-970, Rio Verde-GO, Brazil
[3]Federal University of Goiás, Department of Agronomy, 74001-270, Goiânia-GO, Brazil

***Corresponding author: itamar.texeira@ueg.br**

Abstract
Among essential mineral nutrients, nitrogen is the one that most limits crop growth and development, since plants need fairly high quantities of it. The objective of this work is to evaluate the splitting form of top-dressed N for intercropped common bean and castor cultivars. We used the randomized block design with factorial arrangement of two cultivation years (2009/10 and 2010/11), two common bean cultivars (Pontal and Pérola), two castor cultivars (Energia and Paraguaçu), combined with six forms of top-dressed nitrogen fertilization splitting: without application; 100 kg ha^{-1} applied at 25 days after emergence (DAE); 100 kg ha^{-1} applied at 35 DAE; 30 and 70 kg ha^{-1} applied at 25 and 35 DAE, respectively; 70 and 30 kg ha^{-1} applied at 25 and 35 DAE, respectively; 50 and 50 kg ha^{-1} applied at 25 and 35 DAE, respectively. Extra treatments consisted in the planting of the four studied cultivars in monoculture. The agronomic traits of common bean cultivars Pérola and Pontal are influenced by intercropping with castor. On the other hand, common bean cultivars did not exert any influence on the agronomic behavior of the intercropped castor, regardless of the genotype used. The optimum dose of top-dressed nitrogen in the common bean and castor intercropping system is 30 and 70 kg ha^{-1}, split at 25 and 35 DAE of the mentioned crops. The common bean/castor intercropping system is more efficient than monoculture, according to LER average value (1.64).

Keywords: *Phaseolus vulgaris* L.; *Ricinus communis* L.; intercropping; mineral nutrition; nitrogen.
Abbreviations: DAE_days after emergence, RNA_Ribonucleic acid, DNA_Deoxyribonucleic acid, ATP_Adenosine triphosphate, Rubisco_Ribulose-1,5-bisphosphate carboxylase/oxygenase, LER_Land equivalent ratio.

Introduction

Common bean (*Phaseolus vulgaris* L.) cultivation is of great importance in developing countries of the tropics, due to social issues related to its role in human diet, for being an exploitation alternative in rural properties, and demanding a less skilled workforce (Vieira, 2006). However, its productive base is in the small farm, where it is mainly cultivated in intercropping system. Castor (*Ricinus communis* L.) is an important oilseed crop grown in tropical regions, used as a source for biofuel. China, India, Brazil and Mozambique currently produce around 1.5 million tons, accounting for 96% of world production (Severino and Auld, 2014). With the launching of the National Program of Biodiesel Production and Use (PNPB = Programa Nacional de Produção e Uso de Biodiesel), the Brazilian government caused paradigmatic changes in family farming, encouraging oilseed cropping, like the cultivation of castor. However, that species has a long cycle and needs a fairly large spacing between the lines, which creates problems with weeds and lack of soil reconstitution due to lesser vegetation cover, which can be mitigated by intercropping with other crops (Teixeira et al., 2011). Intercropping is common in tropical regions, especially in small farms. However, the real advantage of this technique in relation to monoculture becomes more evident when the involved crops have different requirements regarding available resources, in quality, amount and season of demand (Jesen et al., 2010; Obiero et al., 2014). Successful intercropping requires knowledge of the production physiology of the combined crops, a knowledge that can be obtained from their physical, chemical and biological responses to management (Lithourgidis et al., 2011). One of the many aspects of intercropping is the fertilization of the involved crops. Interaction can modify the nutrient demand of the combined crops. Most studies of fertilization in intercropping use nutrient doses recommended for monoculture. As to top-dress fertilizer in common bean/castor intercropping, it is carried out either only for castor, considered as the main crop (Oliveira, 2004), or separately for each crop (Corrêa et al., 2006). In both cases, they follow fertilization recommendations for monoculture, i.e. monoculture, available in literature. The recommended nitrogen doses for monocropped bean and castor in tropical conditions like Brazil vary between 80 and 100 kg ha^{-1}, half of it being applied by the time of sowing, and the other half being top-dressed between 25 and 35 days after emergence of the mentioned crops (Cfsemg, 1999; Chagas et al., 1999). Nitrogen is essential to plants and can cause critical influence on most of their physiological processes, such as photosynthesis, respiration, root growth and activity, uptake of other nutrient ions, formation of protein, amino acids, enzymes, RNA, DNA, ATP, chlorophyll. It is also very important for plant metabolism (Marschner, 1995). Lack of nitrogen delays the initial growth of the plant by making carbon uptake impossible. As the plant grows, the lack of nitrogen might limit the regeneration of existing RuBisCO (Epstein and Bloom, 2005). Moreover, most soils do not have enough available nitrogen to support the desired development levels (Below, 2002). It has usually been recommended to split nitrogen fertilization in order to increase N efficiency or to prevent eventual loss by volatilization and, especially, leaching (Kluthcouski et al., 2009). In the Mid-West region of Brazil, where castor cultivation is still emergent, there is no information on the subject, and in some situations, recommendations of monoculture fertilizations are generalized, without real knowledge of the farming demand in the edaphoclimatic conditions that prevail in the region aforementioned. So the objective of this work is to evaluate the splitting form of top-dressed N for different common bean and castor intercropped cultivars in a two-year cultivation.

