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Organomineral fertilization in growth, physiology and phytomass production of castor oil plant BRS energia

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This work aims to study the effect of castor oil plant cake doses (0.0; 1,100; 2,200 and 3,300 Kg ha^{-1}) associated with P doses (0.0 and 90 Kg ha^{-1}) and K doses (0.0 and 60 Kg ha^{-1}) on initial growth period of castor oil plant BRS Energia. The experiment was conducted under greenhouse's conditions at the Embrapa Algodão, located in Brazil. The experimental design of randomized blocks was used in a 4x2x2 factorial arrangement, with 4 replications, totaling 64 experimental units. The castor oil plant cake application influenced the pH, phosphorus (P), potassium (K), magnesium (Mg) and organic matter (M.O.) values in the soil. The variables of growth, height, stem diameter, number of leaves and leaf area increased linearly with the application of castor oil plant doses, as well as for the variables of phytomass production from root, aerial part and total. The doses of castor oil plant cake influenced the nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) contents. The relative chlorophyll content and transpiration increased in a quadratic manner due to the castor oil plant cake application.

Key words: Castor oil plant cake, organic waste, phosphorus, potassium.

INTRODUCTION

Considered a rustic plant with high productive potential, the castor oil plant or castor bean (*Ricinus communis L.*) is an oleaginous belonging to the Euphorbiaceas family and it has been occupied, a prominent place among the main oleaginous plants cultivated in Brazil (Brito et al., 2017). The castor bean can be a profitable alternative for small farmers in the semi-arid region, but it is necessary to solve some problems related to fertilization and

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Table 1. Chemical characteristics of the soil used in the experiment before and after liming, performed at Embrapa-Algodão.

pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SB	H + Al	CTC	V	P	M.O.
1:2.5	Sortive Complex (mmolcdm^{-3})							%	mg dm^{-3}	g kg^{-1}
					Before the liming					
5.4	5.5	2.7	2.3	1.2	11.7	19.2	30.7	38.1	19.1	3.7
					After the liming					
6.5	14.6	10.4	9.2	1.2	35.9	n.d	35.9	100	19.1	3.6

Source: Campina Grande-PB, 2013.

Table 2. Physical characteristics of the soil used in the experiment, performed at Embrapa-Algodão.

Textural Composition			Textural Classification (1)	Density		Total Porosity
Sand	Silt	Clay		Soil	Particles	
--------g kg^{-1}--------				--------g cm^{-3}--------		%
79.35	12.18	8.47	Sandy loam	1.58	2.67	40.67

Physical analysis performed at the Soil Laboratory at Federal University of Campina Grande-PB, 2013.

nutrition management which reflects in the increase of productivity.

Most of Brazilian soils present problems related to fertility (Beltrão et al., 2006; Costa et al., 2013; Torres et al., 2016) making it indispensable to know their ability to supply nutrients for plants, as well as improve fertilizer recommendation, aiming for a more efficient and sustainable production over the years. In this sense, it is important the organic matter maintenance allied to conservationist practices to ensure the immobilized nutrients flow to the soil solution, especially N (Olsen et al., 1997).

Thus, the castor oil plant cake is one of the alternatives for organic fertilization sources in the northeast region which is a by-product from oil extraction and has important characteristics such as high N content, acting as a soil conditioner (Severino, 2005; Marques et al., 2010). The viability of the use in organic fertilization can also be attributed to the low C/N ratio (11:1), making it available through nutrient mineralization instantly. Soil incorporation promotes changes in physical, chemical and biological characteristics which improve the structure, increase the water retention capacity, aeration and soil fertility.

Despite all these favorable characteristics to castor oil plant cake, it has low P content which make necessary the use of sources for these elements associated with castor bean cake, resulting in an organomineral compound. Among the three main macronutrients, P is the one that is required in smaller quantities by plants. However, it is an important element in plant metabolism, because it participates in cell energy transfer, respiration and photosynthesis (Furtini et al., 2001).

Thus, the knowledge about the P amount that should be associated with the castor oil plant cake to formulate an organomineral compound as a fertilizer becomes really important for the increase in nutrients and organic matter in the soil. In this sense, this work aims to study the effect of castor oil plant cake doses associated with P and K doses on the initial growth of the castor bean BRS Energia.

MATERIALS AND METHODS

The experiment was carried out in a protected environment, belonging to the Centro Nacional de Pesquisa do Algodão (CNPA) [National Cotton Research Center] of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) [Brazilian Agricultural Research Company] located in the municipality of Campina Grande-PB, with the geographic coordinates 7°13'50" south latitude and 35°53'52" west longitude and approximate altitude of 550 m at sea level.

