GROWTH AND YIELD OF CASTOR BEAN (*Ricinus communis* L.) CV. 'BRS ENERGIA' UNDER DIFFERENT SPACINGS [1]

[CRECIMIENTO Y RENDIMIENTO DEL RICINO (*Ricinus communis* L.) CV. 'BRS ENERGIA' EN DIFERENTES ESPACIADOS]

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SUMMARY

The use of appropriate spacing when planting large crops is a technology that can be very easily applied, and that can result in a significant increase in yield. The aim of this work was to estimate the best spacing between rows in the Castor Bean cv. 'BRS Energia' (*Ricinus communis* L.), with a view to optimising maximum yield. The experiment was carried out on the Juá farm, in Itatuba, in the State of Paraíba, Brazil, in the 2015 agricultural year. The experimental design was of randomised blocks, with four replications and six treatments of different spacing between rows (0.5, 0.75, 1.0, 1.25, 1.50 and 1.75 m). Values for plant height, stem diameter, number of racemes and yield were determined at the end of the crop cycle. Reducing the spacing promoted an increase in plant height. At the smallest spacing, plants reached heights of more than 2.0 m. At the larger spacings, the plants achieved greater stem diameter and number of racemes. The highest yield was obtained at the two smallest spacings, where yields of more than 2000 kg ha^{-1} were achieved.
Keywords: *Ricinus communis* L.; plant population; densification; yield components.

RESUMEN

El uso de espaciamiento adecuado al plantar grandes superficies de cultivos es una tecnología que puede aplicarse muy fácilmente y que puede dar lugar a un aumento significativo de la productividad. El objetivo de este trabajo fue estimar el mejor espaciado entre hileras en el ricino cv. 'BRS Energia' (*Ricinus communis* L.), con miras a optimizar el rendimiento máximo. El experimento se realizó en la finca de Juá, en Itatuba, estado de Paraíba, Brasil, en el año agrícola 2015. El diseño experimental fue de bloques al azar, con cuatro repeticiones y seis tratamientos de diferente espaciamiento entre hileras (0.5, 0.75, 1.0, 1.25, 1.50 y 1.75 m). Los valores para la altura de la planta, el diámetro del tallo, el número de racimos y la productividad se determinaron al final del ciclo del cultivo. La reducción del espaciamiento promovió un aumento en la altura de la planta. En el espaciado más pequeño, las plantas alcanzaron alturas de más de 2.0 m. A mayores distancias, las plantas alcanzaron un mayor diámetro del tallo y número de racimos. La mayor productividad se obtuvo en los dos espacios más pequeños, donde se alcanzaron rendimientos de más de 2000 kg ha^{-1}.
Palabras clave: *Ricinus communis* L.; población de plantas; densificación; componentes de rendimiento.

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INTRODUCTION

The castor bean is an oilseed of the family Euphorbiaceae, of significant economic importance, which, due to its great adaptive capacity, can be found growing or under production from the State of Rio Grande do Sul to the Amazon. (Azevedo *et al*., 2001). In Brazil, the estimates for the 2016/17 castor bean crop are a planted area reaching about 30 thousand hectares and average yield of 1,000 kg ha^{-1}, which means an increase of 10% in relation to the harvest 2015/16 and the production can reach 200 tons (CONAB. 2017). In the Northeast, it is grown throughout the region, with the State of Bahia being the largest domestic producer, where the castor bean is cultivated under a system of succession planting, mainly with the common bean (*Phaseolus vulgaris* L.) and watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai.). Other states have become important for the cultivation of this oilseed, such as the States of Ceará, with an area of approximately 26,305 ha., and Pernambuco and Minas Gerais with over 6,000 ha (Beltrão and Vale, 2007).

Due to the high demand for castor oil in the chemical industry, there has been consolidation of cropping systems in Brazil to meet the needs of the market; furthermore, the use of the castor bean in the Brazilian program of biodiesel production has seen a significant increase in areas where this euphorbia is cultivated in other states of the Northeast. However, for this expansion of the cultivated area to be economically viable, it is necessary for the farmers to implement new low-cost technologies of simple application for oil crops, with the aim of greater verticalisation of the entire production chain (Azevedo *et al*., 2001; Oliveira, 2014; César and Batalha, 2010).

