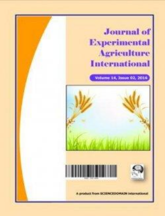

Journal of Experimental Agriculture International

29(3): 1-11, 2019; Article no.JEAI.45433
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Phosphate Fertilization of Low Size Castor Bean in Conventional and Narrow Cultivation in Second Cropping Season

Felipe dos S. de Oliveira[1*], Doglas Bassegio[2], Andréia R. Ramos[3], Girlânio H. da Silva[3], Jackson da Silva[4], Maurício D. Zanotto[3] and Dirceu M. Fernandes[3]

[1]State University of Maringa (UEM), Maringá, PR, Brazil.
[2]West State University of Paraná (UNIOESTE), Cascavel, PR, Brazil.
[3]São Paulo State University (UNESP), Botucatu, SP, Brazil.
[4]Federal Rural University of Pernambuco (UFRPE), Recife, PE, Brazil.

Authors' contributions

This work was carried out in collaboration with all authors. Authors FSO, MDZ and DMF participated in the idea and management of the experiment, besides writing the article. Authors DB and ARR were responsible for the conduction of the experiment, data collection and analysis and improvement in the writing of the study. Authors GHS and JS dealt with bibliographic searches and assisted in writing the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2019/45433
Editor(s):
(1) Dr. Dalong Guo, Professor, College of Forestry, Henan University of Science and Technology, Luoyang, People's Republic of China.
Reviewers:
(1) A. Ramanjaneya Reddy, Dr Y.S.R. Horticultural University, India.
(2) Florin Sala, Banat University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania" from Timisoara, Romania.
Complete Peer review History: http://www.sciencedomain.org/review-history/28048

Original Research Article

Received 12 October 2018
Accepted 16 December 2018
Published 01 January 2019

ABSTRACT

The oil present in the castor bean (*Ricinus communis* L.) has several applications, especially its use in the production of biodiesel. Therefore, the aim of this work is the response of low size castor bean to rates of phosphorus in conventional and narrow cultivation in second cropping season. The experimental design was a randomized complete block (2 x 5) design with four replications, being two population densities and five rates of phosphorus. The evaluated population densities were 67,340 and 33,670 plants ha^{-1} (conventional), and the phosphorus rates evaluated were 0, 30, 60, 90 and 120 kg ha^{-1} of P_2O_5. The conventional cultivation resulted in higher stem diameter, plant

---

*Corresponding author: E-mail: felipe.smc2011@gmail.com;

height, number of racemo^{-1} grains, 100 grain mass, grain yield and oil yield. The number of racemes plant^{-1} was higher in the population density of 33,670 plants ha^{-1} when it was applied P. Phosphate fertilization contributed to increase grain yield (689 kg ha^{-1}) and oil yield (311 kg ha^{-1}), with a maximum technical efficiency rate of 80 kg ha^{-1} of P_2O_5. Castor bean sown in conventional cultivation with basic fertilization containing 80 kg ha^{-1} of P_2O_5 is a promising alternative for the second harvest.

Keywords: Agroenergy; biodiesel; grain yield; Ricinus communis.

1. INTRODUCTION

Castor bean is a euphorbiaceae native to tropical climate, cultivated from latitude 40° North to 40° South. Its main product is the oil or ricinus present in its grains, which has several applications, especially its use in the chemical industry for biodiesel production [1]. India is the largest grain producer of this oilseed, with 87% of the 2.0 million tons produced worldwide. Until 1978, Brazil was the largest producer of castor oil plant in the world, but currently the country is the fourth largest producer, accounting for less than 2% of global production [2].

With the development of new cultivars, possessing high productive potential and desirable traits for mechanized harvesting [3], the castor has expanded in large and medium-scale cultivated areas to the Brazilian Cerrado, more precisely in the Central-West region, becoming an important crop option in the second harvest, even to be included in rotation with other annual crops [4]. However, in large cultivated areas are required more efficient production technologies to maximize crop production [5].

The optimization of the use of line spacing and population density is a practice of simple application and require little financial expenses for the castor bean farmer [6,7], enabling a better use of H_2O, light, nutrients and CO_2 by the plants [8], and consequently is essential to increase yield [3,7,9]. However, the best arrangement of the plants in the area is dependent on the characteristics of each genotype, such as size, growth habit and plant architecture [10], as well as the edaphoclimatic factors of the environment and the production technology employed [11].

Another important factor with great impact on crop yield is the management of phosphate fertilization [12,13,14], because phosphorus (P), when uptake by plants, acts on several metabolic processes, such as photosynthesis, respiration, energy transfer in the form of ADP and ATP, nucleic acid biosynthesis [15,16] and the ionic absorption of phosphorus itself and nitrate [17].

Singly, the plant population and the management of phosphate fertilization may increment the yield of castor seeds. However, until now, there are no studies evaluating the effects of these cultivation techniques on the castor, especially in the fall-winter period in the low size cultivars. In this way, the aim of this work is to evaluate the response of low size castor bean to rates of phosphorus in conventional and narrow growing, in the period of the second cropping season.