Substrate was used, a material from the first 30 cm of the Regolithic entisol (soil of the region) that has medium texture, according to the new classification of Embrapa Solos (2009), from the Estação Experimental da Empresa de Pesquisa Agropecuária (EMEPA) [Experimental Station of the Agricultural Research Company] located in the municipality of Lagoa Seca-PB. A compound soil sample was collected and sent to Laboratório de Solos e Nutrição de Plantas da Embrapa-Algodão [Embrapa Algodão's Laboratory of Soils and Plant Nutrition] for chemical analysis, according to Embrapa (1997), whose chemical and physical characteristics are presented in Tables 1 and 2, respectively.

The treatments were distributed in a randomized block design

Table 3. Chemical composition of castor oil plant cake used in the experiment.

Determinations						
U	**M.O.**	**P.B**	**Cz**	**N**	**P**	**K**
%						
9.27	80.13	50.68	10.40	8.11	1.72	1.77

U= humidity; M.O.= Organic matter; P.B= Crude Protein; Cz= Ashes; N= Nitrogen; P= Phosphor; K= Potassium. Laboratório de Solos e Nutrição de Plantas da Embrapa-Algodão (Laboratory of Soils and Nutrition of Plants of Embrapa-Algodão).

with factorial arrangement 4x2x2 with four doses of castor oil plant cake (00; 1,100; 2,200; 3,300 kg ha^{-1}). It were determined considering the N content in the chemical composition of the cake to provide 0.0; 89.2; 178.4 and 267.6 kg of N/ha, respectively, also two P doses (00 and 90 kg ha^{-1}) and K doses (00 and 60) both determined based on the P and K content present in the soil, using triple superphosphate and potassium chloride as sources. This was made in four replications, totaling 64 experimental units. Each experimental unit was composed of a plastic vase with 35L of capacity and a soil mass of 55.3 kg. At the base of the vase, a 3 cm layer of fine gravel was placed, which was previously washed with running water to facilitate the drainage in the vase. The castor bean cake doses were calculated based on the N content present in its chemical composition (Table 3).

Based on the soil chemical analysis results, the liming was realized with the application of dolomitic limestone for pH correction. The soil was incubated for a period of 20 days, with irrigation until the humidity was raised to 80% of the field capacity, for limestone reaction and consequently, acidity neutralization. After the incubation, the treatments were applied and also the incorporation of the castor oil plant cake doses together with the P and K doses and soil, was incubated for another period of 15 days. After the soil incubation period, five castor seeds of cv. BRS Energia were treated with fungicide, at 3 cm depth and 15 days after emergence and the thinning was performed, leaving the plant more vigorous per vase.

During the experiment, cultural treatments were carried out in the experiment, such as the removal of invasive plants, which were manually removed weekly. In the same way, it was proceeded with the old leaves that senesced in order to avoid the emergence of diseases in the plants. Irrigation was performed daily through the replacement of water lost during evapotranspiration, leaving the vases close to the field capacity. In order to do so, we adopted the vase weighing method, which four vases of each block were weighed, then was made the average of the weighing and the result used for all vases.

At the end of the experiment, 60 days after seedling emergence, the measurement of plant height (ALT), stem diameter (DC) and leaf area (AF) were taken. The plant height was determined with the help of a millimeter ruler, measuring from the lap of the plant to the apex. To determine the stem diameter, a digital caliper was used. It measure in the lap of the plant 1 cm from the ground in a previously marked point. A millimeter ruler was used to determine the leaf area by measuring the leaf length and width and then applying the values to the formula:

$$S = 0,\ 2622 \times P2,\ 4248$$ (Severino, 2004)

where:
S= Leaf Area
P= Main leaf vein length

Specific leaf area (AFE) was determined, which relates the leaf surface to the leaf weight, meaning leaf area availability in each leaf gram indicate the leaf thickness.

$$AFE = AF\ (dm^2\ g^{-1})$$

where:
AF= leaf area
PF= dry matter weight of the leaf.

The leaf area ratio (RAF) was determined by the relationship between specific leaf area and leaf weight ratio, in other words, represents the leaf area available to occur in photosynthesis.

$$RAF = AF\ (dm^2\ g^{-1})$$

where:
AFE = leaf area
PP = dry matter weight of the plant.

The leaf weight ratio (RPF), which is the dry matter fraction produced by photosynthesis, is not used in respiration nor exported to other parts of the plant, which is retained in the leaves and represent how much the plant invested in its production via photosynthesis to the leaves, being a dimensionless calculation.

$$RMF = MF / MP$$

PF= Dry matter weight of the leaf
MT= Dry matter mass of the total plant.

Sixty days after the seedlings emergence, the aerial part was cut from each vase in 1 cm of distance from the soil, separating the plant in aerial part (stem and leaf) and root, which the sum resulted in the total dry mass, determining the relation aerial part - root. So, the vegetable material was washed in running water and then in distilled water, pre-dried in the greenhouse and packed in perforated paper bag. To complete drying, the material was taken to a forced air circulation oven at 65°C until constant weight, and then weighed in an analytical balance of 0.01 g precision to obtain the dry mass.