Involved in this context, the adoption of agricultural practices that promote maximisation of productive potential in the castor bean should be included in scientific research. One agricultural practice representing a very simple technology is the adoption of ideal spacing, defined as the distance between two rows, and which if correctly employed, can result in a significant increase in yield, better soil conservation, and better use of the water available to plants, and besides ensuring these benefits, also allows the use of agricultural machinery and a decrease in weed emergence (Beltrão and Vale, 2007; Magalhães *et al.*, 2013).

With constantly appearance of short stature new cultivars and new hybrids, a deeper understanding of how a plant population is determined becomes necessary. These materials are more demanding regarding water availability and nutrition, and the genotypes show great variability in growth habit under different conditions of soil and climate (Beltrão *et al.*, 2007). Hence, many recent studies involving different crops have shown variability among cultivars growing in different environmental conditions (Vieira *et al.*, 2015; Silva *et al.*, 2016).

The ideal plant population can vary from year to year in any one place. As conditions are different for each harvest and for each situation, any given population could be the most appropriate. Therefore, no ideal number can be accurately calculated for a plant population, only an estimate of the ideal value. (Severino *et al*., 2006a; Lopes *et al.*, 2013). Several studies focus on determining the best row spacing for various crops. As the spacing between rows in an area decreases, the competition between plants for water and nutrients intensifies; on the other hand, at smaller spacings, there is greater light interception, and shading of the weeds occurs earlier, which hinders their growth, having a positive influence on crop yield. (Severino *et al*., 2006b; Magalhães *et al.*, 2013).

The aim of this work is to evaluate the best row spacing for castor bean cv. BRS Energia to optimise maximum yield.

MATERIAL AND METHODS

The experiment was conducted during the 2015 agricultural year, on the Juá Farm in the town of Itatuba, located in the Paraiba wilderness, at an altitude of 180 m, at 28º 23' S and 59º 34' W.

Fourteen soil samples per hectare were taken at a depth of 0-20 cm, following zig-zag patterns that ensured adequate spatial coverage of the target area and minimised the likelihood of 'hot spots' (Hazelton and Murphy, 2016). The samples were sent to the Soil Chemical Analysis Laboratory of Brazilian Agricultural Research Corporation (EMBRAPA), and the soil under study was classified as a Luvisol (EMBRAPA, 2006). The results of the soil analysis, carried out at a depth of 0-20 cm, were as follows: pH (in water) = 6.5; H + Al = 0.46 $cmol_c\ dm^{-3}$; available P = 39.8 mg dm^{-3}; Ca = 96.5 $cmol_c\ dm^{-3}$; Mg = 32.8 $cmol_c\ dm^{-3}$; K = 10.8 $cmol_c\ dm^{-3}$; Na = 1.9 $cmol_c\ dm^{-3}$; organic matter = 12 g kg^{-1}; sum of bases (SB) = 131.2 $cmol_c\ dm^{-3}$; and CEC = 31.2%. Physical analysis of the soil showed a bulk and particle density of 1,580 and 2,400 kg m^{-3} respectively. According to the granulometry, the soil consisted of 57.3% sand.

The experimental design was of randomised blocks, with only one factor, with six treatments and four replications, giving a total of 24 plots. The BRS Energia cultivar was used at spacings of 0.50, 0.75, 1.0, 1.25, 1.50 and 1.75 m, maintaining a constant distance of 1 m between plants, i.e. a density of 7 plants per linear metre. These spacings made it possible to achieve population densities of 20,000; 13,333; 10,000; 8,000; 6,667 and 5,571 plants per hectare respectively. Each lot had a total area of 72 m^2 with a working area of 55 m^2.

Ploughing was carried out using a mouldboard plough, followed by sowing on 28 July 2015, at three seeds per hole. The plants were then thinned ten days after seedling emergence leaving only one plant per hole. Weed control during the crop cycle was by manual weeding using a hoe, once at 20 days and again at 40 days after seedling emergence.

Base fertilisation was carried out when sowing, applying 15 kg of nitrogen per hectare, with ammonium sulphate as the source; 50 kg of phosphorus per hectare from triple superphosphate; and 20 kg ha^{-1} potassium chloride. At 35 days after emergence, another 40 kg of N was applied as cover.