2. MATERIALS AND METHODS

A field experiment was conducted from April to November 2016, in the municipality of São Manuel, State of São Paulo, located at 22° 46' Latitude South, 48° 34' west longitude and 740 m altitude. The climate of the region, according to the classification of Köppen, it is the Cfa type, warm temperate climate (mesothermic) humid, with concentrated rains from November to April, but during the experiment the rains concentration were in June and July; the average annual precipitation of the municipality was 1.376 mm, with an average temperature of the hottest month exceeding 22°C [18]. The daily meteorological data for the municipality of São Manuel, during the period of conduction of the experiment, are presented in Fig. 1.

The soil is classified as typical dystrophic Red-Yellow Latosol, with sandy texture [19]. Before the installation of the test were determined the chemical characteristics (Table 1) of the soil in the depth of 0 to 0.2 m according to Raij et al. [20].

The design used was in randomized blocks, in a factorial scheme (2 x 5), being two population densities and five rates of phosphorus, with four replications. The population densities evaluated were 67,340 and 33,670 plants ha^{-1}. Based on the soil analysis and according to the recommendation proposed by Savy [21], five rates of phosphorus were established, corresponding to 0, 50, 100, 150 and 200% from the recommended rate which were established based on the soil analysis, equivalent to 0, 30, 60, 90 and 120 kg ha^{-1} de P_2O_5, respectively, which were applied in the planting groove as single superphosphate (18% P_2O_5, 12% S).

Each portion was consisted of five and three rows at the population densities of 67,340 (denser) and 33,670 plants ha^{-1} (conventional), respectively, with 4.95 m in length. Being considered as useful area for data collection, the central rows, being discarded 0.33 m from each end of the planting line. The useful areas corresponding to the population densities of 67,340 and 33,670 plants ha^{-1}, were respectively 5.79 and 3.86 m^2.

In the preparation of the soil a heavy harrowing was carried out. It was applied 0.58 t ha^{-1} of dolomite limestone to raise the saturation per base at 60%. Phosphate and potassium fertilization (60 kg ha^{-1} of K_2O) were carried out at the time of sowing. The N was applied in two split doses, 20 kg ha^{-1} at sowing and 40 kg ha^{-1} on the cover', 30 DAE (days after emergence) of the seedlings. The sources of N and K used were urea and potassium chloride, respectively.

The crop was sown on April 25, 2016 using the cultivar AG IMA 110204, where three seeds were placed in the row manually every 0.33 m, with depths of four to eight centimeters, the seeds were treated with the fungicide Vitavax-thiram (120 mL for 100 kg^{-1}), and at 20 DAE, thinning was done leaving three plants per linear meter. The weeds control and other cultural treatments were carried out during the entire period of development of the crop, when necessary.

Table 1. Soil chemical attributes of the experimental area before the installation of the experiment

pH	SOM	P	H+Al	K	Ca	Mg	SB	CEC	BS
$CaCl_2$	g dm^{-3}	mg dm^{-3}	---------------------- mmol$_c$ dm^{-3} -------------------------						%
5.0	9	9	13	0.2	5	2	7	20	35

SOM: Soil organic matter; SB: Sum of bases; CEC: Cation exchange capacity; BS: Base saturation

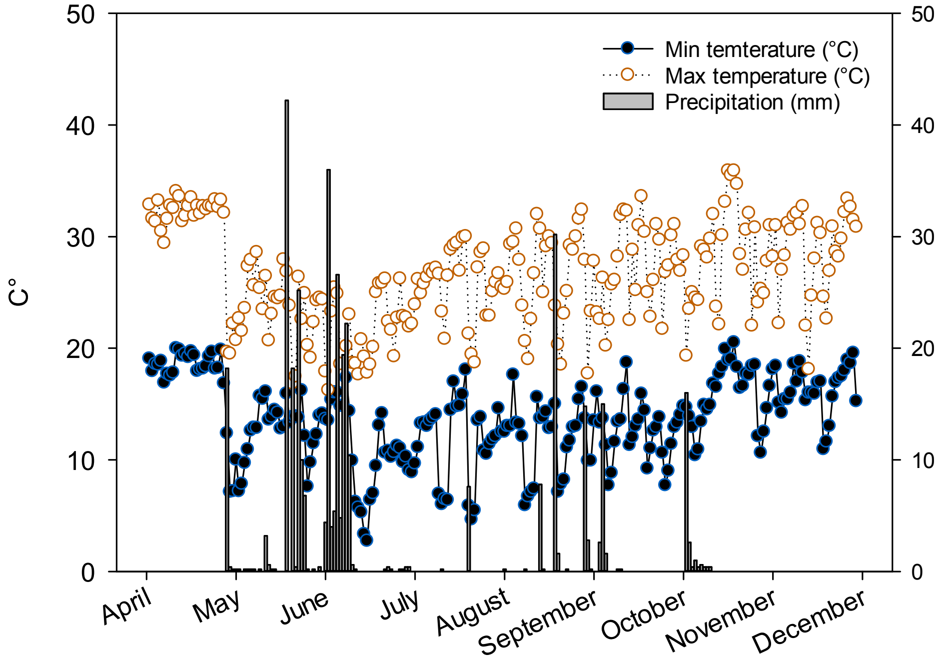

Fig. 1. Precipitation and temperatures recorded in the experimental area during the period of April to December of 2016

The harvest was carried out between 2 to 17 of November 2016. The variables analyzed were: stem diameter (cm): it was determined in the first plant internode, with the aid of a pachymeter, in five plants; plant height (cm): it was carried out by measuring the distance between the soil and the highest point of the plant, in five plants; height of the first raceme insertion (cm): distance measurement between the soil and the insertion point of the racemes, in five plants; number of racemes plant^{-1} (unid.): relation between total number of racemes and total number of plants, considering 4.3 m of the central rows of the useful area; number of racemo^{-1} grains (unid.): relation between total number of grains and total number of racemes, considering 4.3 m of the central rows of the useful area; weight of 100 grains (g): weighing samples of 100 grains in grams using a digital scale.