Results

Common bean agronomic traits

Values of number of pods per plant, number of seeds per pod, hundred seed weight, seed yield and plant height of intercropped common bean were higher for 2010/11 than for 2009/10 (Table 1). Pérola bean cultivar generally presented heavier seeds than Pontal, especially in the splitting forms which used doses of N of 100:0 and 30:70 kg ha^{-1} and in the control (Table 2). The splitting form of 30:70 kg ha^{-1} of N was responsible for the highest mean of hundred seed weight for both studied bean cultivars. The highest seed yield was of 1249 kg ha^{-1} in 2009/10 and of 1480 kg ha^{-1} in 2010/11 with top-dressed N applied in the form 30:70 kg ha^{-1}. The non-application of N caused lower seed yield of the intercropped bean plant for both cultivation years.

Castor agronomic traits

The values of number of racemes per plant, number of fruits per raceme, hundred seed weight, seed productivity and plant height for castor intercropped with bean were higher in 2010/11 than in 2009/10 (Table 3). Energia cultivar produced more fruits per raceme - 17.95, than Paraguaçu cultivar – 7.63 (Table 3). However, Paraguaçu presented higher number values of racemes per plant, hundred seed weight, seed productivity and plant height. 30:70 and 50:50 kg ha^{-1} splitting forms of top-dressed nitrogen provided higher number values of racemes per plant and seed productivity than the other forms, while 30:70 kg ha^{-1} N splitting form provided a higher number value of fruits per raceme, hundred seed weight and plant height. The non-application of top-dressed N resulted in lower values of all evaluated agronomic traits of castor (Table 3). Energia cultivar produced more fruits per raceme than Paraguaçu cultivar, both in 2009/10 and in 2010/11 (Table 4). On the other hand, the highest number values of racemes per plant, hundred seed weight and plant height were found for Paraguaçu cultivar in 2010/11, with means of 14.17, 66.22 g and 3.26 m, respectively. As for the interaction between the factors castor cultivar x splitting form of top-dressed nitrogen, it turns out that the highest number values of racemes per plant, hundred grain weight and plant height were found for Paraguaçu cultivar in intercropping, regardless of the N splitting form (Table 5). The number of racemes per plant was higher with application of 30:70 and 50:50 kg ha^{-1} of N for Paraguaçu cultivar and with application of 30:70 kg ha^{-1} of N for Energia cultivar. The opposite effect was observed for plant height. 30:70 and 50:50 kg ha^{-1} N fertilization splitting forms provided higher means of hundred seed weight for the two studied castor cultivars. The non-application of top-dressed N did not result in lesser number values of racemes per plant, hundred seed weight and plant height of castor intercropped with bean.

Land equivalence ratio

The biological evaluation of the cropping systems was studied by means of LER, showing that combining bean and castor in intercropping is beneficial for productivity, if compared to monoculture, for all evaluated factors, with values ranging from 1.61 to 1.67 (Table 6). Mean LER value of 1.64 obtained in the treatments shows that intercropping is 64% more efficient than monoculture. Moreover, it can be stated that a LER of 1.64 indicates that, in comparison with intercropping, an additional 0.64 ha of monoculture area of the investigated species is necessary to get the same productivity. Regarding LER of N splitting forms in intercropping, it is noteworthy that this system was again more effective than monoculture, since values ranged from 1.61 to 1.64, i.e. above 1.0.