Analysis of the chemical composition of the water from the River Paraíba gave the following results: EC = 1.2 dS m^{-1}; PH = 6.8; Ca = 3.5 $cmol_c\ L^{-1}$; Mg = 2.3 $cmol_c\ L^{-1}$; K = 0.85 $cmol_c\ L^{-1}$; Na = 1.23 $cmol_c\ L^{-1}$; Cl = 1.8 $cmol_c\ L^{-1}$; HCO_3 = 2.3 $cmol_c\ L^{-1}$; and CO_3 = 0.2 $cmol_c\ L^{-1}$. Throughout the period of cultivation, a Dan 2001® micro-sprinkler system was used for irrigation, with a flow rate of 100 l h^{-1} at an irrigation frequency of 7 days. Since the soil displayed good water storage capacity for availability to the plants, and it was sought to optimise the period of water application, and avoid water wastage and the possible saturation of the soil profile in the area of cultivation, a period of 30 minutes was used for each irrigation. Throughout the experiment, approximately 590 mm were supplied; a total volume of 20.4 mm rainfall occurred in July and August, giving a total of 610.4 mm for the complete cycle.

Harvesting took place only once, 170 days after planting, when all the bunches had completely dried; there was thus an increase in the crop cycle due to non-dehiscence of the cultivar. The bunches were harvested and then passed through a castor-processing machine; a Confarmaq® Model Valente 1 was used for dehusking, to obtain the actual weight of the lots.

The variables under analysis were plant height (m); stem diameter (mm), evaluated with the aid of callipers at a height of 10 cm from the ground; number of bunches per plant; and estimated yield (kg ha^{-1}).

The data were submitted to analysis of variance by F-test at 5% probability with the mean values of the treatments compared by Tukey's test. The data of the four replicates for the variables, plant height, stem diameter, number of bunches and yield, as function of the spacings, were submitted to regression analysis. For the statistical analysis, the SAEG version 9.1 software was used (Ferreira, 2014).

RESULTS AND DISCUSSION

The analysis of variance for the treatments and blocks on the variables under analysis, showing significant differences between treatments by F-test at a level of 5% probability. The coefficient of variation (CV) was relatively low for all characteristics, reaching values of less than 10%, except for the number of bunches (18.32%). The coefficients of determination were high, indicating variability among the characteristics under study (Table 1, Appendix).

It can be seen from the results of the analysis of variance that there were no significant effects for block, which was probably due to the homogeneity of the study area. For the treatments, significance was seen for plant height, stem diameter, number of bunches and yield, due to the influence of the spacings on the analysed variables. A similar result was obtained by Gondim*et al*. (2004); those authors, studying the same cultivar under an irrigated regime, found differences of height at the smaller spacings, with an increase in plant height seen as the population density increased. Significant differences were also seen for stem diameter. As plant spacing decreased, the stem diameter also decreased. There was also a reductionin the number of bunches as the spacing decreased,but an increase in yield, mainly due to the greater number of plants per hectare.

Azevedo (1997), studying medium-sized castor bean plants under a rained regime, saw a reduction in production for an increase in population density, mainly due to water limitations, thereby achieving greater yield in a population of smaller plants. However, with the emergence of new short-stature hybrids of 1.50 m that can be cultivated in populations of up to 27,000 plants ha^{-1}, these can reach heights of 2.00 m,if submitted to regular water regimes (Savi Filho, 2005).

The linear effect was significant for plant height, stem diameter, number of bunches and yield; significance was also seen from the cubic effect for number of bunches and yield (Table 2, Appendix).

An increase in plant height was seen as the row spacing decreased, possibly due to competition for light (Figure 1A). To this effect, Severino*et al*. (2006a) report that a change in insertion height of the first bunch is an indication that the reduction in row spacing caused greater plant growth, which may be due to increased competition for light. An increase of 22.99% was found at Spacing 1 over the average height obtained at Spacings 3, 4, 5 and 6, in this case controlled by environmental factors. This result was different to those found by Lopes*et al*. (2013), whose when studying spacing optimisation of the BRS Nordestina cultivar found a decrease in plant height with a reduction between rows, which occurred due to environmental and/or genetic factors. In another study, Severino*et al*. (2006a), working with the BRS Nordestina cultivar in a year of good water availability, saw an increase in plant height when plant spacing was reduced from 3.5 to 2.0 m.