The obtained data were transformed to 13% moisture; oil content (%): to determine the oil content, samples of the seeds were dried in greenhouses at 70°C for 24 hours and submitted to nuclear magnetic resonance analysis [22]; seed yield (kg ha^{-1}): the spikes of the plants contained in the central rows of the useful area were harvested at the time of harvest, and the grains were weighed and corrected to 13% moisture; and oil yield (kg ha^{-1}): obtained by multiplying the seed yield of the castor by the oil content.

The data were submitted to analysis of variance, where the F test ($p \leq 0.05$) of the analysis of variance was used in the comparison of the means of population densities, and for the phosphorus rates, regression analysis was used ($p \leq 0.05$). The data of the variables number of raceme plant^{-1} and number of raceme^{-1} grains were transformed into $\sqrt{x}$.

3. RESULTS AND DISCUSSION

For the interaction between population densities and phosphorus rates only for the variable number of racemes plant^{-1} there was a significant difference, indicating that there is dependence between the factors under study for this variable. For the cause of the variation in population densities, it was detected that there was a significant difference for the variables stem diameter, plant height and number racemes plant^{-1}. For the variation cause variation of phosphorus rates, there was no significant difference for stem diameter, plant height and height of the first raceme insertion (Table 2).

The smaller diameter of the stem (1.05 cm) was observed in the population density of 67,340 plants ha^{-1} (Table 2), and can be explained by the fact that in high population densities, there is probably a lower availability of light energy because of the greater competition between plants in the area, thus they present a lower photosynthetic rate and, as a consequence, less storage capacity of photoassimilates in the stem [23]. The decrease in the diameter of the stem with the increase of the population density by the reduction of the line spacing was verified by [5,6,11].

Regarding plant height, the lowest population density provided higher value (47.64 cm) when compared to the narrow crop [24] affirmed that the increase of the plant population causes intraspecific competition for H_2O, light, nutritive mineral elements and CO_2, resulting in the reduction of plant growth, and this is confirmed by the results of the present research. In what [4] says, when the plant is submitted to less competition for environmental factors, that is, with greater space availability, it presents greater vegetative growth, which results in an increase in the number of racemes in the plant, as a consequence, there is an increase in the number of seeds in the racemes.

For height of the first raceme insertion there was no significant effect of population densities, although there were influences of this factor on stem diameter and plant height (Table 2). The change in insertion height of the first raceme is an indication that in narrow culture there are more individuals per area and, as a consequence, causes changes in growth (increase in internodes length), resulting from increased competition for light [10,25]. In the present study this behavior was not noticed, corroborating with [5,26].

The diameter of the stem, plant height and height of the first raceme insertion were not influenced by the increase of phosphorus rates (Table 2). With lower P availability, it would be expected that there would be a decrease in these variables, since in this condition there is a reduction in the photosynthetic rate, and the little CO_2 absorbed in the photosynthesis, most of it is allocated for root formation in order to increase the capacity of acquiring the nutrient, consequently the plants no longer allocate photoassimilates to form stem, leaves and new photosynthetic cells, damaging the growth of the aerial part [27]. Differently from this study [28] and [13] verified an effect on the growth and development of the castor bean, but of high size, when evaluating different rates of phosphorus.

The population densities of 67,340 and 33,670 plants ha^{-1} differed among themselves as to the number of racemes plant^{-1} at rates 30, 60, 90 and 120 kg ha^{-1} of P_2O_5. For all of these rates, the number of racemes plant^{-1} of the conventional crop was higher than that of the highest population density (Table 3). Several authors [6,9,29] observed that the emission of reproductive structures increases when the plants are more spaced, since in this condition there is a greater area for light absorption and low competition or interference between the plants, when compared to them in higher densities.

In the population density of 33,670 plants ha^{-1} there was an increase in the number of racemes plant^{-1} in a quadratic form, with a higher number of racemes plant^{-1} (2.47) at the calculated rate of 72.5 kg ha^{-1} of P_2O_5, while in the population with 67,340 plants ha^{-1}, with the increase in phosphorus rate the number of racemes plant^{-1} was not altered (Fig. 2). In the conventional cultivation the plants had greater branching capacity, and, in addition, these were favored with greater availability of P, due to less competition for the macronutrient, reasons for which the number of racemes was higher. Several authors have observed influence of phosphorus rates in this variable [13,30].

For interaction between population densities and phosphorus rates there was no significant difference in the number of raceme^{-1} seeds, 100 seed's mass, oil content, seed yield and oil yield. For the cause of variation of population densities, it was detected that there was a significant difference for the variables number of raceme^{-1} seeds, mass of 100 seeds, seed yield and oil yield. For the cause of variation of phosphorus rates, there was a significant difference only for the variables seed yield and oil yield (Table 4).