Discussion

Common bean agronomic traits

Values of pod number per plant, number of seeds per pod, hundred seed weight, seed yield and height of the bean plant observed in intercropping for 2010/11 were higher than for 2009/10 (Table 1), which may be due to greater water availability (Figure 1). The bean plant productivity was higher in 2010/11 than in 2009/10 disregarding the splitting form of top-dressed N, which really confirms that higher water availability in the second year may have helped to reach higher productivity levels. As to the effect of the cultivation system on the agronomic traits of the bean plant, it can be observed that monoculture was responsible for obtaining higher average values of seed number per pod, hundred seed weight and seed yield than intercropped bean with castor (Table 1). The opposite occurred with the height of the bean plant. One can see a lower seed yield of the bean plant in intercropping - 950 kg ha^{-1} than in monoculture – 1758 kg ha^{-1}, which is justified by the competing potential of the intercropped cultivation (castor) on the bean plant, in agreement with the claim of Teixeira et al. (2011). However, we emphasize that the productivity levels obtained with the two systems called into question are above the Brazil average of 913 kg ha^{-1}, obtained in the 2012/13 harvest (Conab, 2014). Costa et al. (2010) and Teixeira et al. (2011) also noted that intercropping interfered in all agronomic traits of the bean plant, and that the most affected trait was the number of pods per plant, while the least affected were the number of grain per pod and hundred seed weight.

Castor agronomic traits

In 2010/11 the highest values of number of racemes per plant, number of fruits per raceme, hundred grain weight, grain yield and plant height to the crops of intercropped with castor/common bean were detected when compared with 2009/10 as described above for the common bean. Pérola bean cultivar, which has a more aggressive growth habit - Type II / III (Santos and Gavilanes, 2006), had no prominent influence on the growth and development of castor, neither did Pontal cultivar, which has a less aggressive habit, confirming that the legume oppugned is suitable for the intercropping system. The fact that Paraguaçu cultivar has

Table 1. Average values of number of pods per plant (NPP), number of seeds per pod (NSP), hundred seed weight (HSW), productivity (PROD) and plant height (HEIGHT) of intercropped bean with castor and monocropped castor, in function of cultivation year, cultivars and splitting form of N.

Cultivation year	NPP	NSP	HSW (g)	PROD (kg ha^{-1})	HEIGHT (m)
2009/10	15.75B*	4.14B	26.50B	870.61B	0.71B
2010/11	19.67A	4.90A	30.90A	1029.76A	0.85A
Bean cultivar					
Pontal	17.59A	4.48B	28.45B	943.61A	0.77A
Pérola	17.83A	4.56A	28.95A	956.76A	0.79A
N splitting (kg ha^{-1})					
Control	12.16F	3.84E	27.44D	530.30F	0.73B
100:0	16.25E	4.39D	28.04C	714.89E	0.75B
0:100	17.57D	4.53C	28.03C	800.28D	0.77B
30:70	22.29A	4.94A	31.18A	1364.55A	0.82A
70:30	18.55C	4.66B	28.36C	1106.66C	0.80A
50:50	19.44B	4.76B	29.15B	1184.42B	0.79A
Intercrop mean	17.71b **	4.52b	28.7b	950.18b	0.78a
Monocrop mean	24.67a	4.75a	31.32a	1758.53a	0.55b

* Means followed by the same lowercase letter in the column do not differ by the Scott-Knott test at 5% probability; ** Means followed by the same uppercase letter in the column do not differ by the Scott-Knott at 5% probability.

Table 2. Average values of hundred seed weight (HSW) and productivity (PROD) of the intercropped bean plant with castor and in monoculture, in function of the interactions bean cultivar x N splitting and cultivation year x N splitting.

Bean cultivar	HSW (g)					
	N splitting (kg ha-1)					
	Control	100:0	0:100	30:70	70:30	50:50
Pontal	26.86Bc	27.50Bc	27.80Ac	30.62Ba	28.63Ab	29.26Ab
Pérola	28.02Ab	28.58Ab	28.27Ab	31.73Aa	28.08Ab	29.04Ab
Cultivation year	PROD (kg ha^{-1})					
	N splitting (kg ha^{-1})					
	Control	100:0	0:100	30:70	70:30	50:50
2009/10	484.42Be	654.00Bd	736.3Bc	1249.08Ba	1018.50Bb	1081.33Bb
2010/11	576.20Af	775.79Ae	864.23Ad	1480.02Aa	1194.82Ac	1287.51Ab

Means followed by the same uppercase letter in the column and the same lowercase letter in the line do not differ according to Scott-Knott test at 5% probability.