These same authors state that the height of the castor bean is directly related to water availability during the cycle and to competition for light. For this reason, a reduction in row spacing can both reduce plant height when water availability is low, and cause an increase in plant size when an adequate water supply is available, as excessive lateral plant growth leads to an increase in competition for light, which may lead to greater height.

Figure 1B shows a good fit of the mathematical model to the data, with a coefficient of determination (R^2) of 0.945; it can be inferred that the model explains 94.5% of the biological phenomenon. It was found that the data followed increasing linear behaviour, i.e. as the spacing increased the plants displayed a greater stem diameter, probably due to the larger area for exploitation of nutrients and light, with a 40.8% increase occurring at Spacing 6 when compared to Spacing 1. At higher population densities, there is greater intraspecific competition for factors limiting growth and development, such as water, nutrients and light. It can be seen from the data for plant height, that the plants suffered from etiolation and displayed a smaller stem diameter, a typical characteristic of etiolated plants.

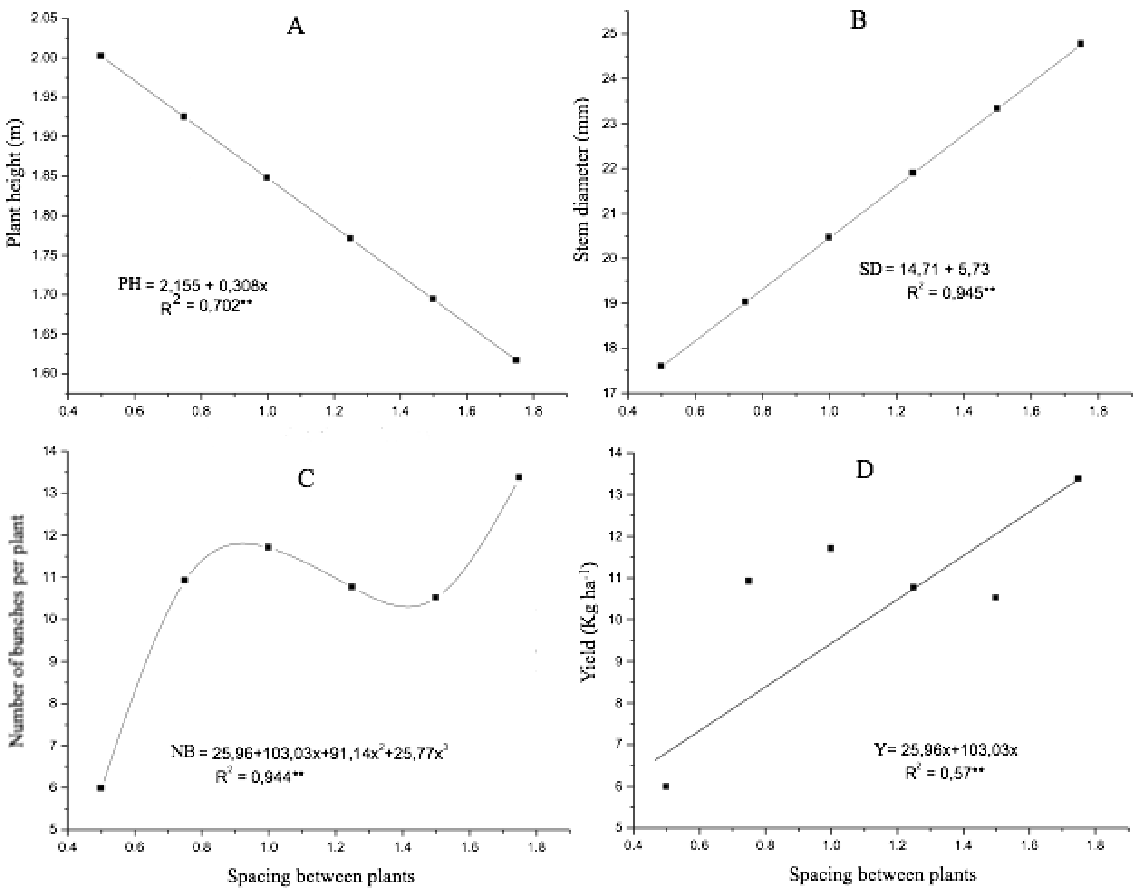

Figure 1. Plant height (A), stem diameter (B), number of bunches per plant (C) and yield (D) of castor bean cv. 'BRS Energia', for different spacing between plants.