Table 2. F values with their respective significance and average test for stem diameter (SD), height of plants (HP) height of first raceme insertion (HFRI) number of racemes plant^{-1} (NRP)

Treatments	SD (cm)	HP (cm)	HFRI (cm)	NRP (unid.)
Densities (plant ha^{-1})				
67,340	1.05 a	39.82 a	16.92 a	1.54 b
33,670	1.17 b	47.64 b	17.11 a	2.03 a
Rates of P_2O_5 (kg ha^{-1})				
0	1.06	38.37	15.71	1.45
30	1.13	45.37	16.83	1.72
60	1.17	45.97	16.76	2.22
90	1.07	42.89	17.41	1.84
120	1.10	45.69	18.16	1.71
F test				
Densities (De)	7.79**	11.77**	0.34^{ns}	24.25**
Rates of P_2O_5 (Do)	0.91^{ns}	1.40^{ns}	0.60^{ns}	5.26**
Linear	0.002^{ns}	2.67^{ns}	2.22^{ns}	2.04**
Quadratic	1.60^{ns}	1.35^{ns}	0.01^{ns}	3.95**
De*Do	0.10^{ns}	2.37^{ns}	0.58^{ns}	3.06*
CV (%)	12.18	16.13	18.81	8.16

*Average followed by distinct letters in the column differ from each other by the test F. **: significant ($P \leq 0.01$); *: Significant ($P \leq 0.05$); ns: not significant; CV: coefficient of variation*

Table 3. Deployment of the significant interaction of the analysis of variance to population densities within each rate of phosphorus in the number of racemes plant^{-1}

Densities (plant ha^{-1})	P_2O_5 (kg ha^{-1})				
	0	**30**	**60**	**90**	**120**
67,340	1.45 a	1.51 b	1.67 b	1.63 b	1.42 b
33,670	1.45 a	1.92 a	2.76 a	2.05 a	1.99 a

Averages followed by distinct letters in the column differ from each other by the F test

Table 4. Values of F with their respective significance and averages test for number of number of grains racemes^{-1} (NGR), mass of 100 grains (M100G), oil content (OC), grain yield (GY) and oil yield (OY)

Treatments	NGR (unid.)	M100G (g)	OC (%)	GY (kg ha^{-1})	OY (kg ha^{-1})
Densities (plants ha^{-1})					
67,340	32.10 b	25.55 b	43.83 a	604.65 b	266.61 b
33,670	38.74 a	29.91 a	45.55 a	669.76 a	307.19 a
Rates of P_2O_5 (kg ha^{-1})					
0	38.21	27.04	43.78	532.06	236.77
30	35.31	25.15	44.72	629.00	281.76
60	32.96	28.94	46.11	710.71	328.44
90	32.70	28.11	43.74	646.46	283.16
120	37.11	28.92	45.11	667.81	304.38
F test					
Densities (De)	9.06**	10.62**	3.19^{ns}	4.50*	5.37*
Rates of P_2O_5 (Do)	0.94^{ns}	1.16^{ns}	0.84^{ns}	3.72*	2.99*
Linear	0.38^{ns}	2.00^{ns}	0.49^{ns}	2.66*	2.21*
Quadratic	3.30^{ns}	0.02^{ns}	0.72^{ns}	2.31*	1.90*
De*Do	0.60^{ns}	0.40^{ns}	2.53^{ns}	1.67^{ns}	1.41^{ns}
CV (%)	9.96	14.94	6.84	15.24	19.30

*Averages followed by distinct letters in the column differ from each other by the test F. **: significant ($P \leq 0.01$); *: Significant ($P \leq 0.05$); ns: not significant; CV: coefficient of variation*

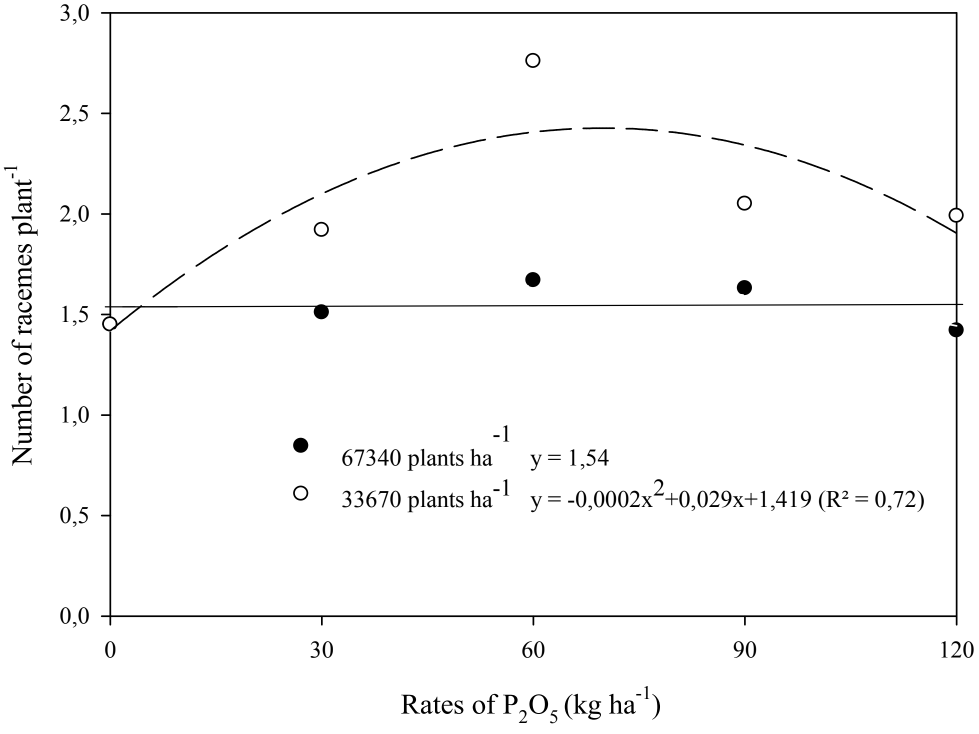

Fig. 2. Deployment of the significant interaction of analysis of variance for phosphorus rates within each population density in the number of racemes plant^{-1}