had higher values of plant height (3.6 m) and number of racemes per plant partly justifies its superiority over Energia (1.56 m), in terms of agronomic traits. It is noteworthy that the greater growth of Paraguaçu cultivar in the climatic conditions of the "Cerrado" is due to larger water availability associated with good fertilization (especially nitrogen fertilization), since the soils of the region are known to be naturally nutrient poor. However, the fact that the castor plants reaching heights above 3.0 meters greatly complicates the harvesting process. Using BRS Nordestina castor cultivar, Silva et al. (2007) obtained the highest productivity with application of 80 kg^{-1} of top-dressed nitrogen in one time. Severino et al. (2006) evaluated the fertilization with macro and micronutrients in the cultivation of castor. They concluded that fertilization, especially nitrogen fertilization, led to increased productivity of Nordestina cultivar, and, like Silva et al. (2007), they found no increase in oil content as a result of nitrogen fertilization. The same research also found that there was a quadratic effect of the nitrogen doses on the number of capsules per plant, but there was no change in the number of bunches per plant. Agronomic traits of castor were not influenced by the cultivation system factor, since seed yield and its components showed similar behavior both in intercropping and in monoculture. According to Teixeira et al. (2011) such behavior may be attributed to the fact that common bean is not very competitive and does not restrain the development of intercropped castor plants. Such results corroborated several studies on intercropping involving the cultivation of bean, showing no danger for the productivity of the intercropped plant (Andrade et al., 2001; Flesch, 2002; Carvalho et al., 2007; Costa and Silva, 2008; Morgado and Willey, 2008; Teixeira et al., 2011; Viegas Neto et al., 2012), with improvement of the system because it is a legume that has a potential to replenish nitrogen present in the soil. The average seed productivity of castor intercropped with bean was 1108 kg ha^{-1}, and 1116 kg ha^{-1} in monoculture, i.e. very similar values, confirming the hypothesis that common bean does not affect the development of castor in intercropping system. In both cases, the aforesaid average productivities obtained in the cropping systems were above the national castor productivity in the last harvest in Mid-South Brazil, that is to say, in the Mid-West, Southeast and South Regions (805 kg ha^{-1}), showing that castor cultivation presents high productivity levels in the edaphoclimatic conditions of the Mid-West region, Brazil.

Land equivalence ratio

The results obtained here for LER agree with other researches where the cultivation of castor intercropped with other species proved to be more efficient than monoculture (Beltrão et al., 2010; Kumar et al., 2010; Teixeira et al., 2012). Furthermore, one can also notice that the intercropping of common bean did not reduce the productivity of the oil-producing plant in question. Besides, the superiority of the intercropping of bean with castor in relation to monoculture was confirmed, especially for small and medium farms, because it improves land usage and other available resources and, consequently, the life quality of the farmers, by increasing their income.

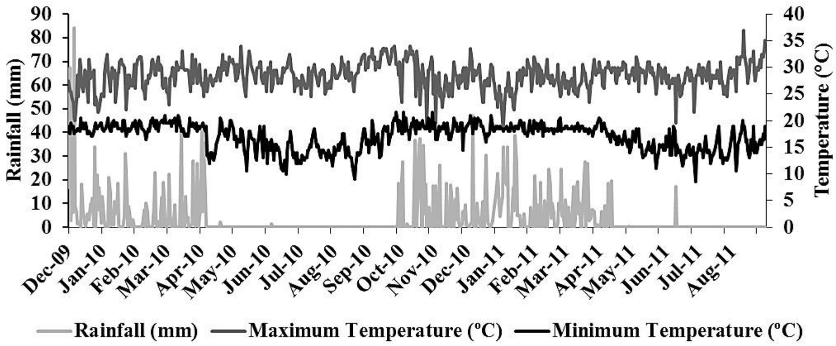

Fig 1. Daily climate data for rainfall in millimeters (mm), maximum temperature (Max. Temp.) and minimum temperature (Min. Temp.) in degrees Celsius (°C), measured during the cycle of bean and castor intercropping and monoculture in Anápolis (Goiás, Brazil) between December 2009 and August 2011.