After determining the dry mass of the aerial part of the plants, it was Spelling eror in a Wiley mill type and mineralized by sulfuric digestion to determine macronutrients (TEDESCO et al., 1995). The photosynthetic capacity, the internal CO2 concentration, the stomatal conductivity, and the transpiration rate were obtained in saturated light using the Infrared Gas Analyzer (IRGA - Infra RedGasAnalyzer) LI-6400 model (LICOR®, Inc., Lincoln, NE , USA) according to the methodology described by Walker (1987) and Prado and Moraes (1997).

Table 4. Summary of the variance analysis and respective mean squares for the chemical attributes of the soil.

Variation source	GL	Mean squares					
		pH	**Ca**	**Mg**	**P**	**K**	**M.O.**
Linear Reg.	1	0.15**	26.50^{ns}	53.95**	7592.23**	0.10**	8.51**
Quadratic Reg.	1	0.01^{ns}	11.81^{ns}	1.44^{ns}	447.85^{ns}	0.16^{ns}	2.32*
Cubic Reg.	1	0.03^{ns}	1.55^{ns}	0.36^{ns}	942.22^{ns}	0.09^{ns}	1.56^{ns}
Blocs (B)	3	0.014	9.98	3.37	75.65	0.07	14.0
Cake (T)	3	0.068*	13.29^{ns}	18.58**	2994.13**	0.12^{ns}	4.13**
Phosphorus (P)	1	0.113*	121.27**	3.61^{ns}	62819.15**	1.05**	14.06^{ns}
Potassium (K)	1	0.213**	6.82^{ns}	4.00^{ns}	43.39^{ns}	13.87**	6.12**
T x P	3	0.048*	18.48^{ns}	3.05^{ns}	1325.22**	0.36*	1.33^{ns}
T x K	3	0.063^{ns}	14.77^{ns}	1.62^{ns}	226.12^{ns}	0.09^{ns}	4.88^{ns}
P x K	1	0.0001^{ns}	7.63^{ns}	0.0006^{ns}	152.21^{ns}	0.22^{ns}	5.40^{ns}
T x P x K	3	0.035^{ns}	11.13^{ns}	3.72^{ns}	155.82^{ns}	0.05^{ns}	7.09^{ns}
Residue	45	0.026	10.56	3.43	330.53	0.126	0.601
CV (%)		2.16	18.71	18.35	38.96	20.56	15.71

Potential of hydrogen (pH), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K) and organic matter (M.O.), GL - Degree of freedom; ns - not significant; ** and, * meaning 1 and 5% of probability, respectively, by the F test. Source: Campina Grande, PB, 2013.

The relative chlorophyll index (IRC) was determined using a portable chlorophyllometer, Clorofilog 1030®. Before the readings, the instrument was calibrated according to the recommendations found in the manual. Some care was taken with damaged leaves not to used it as sample, or with pest symptoms and disease attack. The determinations were performed in the morning, shading the device to avoid interference of the solar rays. There were realized two readings per plant, one in the leaf of the middle third and the other in the leaf of the upper third of the plant, the leaves was observed with fully developement, avoiding the leaf vein region.

The results were submitted to variance analysis, by the F-test at 5 and 1% probability levels, the averages were compared by Tukey test at 5% of probability; the quantitative treatments were submitted to regression analyzes of greater significance (Pimentel Gomes., 1990), using the software SAS (Statistical Analysis System).

RESULTS AND DISCUSSION

The summary of the variance analysis with the mean squares and their respective significance by the F test with 5% probability for the parameters as soil fertility, potential of hydrogen (pH), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K) and organic matter (MO) as a function of the castor oil plant cake, P and K factors are shown in Table 4.

Among the soil fertility variables in the end of the experiment, it was possible to observe that there was a significant effect of the interaction between the factors cake and P for pH, P and K variables. Silva et al. (2012) verified that the levels of residual P, K, Ca and Mg in the soil, with the exception of Ca, were linearly increasing as a function of castor bean cake doses. However, there was a significant response of the Mg and M.O. Contents as a function of the isolated effect of the castor bean cake doses plus this result was already expected due to the amount of M.O. present in the castor bean cake. Fernandes et al. (2009), using two doses of castor bean cake (0.0 and 10 t ha^{-1}), obtained a significant increase (23 g kg^{-1}) in the M.O. content of the soil with the application of 10 t ha^{-1} castor bean cake relative to the control sample (12 g kg^{-1}).

The Table 5 shows the averages of the variables studied in the soil (pH, Ca, Mg, P, K and M.O.) in function of P and K doses, where it is possible to verify that there was a significant difference between the P doses studied (0.0 and 90 kg ha^{-1}). higher mean values for pH, Ca, P and K with the applicattion of 90 kg ha^{-1} doses was observed, when compared to the control sample (0.0 kg of P) however, there was no statistical difference between the doses worked on the contents of Mg and M.O. in the soil.