The number of raceme^{-1} grains was higher (39.74) in the population density of 33,670 plants ha^{-1} (Table 4). According to Taiz and Zeigher [31], in conditions where there is intense competition, mainly for light, caused by the greater population density, or by the smaller line spacing, the plants present a low amount of dry matter, as a consequence, they have a low apparatus photosynthetic, reflecting low production of reproductive structures.

Phosphorus rates did not influence number raceme^{-1} grains data (Table 4). According to Moro et al. [32], the number of grains plant^{-1} is a characteristic with wide variation and not always the modifications are coming from the fertilization of the soil.

In the population density 33,670 plants ha^{-1}, with 29.91 g, it was obtained a larger mass of 100 grains (Table 4). For [4], interference in the formation and accumulation of grain reserves is associated with the reduction of the photosynthetic rate caused by the increase of intraspecific competition by light in the densification between the plants in the area. Similar results were found by [5,33], which found a decrease in the mass of 100 grains through the narrowing of space between plants.

Although the mass of 100 grains suffer high influence from the environmental conditions, for this variable there was no effect as a function of the rates of phosphorus used in the fertilization (Table 4). Corroborating the reports of [34] in the study culture; [35] in crambe (*Crambe abyssinica* Hochst); [36,37] in peanut (*Arachis hypogaea* L.), which also did not find a significant difference among the treatments of phosphate fertilization studied.

The oil content in the grains had no significant effect on the population densities under study (Table 4). This variable in castor bean has high heritability [7]. Several authors [9,10,33] also did not observe variation in the percentage of oil in the percentage of oil in the grains in the castor bean crop exposed to different row spacing. Severino et al. [11] found a reduction in the oil content in the castor bean with the increase in population density. These authors related the constraining results found in the literature to little understanding about the effect of factors of the production environment and crop management on this variable.

In this work, no response of the variable oil content was observed in relation to the phosphorus rates applied in the sowing furrow (Table 4). The same behavior was observed with peanut by [38], and with crambe by several authors [35,39], who did not find differences between the rates studied. However, it differs from the results obtained by [24], where the oil content in the seed was increased from 47.6 to 50.2% between rates 0 and 100 kg ha^{-1} of phosphorus. Sachs et al. [40] verified an increase in oil content in the achenes of the sunflower (*Helianthus annuus* L.) by phosphate fertilization. Many factors can affect the oil content in the present experiment, what include the minimum rate of nutrients applied in the soil not be enough to affect the plants or period of growth stage vegetative [41].

Because of the divergence between the researches on the positive effect of P rates on the oil content, it is possible that the adequate management of the phosphate fertilization is essential to express a higher oil content in the castor and other oilseeds, even though it is a trait of high heritability.

The highest grain yield (670 kg ha^{-1}) was obtained at the density of 33,670 plants ha^{-1} (Table 4). The increase in grain yield obtained by the use of wider spacing Is probably due to the best relationship between amount of racemic plant^{-1}, amount of racemo^{-1} grains and grain mass. This work corroborates the recommendation of [42]. [5,11,33] using the genotypes BRS Nordestina, IAC 2028 and FCA-PB respectively, noticed that increasing the population density there was an increase in yield, pointing out that the density of plants in the area could be used as a way of increasing yield. However, when studying with high population densities, only the use of closer rows may not have efficiency to increase grain yield of the low size castor oil plant [4].

The grain yield was influenced by the phosphorus rates, with a maximum yield of 689 kg ha^{-1} at the rate of 80 kg ha^{-1} of P_2O_5 (Fig. 3). With this, an increase of 23% was verified in relation to the plants that did not receive phosphate fertilization. This result confirms those found by several studies in which they observed a positive effect of the addition of P in the castor bean, as verified by several authors [13,34,43].

Oliveira et al. [12], studying the behavior of the cultivars AL Guarany 2002 and Lyra, observed an increase in yield through the application of increasing rates of P_2O_5, showing that the maximum grain yield of AL Guarany 2002 (2,822 kg ha^{-1}) and Lyra (2,780 kg ha^{-1}) were obtained in the rates of 120 kg ha^{-1} and 90 kg ha^{-1} of P_2O_5, respectively. The authors attributed the beneficial impact of phosphorus supply on the yield of the cultivars to the low P content available in the soil (5.9 mg dm^{-3}) and the relevance of this macronutrient to the productive behavior of oil-producing crops.