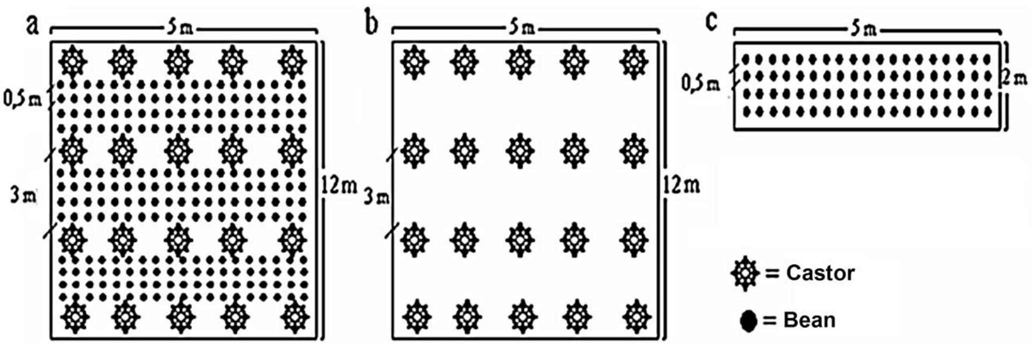

Fig 2. Diagrams illustrating the arrangement of castor lines with common bean intercropped between the lines (a), and of castor (b) and common bean (c) in monoculture.

Materials and Methods

General information

Experiments were carried out in two cultivation years, 2009/10 and 2010/11, in the period between December and August, at Emater Experimental Station in Anápolis (Goiás, Brazil). The area's geographic coordinates are: 17º43'19"S 48º09'35W. The municipality's average elevation is 820 m and the regional climate is classified as humid Cwa-mesothermal, with average annual rainfall of 1750 mm and temperature of 25ºC. Monthly climate averages of rainfall and temperature (maximum and minimum) in the two cultivation years can be seen in Fig. 1. In the 2009/10 harvest, samples of soil classified as dystrophic red-yellow latosol in the 0-20 cm layer were collected and sent to the laboratory for chemical-physical analysis, with the following results: pH (H_2O) - 6.1; P (Mehlich) - 5.14 mg kg^{-1}; K (Mehlich) - 0.58 mg kg^{-1}; Ca + Mg - 3.5 $cmol_c$ kg^{-1}; Al - 0.0 $cmol_c$ kg^{-1}; H+Al - 2.6 $cmol_c$ kg^{-1}; $CEC_{pH\ 7.0}$ - 6.68 $cmol_c$ kg^{-1}; V - 62%; organic matter - 21.7 g dm^{-3}; sand 275 g kg^{-1}; silt 176 g kg^{-1} and clay 549 g kg^{-1}. 2010/11 harvest's experiment was carried out in the same area in the previous year, with the following results for the chemical-physical analysis: pH (H_2O) - 5.9; P (Mehlich) - 5.1 mg kg^{-1}; K (Mehlich) - 0.58 mg kg^{-1}; Ca + Mg - 3.5 $cmol_c$ kg^{-1}; Al - 0.0 $cmol_c$ kg^{-1}; H+Al - 2.5 $cmol_c$ kg^{-1}; $CEC_{pH\ 7.0}$ - 6.67 $cmol_c$ kg^{-1}; V - 61%; organic matter - 22.7 g dm^{-3}; sand - 315 g kg^{-1}; silt - 153 g kg^{-1} and clay 532 g kg^{-1}.

Experimental design and treatments

We used the randomized block design with factorial arrangement of 2 x 2 x 2 x 6 + 4 extra treatments, with three replications. Treatments consisted of two cultivation years (2009/10 and 2010/11), two bean cultivars (Pontal and Pérola), two castor cultivars (Energia and Paraguaçu), combined with six splitting forms of top-dressed nitrogen fertilization: without application (control); 100 kg ha^{-1} applied at 25 DAE; 100 kg ha^{-1} applied at 35 DAE; 30 and 70 kg ha^{-1} applied at 25 and 35 DAE, respectively; 70 and 30 kg ha^{-1} applied at 25 and 35 DAE, respectively; 50 and 50 kg ha^{-1} applied at 25 and 35 DAE, respectively. Extra treatments consisted of the planting of both cultivars of bean and castor in monoculture, using a single dose of 40 kg ha^{-1} of top-dressed N at 35 DAE with urea as source.

Implementation and conduct

Castor intercropped plots consisted of four rows of 5.0 m length, spaced 3.0 m apart, the space being occupied by four bean lines spaced 0.5 m apart. Castor monocropped plots consisted of four rows of 5.0 m length spaced 3.0 m apart, while bean plots consisted of four rows spaced 0.5 m apart. Both in intercropping and monoculture, the two central lines of each plot were taken as usable area (Fig. 2). The soil preparation was conventional, with one plowing and two harrowings. Liming was not needed, due to the low rate of exchangeable acid and because of good Ca and Mg availability.