The K application did not influence the Ca, Mg and P contents, but it was observed higher mean values with the applicattion of 60 kg ha^{-1} doses for pH, M.O. and K variables. This behavior was already expected for K due to its supply through fertilization (1.2 mmolc dm^{-3}), considered in the average range for most crops (Ribeiro et al., 1999).

The unfolding of P doses within the castor oil plant cake doses showed that, the pH of the soil at the end of the experiment was strongly influenced by the doses of castor bean cake with the decreasing linear adjustment for the absence of P and quadratic for the 90 kg ha^{-1} dose with high coefficients of determination.

In Table 6, the summaries of variance analyses with

Table 5. Averages of soil chemical attributes.

Treatments	Variables analyzed					
	pH	Ca	Mg	P	K	M.O.
Phosphorus doses						
0 Kg ha^{-1} of P	7.46^{b}	15.99^{b}	9.84^{a}	15.33^{b}	1.60^{b}	4.78^{a}
90 Kg ha^{-1} of P	7.55^{a}	18.75^{a}	10.34^{a}	77.99^{a}	1.85^{a}	5.08^{a}
DMS	0.081	1.636	0.932	9.15	0.178	0.390
Potassium doses						
0 Kg ha^{-1} of K	7.40^{b}	17.O04^{a}	9.85^{a}	45.84^{a}	1.26^{b}	4.65^{b}
60 Kg ha^{-1} of K	7.56^{a}	17.70^{a}	10.33^{a}	47.49^{a}	2.19^{a}	5.22^{a}
DMS	0.081	1.636	0.932	9.15	0.178	0.390

Potential of hydrogen (pH), calcium (Ca), magnesium (Mg), phosphorus (P) and potassium (K). The averages in the columns followed by same letters do not differ among themselves by the Tukey test. Source: Campina Grande, PB.

Table 6. Summary of variance analyses and respective mean squares for the variables of growth.

Variation source	GL	Mean squares			
		ALT (cm)	DC (mm)	NF	AF (cm²)
Linear Reg.	1	1524.69**	111.99**	15.75**	3399784.57**
Quadratic Reg.	1	43.06^{ns}	3.16^{ns}	0.39^{ns}	20206.62^{ns}
Cubic Reg.	1	3.93^{ns}	0.84^{ns}	0.15^{ns}	18477.12^{ns}
Blocs (B)	3	7.73	3.52	2.80	806114.05
Cake (T)	3	523.89**	38.66**	5.43**	1146156.10**
Phosphorus (P)	1	1410.94**	79.14**	3.51*	2700106.24**
Potassium (K)	1	93.84*	0.32^{ns}	1.89^{ns}	117940.73^{ns}
Contrasts					
T x P	3	24.62^{ns}	1.60^{ns}	3.68**	35208.96^{ns}
T x K	3	30.09^{ns}	2.90^{ns}	0.39^{ns}	125066.43^{ns}
P x K	1	0.03^{ns}	0.43^{ns}	0.76^{ns}	533.61^{ns}
T x P x K	3	23.76^{ns}	1.65^{ns}	1.68^{ns}	165808.20^{ns}
Residue	45	23.41	1.81	0.840	167287.78
CV (%)		13.42	11.05	12.25	39.20

Plant height (ALT), stem diameter (DC) number of leaves (NF) and leaf area (AF) of castor bean plants, GL - Degree of freedom; ns - not significant; ** and, * meaning 1 and 5% of probability, respectively, by the F test. plant height (ALT), stem diameter (DC) number of leaves (NF) and leaf area (AF) of castor bean plants. Source: BRS Energia,Campina Grande-PB, 2013.

the mean squares and their respective significance by F-test at 5% probability for height (ALT), stem diameter (DC), number of leaves (NF) and leaf area (AF) are presented. The statistical analysis revealed significant effect of the interaction between the castor bean doses with P doses only for the number of leaves. However, there was an isolated effect of castor oil plant cake doses for the variables height, stem diameter, number of leaves and leaf area.

The mean values of growth variables analyzed in function of P and K doses are presented in Table 7, where it can be verified that there was a significant difference between the P doses studied (0.0 and 90 kg ha^{-1}). It can be observed that the average values were higher for the variable height, stem diameter, number of leaves and leaf area when fertilized with 90 kg ha^{-1} dose as compared to the control sample (0.0 kg of P). The summary of the variance analysis by the mean squares and their respective significance by F-test at 5% probability for growth measures (specific leaf area, leaf mass ratio and leaf area ratio) are presented in Table 8.

The statistical tests did not indicate a significant

Table 7. Averages for growth variables.