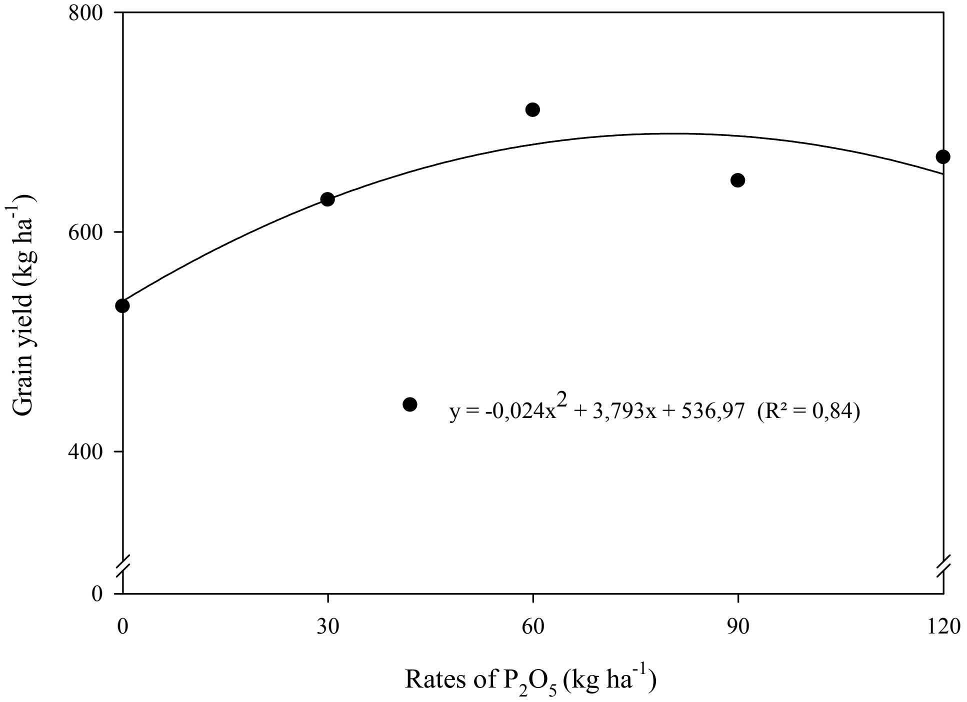

Fig. 3. Grain yield values (kg ha^{-1}) at different rates of phosphorus

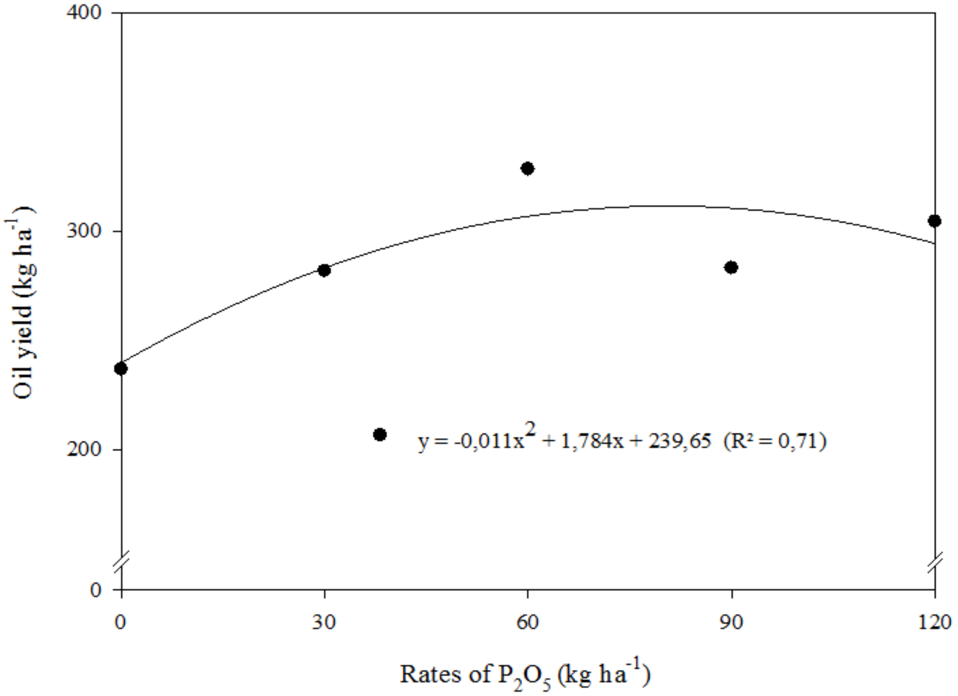

Fig. 4. Values of oil yield (kg ha^{-1}) at different rates of phosphorus

The increase in grain yield as a function of phosphate fertilization occurred due to the phosphorus propitiating greater extraction of nutritional mineral elements by the plant with correct supply of P_2O_5, especially N [17], better absorption of CO_2 [44,45] and by the reason for this nutrient is strongly linked to the process of energy release and storage in the form ADP and ATP [13,15].

The performance of the castor observed in this study strengthens, until then, the assumption that phosphorus is the most important element in increasing crop yield [30,46].

As the population densities under study did not significantly influence the oil content in the seeds, the oil yield was similarly influenced by grain yield, with a positive correlation between the two variables ($r = 0.96$, $p < 0.001$), that is, the highest oil yield (307.19 kg ha^{-1}) was obtained in the population density of 33,670 ha^{-1} plants (Fig. 4). Similar results were observed by several authors [4,5,9,33], where they observed a high correlation between grain and oil yields at the population densities evaluated.