Table 3. Average values of number of racemes per plant (NRP), number of fruits per raceme (NFR), hundred seed weight (HSW), productivity (PROD) and plant height (HEIGHT) of castor intercropped with bean and in monoculture, in function of year of planting, castor cultivars and splitting form of N.

Cultivation year	NRP	NFR	HSW (g)	PROD (kg ha^{-1})	HEIGHT (m)
2009/10	9.42B*	11.34B	43.48B	1022.05B	2.16B
2010/11	11.00A	14.23A	50.24A	1194.33A	2.46A
Castor cultivar					
Energia	7.23B	17.95A	32.01B	950.20B	1.56B
Paraguaçu	13.17A	7.63B	61.71A	1266.17A	3.06A
N splitting (kg ha^{-1})					
Control	3.21D	10.76D	42.30E	545.80D	1.55E
100:0	7.08C	12.59C	44.38D	926.26C	2.13D
0:100	7.76C	13.04C	44.16D	899.38C	2.17D
30:70	15.50A	13.99A	52.96A	1559.77A	2.81A
70:30	12.64B	12.94C	46.04C	1200.11B	2.53C
50:50	15.05A	13.41B	41.31B	1517.80A	2.68B
Intercrop mean	10.21a **	12.79a	45.86a	1108.19a	2.31a
Monocrop mean	9.97a	13.06a	44.95a	1115.84a	2.24a

* Means followed by the same uppercase letter in the column do not differ according to the Scott-Knott test at 5% probability; ** Means followed by the same lowercase letter in the column do not differ according to the Scott-Knott test at 5% probability.

Table 4. Average values of number of racemes per plant (NRP), number of fruits per raceme (NFR), hundred seed weight (HSW), height (HEIGHT) of castor intercropped with bean in function of the interaction cultivation year x castor cultivar.

Cultivation year	NRP	
	Castor cultivars	
	Energia	Paraguaçu
2009/10	6.66Bb	12.18Ba
2010/11	7.81Ab	14.17Aa
Cultivation year	NFR	
	Castor cultivars	
	Energia	Paraguaçu
2009/10	16.17Ba	6.51Bb
2010/11	19.72Aa	8.75Ab
Cultivation year	HSW (g)	
	Castor cultivars	
	Energia	Paraguaçu
2009/10	29.75Bb	57.20Ba
2010/11	34.26Ab	66.22Aa
Cultivation year	HEIGHT (m)	
	Castor cultivars	
	Energia	Paraguaçu
2009/10	1.46Bb	2.87Ba
2010/11	1.66Ab	3.26Aa

Means followed by the same uppercase letter in the column and the same lowercase letter in the line do not differ according to Scott-Knott test at 5% probability.

Table 5. Average values of the number of racemes per plant (NRP), hundred seed weight (HSW) and height (HEIGHT) of castor intercropped with bean, coming from the interaction between the factors castor cultivar and N splitting.

Castor cultivar	NRP					
	N splitting (kg ha^{-1})					
	Control	100:0	0:100	30:70	70:30	50:50
Energia	1.52Be	5.20Bd	5.81Bd	12.00Ba	8.27Bc	10.62Bb
Paraguaçu	4.90Ad	8.96Ac	9.96Ac	19.00Aa	17.01Ab	19.48Aa
Castor cultivar	HSW (g)					
	N splitting (kg ha^{-1})					
	Control	100:0	0:100	30:70	70:30	50:50
Energia	28.82Bb	29.72Bb	30.87Bb	36.27Ba	30.44Bb	35.93Ba
Paraguaçu	55.78Ae	59.04Ad	57.44Ae	69.66Aa	61.64Ac	66.70Aa
Castor cultivar	HEIGHT (m)					
	N splitting (kg ha^{-1})					
	Control	100:0	0:100	30:70	70:30	50:50
Energia	0.89Bc	1.64Bb	1.65Bb	1.82Ba	1.64Bb	1.73Ba
Paraguaçu	2.22Ae	2.62Ad	2.69Ad	3.81Aa	3.42Ac	3.63Ab

Means followed by the same uppercase letter in the column and the same lowercase letter in the line do not differ according to Scott-Knott test at 5% probability.

Table 6. Relation between bean productivity in intercropping and monoculture (Ib/Mb), castor productivity in intercropping and monoculture (Ic/Mc) and land equivalent ratio (LER).