Treatments	Variables analyzed			
	ALT (cm)	DC (mm)	NF	AF (cm^2)
Phosphorus doses				
0 Kg ha^{-1} of P	31.37^b	11.09^b	7.25^b	837.85^b
90 Kg ha^{-1} of P	40.76^a	13.32^a	7.71^a	1248.65^a
DMS	2.43	0.67	0.46	205.04
Potassium doses				
0 Kg ha^{-1} of K	34.85^b	12.28^a	7.31^a	1000.33^a
60 Kg ha^{-1} of K	37.28^a	12.13^a	7.65^a	1086.18^a
DMS	2.43	0.67	0.46	205.04

Plant height (ALT), stem diameter (DC) number of leaves (NF) and leaf area (AF) of castor oil plants Cv. BRS Energia, in function of phosphorus (P) and potassium (K) doses. The averages in the columns followed by same letters do not differ among themselves by the Tukey test. Source: Campina Grande-PB, 2013.

Table 8. Summary of variance analyses and respective mean squares for the variables of growth components.

Variation source	GL	Mean squares		
		AFE	RMF	RAF
Linear Reg.	1	167.504^{ns}	0.056^{ns}	507.880*
Quadratic Reg.	1	5247.191^{ns}	0.098**	78.721^{ns}
Cubic Reg.	1	17.784^{ns}	0.004^{ns}	61.881^{ns}
Blocs (B)	3	2380.489	0.026	348.504
Cake (T)	3	1810.827^{ns}	0.053*	216.161*
Phosphorus (P)	1	0.001^{ns}	0.038^{ns}	1115.560**
Potassium (K)	1	1721.420^{ns}	0.003^{ns}	0.462^{ns}
Contrasts				
T x P	3	2517.383^{ns}	0.031^{ns}	35.715^{ns}
T x K	3	250.933^{ns}	0.003^{ns}	171.111^{ns}
P x K	1	12. 762^{ns}	0.0008^{ns}	18.705^{ns}
T x P x K	3	3312.121^{ns}	0.021^{ns}	22.428^{ns}
Residue		2204.43	0.016	89.65
CV (%)		43.15	27.73	20.29

Specific leaf area (AFE), leaf mass ratio (RAF) and leaf area ratio (RMF) of castor bean plants CV, GL - Degree of freedom; ns - not significant; ** and, * meaning 1 and 5% of probability, respectively, by the F test. Source: BRS Energia, Campina Grande-PB, 2013.

interaction effect between the factors studied for any of the analyzed variables. However, there was a significant effect of the castor oil plant cake only on leaf mass ratio (RMF) and leaf area ratio (RAF). As for P, there was a significant effect only on the leaf area ratio. And for K, no significant effect was observed on any analyzed variables. The growth analysis expresses the morphophysiological conditions of the plant and quantifies the net production, derived from the photosynthetic process being the performance result of assimilatory system during a certain period of time. This performance is influenced by the biotic and abiotic factors of plant (Larcher, 2006). In this specific case, it was more due to the effects of the castor bean cake doses.

According to the literature, low levels of P slows the initial growth of castor bean plants and causes a considerable reduction in productivity (Machineski et al., 2011), because this is one of the main nutrient for this oleaginous plant by participating in important reactions with emphasis on processes related to energy flow,

Table 9. Average of specific variables of castor oil plants Cv.

Treatments	Variables analyzed		
	AFE	RMF	RAF
Phosphorus doses			
0 Kg ha^{-1} of P	108.803^{a}	0.441^{a}	42.485^{b}
90 Kg ha^{-1} of P	108.793^{a}	0.490^{a}	50.835^{a}
DMS	23.64	0.06	4.76
Potassium doses			
0 Kg ha^{-1} of K	23.612^{a}	0.459^{a}	46.575^{a}
60 Kg ha^{-1} of K	113.984^{a}	0.473^{a}	46.745^{a}
DMS	23.64	0.06	4.76

Leaf area (AFE), leaf mass ratio (RAF) and leaf area ratio (RMF). The averages in the columns followed by same letters do not differ among themselves by the Tukey test . Source: BRS Energia, Campina Grande-PB, 2013.

making up the ATP molecule and other molecules that compose some storage substances in seeds such as oils, proteins and carbohydrates. For K, only the height variable was influenced by its application, the highest average was related to the application of 60 kg ha^{-1} doses. No difference was observed between the K doses studied for the variables stem diameter, number of leaves and leaf area. Unsatisfactory P and K levels slows down the plants initial growth and causes considerable reduction on productivity (Severino et al., 2006; Ma et al., 2012).

No significant interaction effect between the cake and K was observed on any of the analyzed variables of growth, also this similar behavior was observed between the P and K factors. However, there was an isolated effect of P factor for all growth variables analyzed, but only the height variable was influenced K doses. Severino (2005) evaluating the effect of increasing potassium doses on production components of BRS Nordestina cultivar, verified an average primary racemic length of 51.28 cm.