The number of bunches tended to decrease as the plant population increased, as seen in Figure 1C, where there was a good fit of the mathematical model, with a coefficient of determination (R^2) of 0.944, suggesting that the model can explain 94.4% of the biological phenomenon. However, the decrease in the number of bunches per plant was offset by the greater number of plants in the same area, thereby increasing yield by 100% when compared to the averageyield at spacing 3,4,5 and 6 with treatments 1 and 2, like a result found by Gondim*et al*. (2004). Plants at larger spacing occupy a greater area for the capture of light and do not display the same interference or competition as those at smaller spacing, they therefore have better productive architecture, being able to express their full potential by the emission of a greater number of bunches.

It was verified a lower yield in bunches in the T1 treatment, this yield being 26.15% lower than the yield observed in the treatment 2. Then, it was observed an increase in the yield of bunches in treatments T2, T3, T4 and T6, except For the T5 that presented lower value. Comparing to the greater spacing, an increase of 66.20% was observed, possibly due to the good edapho-climatic conditions (Figure 1D)

Other information to be considered in relation to the increase in yield at smaller spacings is that according to Brito (2002), there is better and more uniform absorption of radiation at these spacings. This hypothesis was mentioned first by Heitholt *et al*. (1993) and Krieg (1996), who claim that denser spacing maximises the interception of light per unit area of leaf. Although those studies used cotton, the hypothesis can be extended to other crops.

Maximum values for yield were obtained at spacings of 0.5 and 0.75; however, further studies into spacing optimisation are necessary, since soil and climate conditions vary according to region, and larger spacings may therefore achieve greater yield than those of smaller spacings.

In this study, at spacings greater than 1.75 x 1.0 m, the plants produced a greater number of bunches, one of the fundamental components for estimating production in the castor bean; however due to a smaller number of plants per hectare, the agronomic yield was smaller than yields at greater densities, i.e. with more plants per hectare.

In fact, from the contrasting results obtained by different authors for spacing, and available in the literature, it seems that such results are generally attributed to the most diverse causes of variation. The relationship between the environment and yield in the castor bean is complex, as it results from growth, with the phenomenon arisingfrom the interaction between the environment, cultivar and agricultural technique.

The possibility of an increase in the yield of castor bean crops by a reduction in spacing needs to be evaluated for other years and different conditions of soil and climate, but the results obtained in this experiment are an indication that such an improvement is possible and should be considered in the technical recommendations for this crop, since with reductions in spacing, better soil conservation can be achieved. Studies of spacing and soil conservation in the castor bean crop are just beginning, and should increase in the short term.

CONCLUSIONS

At higher plant densities, there was an increase in plant height above 2.00 m; Lower density of plants provided an increase in the number of bunches, however, did not increase the yield. The plants cultivated in the two smaller spacings showed higher yield when compared to the plants grown in larger spacings, with yield higher than 2.0 Kg ha^{-1}.

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Appendix

Table 1 - Summary of analysis of variance of the observed characteristics of castor bean cv. ‘BRS Energia’ for different spacing between plants.

S.V.	D.F.	Mean Square			
		Plant height	Stem diameter	Number of bunches	Yield
Blocks	3	0.2598 ns	0.1601 ns	0.5175 ns	1.4947 ns
Treatments	5	5.1911 **	8.3131 **	6.8734**	697.32 **
Residual	15	0.34165	3.66514	55.958	20178.25
CV (%)		8.34	9.04	18.32	8.26

* significant at 5% probability; ** significant at 1% probability; ns - not significant.

Table 2. Summary of the regression for plant height, shoot diameter, numbers of bunches and yield of castor bean cv. ‘BRS Energia’ for different spacing between plants.

	Meansquare			
Regression	Plant height	Stem diameter	Number of bunches	Yield
Linear	18.2217 **	39.3131 **	18.4969 **	2619.93 **
Quadratic	3.3854 ns	1.8098 ns	32.6832ns	1.7555 ns
Cubic	3.9320 ns	0.0468 ns	11.2718**	503.26**
Residual	0.02278	3.66514	3.73056	1345.2168

* significant at 5% probability; ** significant at 1% probability; ns - not significant.