Bean cultivars	Ib/Mb	Ic/Mc	LER
Pontal	0.62	1.05	1.67
Pérola	0.64	0.97	1.61
Castor cultivars			
Energia	0.67	1.00	1.67
Paraguaçu	0.59	1.02	1.61
N splitting			
Control	0.60	1.01	1.61
100:0	0.63	1.01	1.65
0:100	0.61	1.00	1.62
30:70	0.65	1.01	1.66
70:30	0.64	1.02	1.66
50:50	0.64	1.02	1.66
Mean	0.63	1.01	1,64

For sowing fertilization, we used the formula 05-25-15 + 0.3% Zn in the dose of 400 kg ha^{-1} for both cultivations in the two years. Castor and common bean sowing was made simultaneously and manually in the furrows, at depths of 7.0 cm. 25% extra seeds were sown and plant thinning was carried out at 10 DAE, with the aim of reaching castor and common bean density of 1 and 12 plants per running meter, respectively. At 25 and 35 DAE, top-dressed urea fertilizations were made according to studied doses, in a continuous band along the planting lines both for castor and common bean. The other applied treatments were the normal treatments for both cultivations.

Assessed traits

At seed maturity, the bean plants of each experimental unit usable area had their height, primary components (number of pods per plant, number of seeds per pod and hundred seed weight) and seed productivity measured. At seed maturity, the castor plants had their yield components (average number of racemes per plant, number of fruits per raceme, hundred seed weight) and productivity measured, with fruits at 7% humidity.

LER - was calculated using Eq. 1:

$$LER = (Ib / Mb) + (Ic / Mc) \quad (1)$$

where:

LER_Land equivalent ratio;
Ib = Intercropped bean yield;
Mb = Monocropped bean yield;
Ic = Intercropped castor yield;
Mc = Monocropped castor yield.
Intercropping will be efficient when LER will be higher than 1.0 and detrimental to production when lower than 1.0.

Statistical analysis

Nutritional and agronomic data were initially submitted to individual variance analysis (ANOVA). Subsequently, combined variance analysis (MANOVA) of the variables common to both experiments was carried out to analyze the planting system, as suggested by Banzatto and Kronka (2006). The Scott-Knott test at 5% of p-level, when relevant, was carried out for comparison of obtained means. All statistical analyses were carried out using SISVAR 5.1 software (Ferreira, 2011).

Conclusions

The agronomic traits of common bean cultivars Pérola and Pontal are influenced by intercropping with castor. On the other hand, bean genetic material did not carry any influence on the agronomic behavior of intercropped castor, regardless of the used genotype. The adequate dose of top-dressed nitrogen in the common bean and castor intercropping system must be 30 and 70 kg ha^{-1}, split at 25 and 35 days after crop emergence. The common bean and castor intercropping system is more efficient than monoculture according to mean LER value (1.64).

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References

Andrade MJB, Moraes AR, Teixeira IR, Silva MV (2001) Avaliação de sistemas de consórcio de feijão com milho-pipoca. Ciênc Agrotec. 25: 242-250.
Banzatto, DA, Kronka SN (2006) Experimentação agrícola. 4nd ed., Funep, Jaboticabal, Brazil
Below FE (2002) Fisiologia, nutrição e adubação nitrogenada do milho. Inf Agrop. 99: 12.
Beltrão NEM, Vale LS, Marques LF (2010) La temporada de siembra en el consorcio de ricino y de sésamo. Rev Verde Agric Desenv Sust. 5: 67-73.
Carvalho AJ, Andrade MJB, Guimarães RJ (2007) Production systems for bean associated with recently planted dense coffee shrub cropping. Ciênc Agrotec. 31: 133-139.
Cfsemg - Comissão de Fertilidade do Solo do Estado de Minas Gerais (1999) Mamona. In: Ribeiro AC, Guimarães PTG, Alvarez VH. (Ed.). Recomendação para o uso de corretivos e fertilizantes em Minas Gerais: 5ª Aproximação. Comissão de Fertilidade do Solo do Estado de Minas Gerais, Viçosa, Brazil, pp 311.
Chagas JM, Braga JM, Vieira C, Salgado LT, Junqueira Neto A, Araújo GAA, Andrade MJB, Lana RMQ, Ribeiro AC (1999) Feijão. In: Ribeiro AC, Guimarães PTG, Alvarez VH. (Ed.). Recomendação para o uso de corretivos e fertilizantes em Minas Gerais: 5ª Aproximação. Comissão de Fertilidade do Solo do Estado de Minas Gerais, Viçosa, Brazil, pp 306-307.