The Table 9 presents the mean values of growth variables analyzed in function of the P and K doses, where it can be verified that there was a significant difference between the P doses studied (0.0 and 90 kg ha^{-1}). It was observed that the mean values were higher only for leaf area ratio (RAF) variable when fertilized with 90 kg ha^{-1} doses, compared to the control sample (0.0 kg of P). According to Rodrigues (1982), the leaf area ratio represents the relative size of the photosynthetic apparatus being quite appropriate to evaluate the genotypic, climatic and plant communities effects, so the RAF trend is to decrease from a certain cycle phase in function of the reduction of the useful leaf area (Alvarez et al., 2000). While for K, the 60 kg ha^{-1} doses did not influence any of the analyzed variables. No difference was observed between the K doses studied for the specific leaf area (AFE), leaf mass ratio (RAF) and leaf area ratio (RMF) variables.

By the summary of the variance analysis (Table 10) it was possible to observe the average squares and their respective significance by F-test at 5% probability for the mineral composition variables of plants. It was observed that there was a significant interaction effect spelling bean cake doses and P doses on the nutritional components (N, K, Ca, Mg) in the dry mass of the aerial part of the plant, except for P and S contents. For interaction between K doses and castor bean cake doses, no significant effect was observed between these factors for any of the analyzed variables. Through the analysis of the isolated effects of the studied factors, it was verified that the castor oil plant cake doses significantly influenced the P content in the dry matter of the aerial part of the castor bean plants, this is mainly due to the fact that the castor cake has cake in its chemical composition.

Silva et al. (2012) working with castor bean cake doses as nutrient source to plants, verified higher accumulation of P content in the dry mass of the aerial part of castor bean plants. The statistical analyzes for the isolated P rates showed significant effect only for the N, P, K and S contents. But for K doses, these influenced only P and K contents in the dry mass of the aerial part of the plant (Table 10).

The average values of the plant mineral composition variables (N, P, K, Ca, Mg and S) are presented in Table 1111 in function of P and K doses, where it is possible to verify that there was a significant difference between the P doses analyzed (0.0 and 90 kg ha^{-1}). The mean values for the variables N, P, K and S were higher than the control group (0.0 kg of P) with the application of 90 kg ha^{-1} doses. However, there was no statistical difference between the doses that studied about Ca and Mg levels

Table 10. Summary of variance analyses and respective mean squares for the the nutritional components of the aerial part of castor oil plant.

Variation source	GL	Mean squares					
		N	P	K	Ca	Mg	S
Linear Reg.	1	0. 552*	0.074^{ns}	0.105	0.756*	0.136*	0.0003^{ns}
Quadratic Reg.	1	0.068^{ns}	0.191**	0.160	0.079^{ns}	0.031^{ns}	0.0047^{ns}
Cubic Reg.	1	0.124^{ns}	0.007^{ns}	0.098	0.020^{ns}	0.364^{ns}	0.0028^{ns}
Blocs (B)	3	0.164	0.0003	0.071	0.093	0.020	0.0013
Cake (T)	3	0.248^{ns}	0.0911*	0.121*	0.285*	0.056*	0.0026^{ns}
Phosphorus (P)	1	1.822**	0.3969**	1.050**	0.122^{ns}	0.037^{ns}	0.0236*
Potassium (K)	1	0.216^{ns}	0.5292**	13.875**	6.825^{ns}	0.011^{ns}	0.00001^{ns}
Contrasts							
T x P	3	1.170**	0.0582^{ns}	0.367**	18.485**	0.026^{ns}	0.0029^{ns}
T x K	3	0.258^{ns}	0.0388^{ns}	0.091^{ns}	14.777^{ns}	0.006^{ns}	0.0047^{ns}
P x K	1	0.573^{ns}	0.0182^{ns}	0.225^{ns}	7.631^{ns}	0.038^{ns}	0.00097^{ns}
T x P x K	3	0.250^{ns}	0.0079^{ns}	0.054**	11.135^{ns}	0.067*	0.0083^{ns}
Residue		0.113	0.026	0.042	0.107	0.021	0.004
CV (%)		20.49	23.50	20.56	11.58	18.65	22.46

Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S), GL - Degree of freedom; ns - not significant; ** and, * meaning 1 and 5% of probability, respectively, by the F test. Source: Campina Grande-PB, 2013.

Table 11. Average of nutritional variables.