The oil yield was influenced by the phosphorus rates, similar to the grain yield, as the addition of P did not increase the oil content. The maximum oil yield was 311 kg ha^{-1} at the 80 kg ha^{-1} rate of P_2O_5 (Fig. 4). This result reinforces the importance of this macronutrient to the increase of oil yield, as observed in the studies carried out by Rogério et al. [39] in the crambe, where the deficiency of P, limited the production of oil by area.

4. CONCLUSION

The increase in population density reduced the growth and development of the cultivar, low size, AG IMA 110204, regardless of the rates of phosphorus.

The productive performance of castor bean was favored in isolation by the low population density and the rate of 80 kg ha^{-1} of P_2O_5, being a great alternative for the farmers of Brazilian Cerrado.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Berman P, Nizri S, Wiesman Z. Castor oil biodiesel and its blends as alternative fuel. Biom. Bioen. 2011;35(7):2861-2866. English
2. FAOSTAT. United Nations Food and Agriculture Organization. Castor oil seeds. Roma: Faostat; 2017. English
Available:http://www.fao.org/faostat/en/#data/QC
3. Severino LS, et al. Review on the challenges for increased production of castor. Agro. Jour. 2012;104(4):853-880. English
4. Souza-Schlick GD, Soratto RP, Bottino D, Fernandes AM. Growth and productivity of small castor bean in different plant spacing and population densities. Interciência. 2012;37(1):49-54. English
5. Souza-Schlick GD, Soratto RP, Pasquali CB, Fernandes AM. Performance of the IAC 2028 castor as a function of row spacing and plant population density in the second crop. Bragantia. 2011;70(3):519-528. English
6. Bizinoto TKMC, Oliveira EG, Martins SB, Souza AS, Gotardo M. Cultivation of castor beans influenced by different plant populations. Bragantia. 2010;69(2):367-370. English
7. Soratto RP, Souza-Schlick GD, Fernandes AM, Zanotto MD, Crusciol CAC. Narrow row spacing and high plant population to short height castor genotypes in two cropping seasons. Ind. Crop. Prod. 2012;35(1):244-249. English
8. Petinari RA, Soratto RP, Sousa-Schlick GD, Zanotto MD, Bergamasco SMPP. Costs of production and profitability of castor bean cultivars in different plant arrangements. Pesq. Agrop. Trop. 2012;42(2):143-149. English
9. Souza-Schlick GD, Soratto RP, Zanotto MD. Optimizing row spacing and plant population arrangement for a new short-height castor genotype in fall-winter. Act. Sci; Agron. 2014;36(4):475-481. English
10. Severino LS, Moraes CRA, Gondim TMS, Cardoso GD, Beltrão NEM. Growth and productivity of castor bean influenced by planting at different row spacings. Rev. Sci. Agron. 2006d;37(1):50-54. English
11. Severono LS, Coelho DK, Moraes CRA, Gondim TMS, Vale LS. Optimization of planting spacing for the castor bean cultivar BRS Nordestina. Rev. Braz. Oleag. and Fib. 2006a;10(2):993-999. English
12. Oliveira JPM, Scivittaro WB, Castilhos RMV, Oliveira Filho LCI. Phosphate fertilization for castor bean cultivars in Rio