Conab - Companhia Nacional de Abastecimento, Brazil (2014) Acompanhamento da safra brasileira, grãos: oitavo levantamento. 2014. Available at: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/14_05_08_10_11_00_boletim_graos_maio_2014.pdf

Corrêa MLP, Távora FJAF, Pitombeira JB (2006) Behavior of castorbean cultivars intercropped with cowpea and grain sorghum. Rev Ciênc Agron. 37: 200-207.

Costa ASV, Silva, MB (2008) Intercrop with mayze and bean at Vale do Rio Doce, Minas Gerais. Ciênc Agrotec. 32: 663-667.

Costa DS, Barbosa RM, Sá ME (2010) Production systems and bean cultivars in intercropping with maize. Sci Agraria. 11: 425-430.

Epstein E, Bloom AJ (2005) Mineral nutrition of plants: principles and perspectives. 2nd ed. Sinauer Associates, Sunderland, Massachusetts.

Ferreira DF (2011) Sisvar: a computer statistical analysis system. Ciênc Agrotec. 35: 1039-1042.

Flesch RD (2002) Temporal and spatial effects on maize-bean row intercropping. Pesq Agropec Bras. 37: 51-56.

Jesen ES, Peoples MB, Hauggaardnielsen H (2010) Faba bean in cropping systems. Field Crops Res. 115: 203-216.

Kluthcouski J, Stone LF, Aidar H (2009) Fundamentos para uma agricultura sustentável, com ênfase na cultura do feijoeiro. Embrapa/Embrapa arroz e feijão, Embrapa. Santo Antônio de Goiás- GO, Brazil

Kumar HCS, Mudalagiriyappa, Nanjappa HV, Ramachandrappa BK (2010) Productive performance of castor (*Ricinus communis* L.) based intercropping systems under rainfed conditions of central dry zone in Karnataka. J Agricultural Sci. 44: 481-484.

Lithourgidis AS, Dordas CA, Damalas, CA, Vlachostergios DN (2011) Annual intercrops: an alternative pathway for sustainable agriculture. Aust J Crop Sci. 5: 396-410.

Marschner H (1995) Mineral nutrition of higher plants. 2nd ed. Academic Press Inc., San Diego, CA, USA.

Morgado LB, Willey RW (2008) Optimum plant population for maize-bean intercropping system in the brazilian semi-arid region. Sci Agrícola. 65: 474-480.

Obiero C, Birech R, Maling'a J, Ngetich K, Freyer B (2014) Performance of maize and beans under castor-based intercropping system. Amer J Exp Agriculture. 4: 101-113.

Oliveira AS (2004) Análise foliar. In: Sousa DMG, Lobato E. (eds). Cerrado: correção do solo e adubação. 2nd ed. Embrapa Informação Tecnológica. Brasília, DF, Brazil.

Santos JB, Gavilanes ML (2006) Botânica. In: Vieira C., Paula Júnior T.J., Borém A. (eds). Feijão. 2nd ed. UFV, Viçosa, Brazil.

Severino LS, Auld, DL (2014) Study on the effect of air temperature on seed development and determination of the base temperature for seed growth in castor (*Ricinus communis* L.). Aust J Crop Sci. 8: 290-295.

Severino LS, Ferreira GB, Moraes CRA, Gondim TM.S, Freire WSA, Castro DA, Cardoso GD, Beltrão NER (2006) Growth and yield of castor bean fertilized with macronutrients and micronutrients. Pesq Agropec Bras. 41: 563-568.

Silva TRB, Leite VE, Silva ARB, Viana, LH (2007) Nitrogen sidedressing fertilization on castor plant in no tillage system. Pesq Agropec Bras. 42: 1357-1359.

Teixeira IR, Silva GC, Oliveira JAP, Timossi PC (2012) Plant arrangement the common beans intercropped castor. Rev Caatinga. 25: 85-91

Teixeira IR, Teixeira GCS, Timossi PC, Silva, AG (2011) Bean cultivars intercropping castor bean. Rev Caatinga. 24: 55-61.

Viegas Neto AL, Heinz R, Gonçalves MC, Correia AMP, Mota LHS, Araújo WD (2012) Popcorn intercropped with bean under different plant arrangements. Pesq Agropecu Trop. 42: 28-33.

Vieira C (2006) Cultivos consorciados. In: Vieira C, Paula Júnior TJ, Borém A. (eds). Feijão, UFV, Viçosa, Brazil, pp 493-528.