Treatments	Variables analyzed					
	N	P	K	Ca	Mg	S
Phosphorus doses						
0 Kg ha^{-1} of P	1.473^{b}	0.297^{b}	1.600^{b}	2.793^{a}	0.814^{a}	0.266^{b}
90 Kg ha^{-1} of P	1.810^{a}	0.454^{a}	1.856^{a}	2.880^{a}	0.765^{a}	0.305^{a}
DMS	0.169	0.082	0.178	0.165	0.074	0.032
Potassium doses						
0 Kg ha^{-1} of K	1.584^{a}	0.285^{b}	1.706^{b}	2.802^{a}	0.803^{a}	0.285^{a}
60 Kg ha^{-1} of K	1.700^{a}	0.466^{a}	1.942^{a}	2.881^{a}	0.776^{a}	0.286^{a}
DMS	0.169	0.082	0.102	0.165	0.074	0.032

Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S), in function of phosphorus (P) and potassium (K). Source: Campina Grande-PB, 2013.

in the aerial part of the plant. For K doses (Table 11), higher mean values with 60 Kg ha^{-1} doses only for P and K variables were observed. Table 12 presented the summary of the variance analysis by the mean squares and their respective significance by F-test at 5% probability for the physiological variables of photo-synthesis (Fot), transpiration (TRmmol), internal CO_2 concentration (Ci), stomatal conductance (Cond) and relative chlorophyll index (IRC).

Based on the statistical tests results, there was no significant interaction effect between the factors studied (bean cake, phosphorus and potassium) for some of the analyzed variables. However, there was a significant isolated effect of the castor bean on the transpiration variables and relative index of chlorophyll. A significant effect in the photosynthesis and transpiration variables for P was observed. Meanwhile, there was no significant effect between K and any of the variables analyzed.

The average values for physiological variables (photosynthesis, transpiration, internal CO_2 concentration, stomatal conductance and relative chlorophyll index) due to P and K doses are shown in Table 13, where it

Table 12. Summary of variance analyses and respective mean squares for various variables.

Variation source	GL	Fot	Mean squares			
			TRmmol	Ci	Cond	IRC
Linear Reg.	1	47.555^{ns}	0.002^{ns}	2.048^{ns}	0.0002^{ns}	0.0206^{ns}
Quadratic Reg.	1	0.714^{ns}	2.250*	0.010^{ns}	0.021^{ns}	0.0213**
Cubic Reg.	1	8.153^{ns}	2.363^{ns}	119.805^{ns}	0.012^{ns}	0.0069^{ns}
Blocs (B)	3	27.178	9.544	4464.302	0.087	0.008331
Cake (T)	3	191.338^{ns}	1.538*	40.621^{ns}	0.011^{ns}	0.016322**
Phosphorus (P)	1	121.385**	3.285*	208.080^{ns}	0.028^{ns}	0.000014^{ns}
Potassium (K)	1	6.786^{ns}	1.995^{ns}	2457.680^{ns}	0.016^{ns}	0.000002^{ns}
Contrasts						
T x P	3	18.807^{ns}	0.698^{ns}	3851.708^{ns}	0.007^{ns}	0.000656^{ns}
T x K	3	26.246^{ns}	3.713^{ns}	2095.541^{ns}	0.014^{ns}	0.000627^{ns}
P x K	1	12.311^{ns}	3.027^{ns}	1907.507^{ns}	0.022^{ns}	0.011827^{ns}
T x P x K	3	11.363^{ns}	2.686^{ns}	3142.196^{ns}	0.023^{ns}	0.005843^{ns}
Residue		32.208	0.564	1968.878	0.010	0.14713
CV (%)		22.39	19.03	20.88	31.44	11.25

photosynthesis (Fot), transpiration (TRmmol), internal CO_2 concentration (Ci), stomatal conductance (Cond) analyzed with IRGA device, and relative chlorophyll index (IRC). Source: Campina Grande-PB, 2013.

Table 13. Average of various variables.

Treatments	Variables analyzed				
	Fot	TRmmol	Ci	Cond	IRC
Phosphorus doses					
0 Kg ha^{-1} of P	23.621^{b}	3.720^{b}	216.237^{a}	0.350^{a}	0.508^{a}
90 Kg ha^{-1} of P	27.079^{a}	4.173^{a}	214.253^{a}	0.308^{a}	0.507^{a}
DMS	2.857	0.378	22.342	205.04	0.028
Potassium doses					
0 Kg ha^{-1} of K	23.973^{a}	3.770^{a}	219.416^{a}	0.313^{a}	0.508^{a}
60 Kg ha^{-1} of K	26.727^{a}	4.123^{a}	211.066^{a}	0.345^{a}	0.508^{a}
DMS	2.857	0.378	22.342	205.04	0.028

Photosynthesis (Fot), transpiration (TRmmol), internal CO_2 concentration (Ci), stomatal conductance analyzed (Cond) and relative chlorophyll index (IRC) variables in function of phosphorus (P) and potassium (K) doses.The average in the columns followed by same letters do not differ among themselves by the Tukey test. Source: Campina Grande-PB, 2013.

was possible to observe that there was a significant difference between the P doses studied (0.0 and 90 kg ha^{-1}).

The analysis revealed that the average values were higher for photosynthesis and transpiration variables with the application of 90 kg ha^{-1} dose than the control sample (0.0 kg of P) for these variables. However, there was no statistical difference between P doses worked on the other analyzed variables. For K, the statistical analysis did not indicate any significant effect of this element on any of the analyzed variables. The summary of the variance analysis by the mean squares and their respective significance by F-test at 5% probability for the production variables (root dry mass, shoot dry mass and total dry mass) are presented in Table 14.