Grande do Sul. Sci. Rur. 2010;40(8):1835-1839. English

13. Silva DF, Trindade RCP, Oliveira MW, Ferro JHA, Calheiros AS. Vegetative growth and productivity of castor bean due to variety and phosphate fertilization. Caatinga. 2012;25(1):160-167. English
14. Silveira TC, Pegoraro RF, Portugal AF, Resende AV. Production of castor bean submitted to combinations with sources of phosphorus and liming. Rev. Braz. Eng. Agri. Amb. 2015;19(1):52-57. English
15. Xu HX, Weng XY, Yang Y. Effect of phosphorus deficiency on the photosynthetic characteristics of rice plants. Rus. Jour. Plan. Phy. 2007;54(6):741-748. English
16. Hernández I, Munné-Bosch S. Linking phosphorus availability with photo-oxidative stress in plants. Jour. Exp. Bot. 2015;66(10):2889-2900. English
17. Jeschke WD, Peuke A, Kirkby EA, Pate JS, Hartung W. Effects of P deficiency on the uptake, flows and utilization of C, N and H_2O within intact plants of *Ricinus communis* L. Jour. Exp. Bot. 1996;47(11): 1737-1754. English
18. Cunha AR, Martins D. Climate classification for the municipalities of Botucatu and São Manuel, SP. Irriga. 2009;14(1):1-11. English
19. Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JÁ, Cunha TJF, Oliveira JB. Brazilian system of soil classification. 3rd Ed. Brasília: Embrapa; 2013. English
20. Raij B, Andrade JC, Cantarella H, Quaggio JA. Chemical analysis for fertility evaluation of tropical soils. Campinas: IAC; 2001. English
21. Savy Filho A. Mamona. In: Raij BV; Cantarella H, Quaggio JÁ, Furlani AMC, Editors. Fertilizer and liming recommendations for the state of São Paulo. 2nd Ed, Campinas: IAC; 1997. English
22. Colnago LA, Azeredo RBV, Marchi Netto A, Andrade FD, Venâncio T. Rapid analyses of oil and fat content in agri-food products using continuous wave free precession time domain NMR. Mag. Res. Che. 2011;49(1):113-120. English
23. Carvalho EV, Sá CHAC, Costa JL, Afférri FS, Siebeneichler SC. Planting density in two castor bean cultivars in the South of Tocantins. Rev. Sci. Agron. 2010;41(3): 387-392. English
24. Severino LS, Ferreira GB, Moraes CRA, Gondim, TMS, Freire WSA, Castro DA, Cardoso GD, Beltrão NEM. Growth and productivity of castor beans fertilized with macronutrients and micronutrients. Pesq. Agro. Bra. 2006c;41(4):563-568. English
25. Fioreze SL, Fioreze ACCL, Pivetta, LG, Rodrigues JD, Zanotto MD. Agronomic characteristics of castor bean plants affected by planting method and sowing density. Rev. Sci. Agron. 2016;47(1):86-92. English
26. Lopes GEM, Vieira HD, Partelll FL. Response of castor bean plants to different row spacings and planting seasons. Am. Jour. Plan. Sci. 2013;4(1):10-15. English
27. Poorter H, Niklas KJ, Reich PB, Oleksyn J, Poot P, Mommer L. Biomass allocation to leaves, stems and roots: meta-analyses of interspecific variation and environmental control. New Phytologist. 2012;193(1):30-50. English
28. Almeida Junior AB, Oliveira FA, Medeiros JF, Oliveira MKT, Linhares PCF. Effect of phosphorus doses on initial development of castor bean. Caatinga. 2009;22(1):217-221. English
29. Anastasi U, Sortino O, Cosentino SL, Patanè C. Seed yield and oil quality of perennial castor bean in a Mediterranean environment. Int. Jour. Plan. Sci. 2015;9(1):99-116. English
30. Severino LS, Ferreira GB, Moraes CRA, Gondim TMS, Cardoso GD, Viriato JR, Beltrão NEM. Productivity and growth of the castor bean in response to organic and mineral fertilization. Pesq. Agro. Braz. 2006b;41(5):879-882. English
31. Taiz L, Zeigher E. Plant physiology. 5th Ed. Porto Alegre: Artmed; 2013. English
32. Moro E, Crusciol CAC, Carvalho LLT. Nitrogen application times for castor bean hybrids in the no-tillage system. Sem. Sci. Agr. 2011;32(2):391-410. English
33. Soratto RP, Souza-Schlick GD, Giacomo BMS, Zanotto MD, Fernandes AM. Spacing and population of small-sized castor bean plants for mechanized harvesting. Pesq. Agro. Braz. 2011;46(3): 245-253. English
34. Cunha DA, Teixeira IR, Jesus FF, Guimarães RT, Teixeira GCS. Phosphate fertilization and production of common bean and castor bean in a consortium. Bios. Jour. 2014;30(5):617-628. English
35. Rogério F, Santos JI, Silva TRB, Migliavacca RA, Gouveia B, Barbosa MC.

Effect of phosphorus doses on the development of crambe. Bios. Jour. 2012;28(1):251-255. English

36. Nakagawa J, Nakagawa J, Toledo FF, Machado JR. Effects of increasing doses of phosphate fertilizer on peanut crop (*Arachis hypogaea* L.). Bot. Sci. 1977;2(1):129-136. English
37. Nakagawa J, Imaizumi I, Nakagawa J, Rossetto CAV. Effects of phosphate fertilizers and methods of application on peanut cultivation. Rev. Braz. See. 1990;12(3):23-39. English
38. Kasai FS, Athayde MLF, Godoy IJ. Phosphate fertilization and harvesting times in peanuts: effects on oil and protein production. Bragantia. 1998;57(1):01-06. English
39. Rogério F, Silva TRB, Santos JIS, Poletine JP. Phosphorus fertilization influences grain yield and oil content in crambe. Ind. Crop. Prod. 2013;41(1):266-268. English
40. Sachs LG, Portugal AP, Prudencio-Ferreira SH, Ida EI, Sachs PJD, Sachs JPD. Effect of NPK on sunflower chemical productivity and components. Sem. Sci. Agr. 2006;27(4):533-546. English
41. David EDFS, Mischan MM, Boaro CSF. Development and yield of essential oil of mint (*Mentha x piperita* L.) grown in nutrient solution with different levels of phosphorus. Biotemas. 2007;20(2):15-26. English
42. Sá RO, Galbieri R, Bélot J, Zanotto MD, Dutra SG, Severino LS, Silva CJ. Castor plant: Option for crop rotation aiming the reduction of gall nematodes in cotton cultivation. Cuiabá: IMAmt; 2015. English
43. Ribeiro S, Chaves LHG, Guerra OC, Gheyis HR, Lacerda RD. Response of the castor bean BRS-188 Paraguaçu to the application of nitrogen, phosphorus and potassium. Rev. Sci. Agr. 2009;40(4):465-473. English
44. Singh SK, Badgujar GB, Reddy VR, Fleisher DH, Timlin DJ. Effect of phosphorus nutrition on growth and physiology of cotton under ambient and elevated carbon dioxide. Jour. Agro. Crop. Sci. 2013;199(1):436-448. English
45. Zhang K, Liu H, Tao P, Chen H. Comparative proteomic analyses provide new insights into low phosphorus stress responses in maize leaves. PloS one. 2014;9(5):01-16. English
46. Pacheco DD, Gonçalves NP, Saturnino HM, Antunes PD. Production and nutrient availability for castor bean (*Ricinus communis*) fertilized with NPK. Rev. Bio. Sci. Ter. 2008;8(1):153-160. English

---

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/28048