Among the variables of phytomass production evaluated at the end of the experiment, it was verified that there was no significant interaction effect between the cake and P factors for none of the analyzed variables. Meanwhile, there was an isolated effect of castor bean doses for variables, root dry mass, dry shoot mass and total dry mass. The statistical analyzes also revealed an isolated effect of P rates for these phytomass production variables (Xie et al., 2014). However, no significant effect

Table 14. Summary of the variance analysis and their respective mean squares for growth components.

Variation source	GL	Mean squares		
		MSR (g)	MSPA (g)	MST (g)
Linear Reg.	1	93.48**	1475.16**	2311.35**
Quadratic Reg.	1	15.13*	3.90^{ns}	34.39^{ns}
Cubic Reg.	1	0.67^{ns}	1.41^{ns}	4.04^{ns}
Blocs (B)	3	5.62	113.43	151.43
Cake (T)	3	36.43**	493.49**	783.26**
Phosphorus (P)	1	110.77**	1652.01**	2618.36**
Potassium (K)	1	0.12^{ns}	8.67^{ns}	6.70^{ns}
Contrasts				
T x P	3	2.93^{ns}	21.12^{ns}	37.27^{ns}
T x K	3	6.71^{ns}	64.34^{ns}	105.06^{ns}
P x K	1	0.001^{ns}	105.72^{ns}	105.01^{ns}
T x P x K	3	1.37^{ns}	35.23ns	40.33^{ns}
Residue		2.82	43.07	55.31
CV (%)		32.97	36.15	31.98

Root dry mass (MSR), shoot dry mass (MSPA) and total dry mass (MST) of castor bean CV, GL - Degree of freedom; ns - not significant; ** and, * meaning 1 and 5% of probability, respectively by the F test. Source: BRS Energia, Campina Grande-PB, 2013.

Table 15. Average of the production variables.

Treatments	Variables analyzed		
	MSR (g)	MSPA (g)	MST (g)
Phosphorus doses			
0 Kg ha^{-1} of P	3.78^{b}	13.07^{b}	16.85^{b}
90 Kg ha^{-1} of P	6.41^{a}	23.23^{a}	29.65^{a}
DMS	0.84	3.30	3.74
Potassium doses			
0 Kg ha^{-1} of K	5.05^{a}	17.78^{a}	22.93^{a}
60 Kg ha^{-1} of K	5.14^{a}	18.52^{a}	23.57^{a}
DMS	0.84	3.30	3.74

Root dry mass (MSR), shoot dry mass (MSPA), total dry mass (MST), in function of phosphorus (P) and potassium (K) doses.The averages in columns followed by same letters do not differ among themselves by the Tukey test. Source: Campina Grande-PB, 2013.

of K doses was observed on the variables analyzed, as well as on the interaction between K doses and castor bean cake. For Phosphorus application on the castor bean fertilization, it was observed that there was a significant differences for root dry mass, shoot dry mass and total dry mass of castor bean plants (Table 15). The highest results for this variable were observed when 90 kg ha^{-1} of P_2O_5 was applied. Generally, poor soils in P are responsive to phosphate fertilization. Phosphorus is one of the most important macronutrients for vegetative growth because it participates in the formation of important enzymes involved in the absorption process of N and in the energy consumption in the form of ATP (Marschner, 2005).

Brito Neto et al. (2017) found that P is essential for the good development and increase of castor bean production because, P participates in the formation of fatty acids and seed filling. The results obtained in this work confirm that the supply of adequate doses of phosphorus from the beginning of development stimulates the root development which is important for the formation of the primordia of the reproductive parts, essential for good formation of fruits and thus increasing the production of this oilseed and other nutrients availability, management of fertilization (form, type and application time), soil sampling form and plant age (Boem et al., 2011; Silva et al., 2012b; Costa et al., 2013).

The average test did not show a significant difference between the K doses for the phytomass production variables (root dry mass, shoot dry mass and total dry mass). The nitrogen fertilization facilitated a faster growth and higher dry matter mass production because N promoted higher root growth, higher photosynthetic efficiency and increased leaf area (Corsi,1993; Brito Neto et al., 2014).

Conclusion

The castor bean cake reduced the pH of the soil and increased the P, Mg, K and M.O. levels from soil; the mineral composition of the castor bean was significantly influenced by the castor bean cake doses with the linear increment for N, P, K, Ca, and Mg contents. The water type did not influence significantly the number of leaves variable for both cultures being themselves.

Physiological variables, transpiration and relative chlorophyll index were influenced by castor bean cake doses. The addition of castor bean cake influenced significantly the root, shoot and total phytomass production of castor bean plants.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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