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Response of *Jatropha curcas* plants to changes in the availability of nitrogen and phosphorus in Oxissol

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The present study aimed at identifying the correct nitrogen and phosphate fertilization for the maximum productivity of *Jatropha curcas* plants. The study was carried out at the experimental field of the Ipameri Campus of the State University of Goiás. Three-year-old physic nut plants under full production were used. After analysis of the soil classified as Oxissol, pH correction was performed in accordance with technical recommendations for the species. The experiment followed a randomized block design with a 4 × 2 factorial arrangement [four doses of N (0, 100, 200 and 300 kg/ha) and two levels of phosphate fertilization (0 and 50 kg/ha). Fertilization was made in semicircle following the crown projection, 20 cm away from the stem. The lower leaf concentration of phosphorus in plants treated with 50 kg ha^{-1} in relation to plants fertilized with phosphorus shows there was no deficiency in the plants that did not get phosphorus and possibly the 50 kg ha^{-1} represented the excess of phosphorus due to the high content of organic matter. However, the high organic matter was not sufficient to meet the demand for nitrogen due to the high demand for *J. curcas* for this nutrient. Seed productivity presented a significant increase in relation to nitrogen fertilization. For 3-year-old plants cultivated at a spacing of 4 × 2 m, a fertilization of 81 kg ha^{-1} is thus recommended.

Key words: Biofuel, mineral nutrition, growth, nitrogen, phosphorus.

INTRODUCTION

The increase in greenhouse gases in the earth's atmosphere has compromised natural resources and intensified the search for renewable energies. The search for an energy alternative to fossil fuels requires the evaluation of renewable sources with low impact on the environment like biofuels (Matos et al., 2014).

The choice of the alternative source of energy must be made carefully with an impact as low as possible on the environment. In this context, biofuels are an option which may partially substitute fuels derived from oil and natural gas in internal combustion engines and in other types of energy generation (Freitas et al., 2011; Pan and Xu, 2011). Biofuels pollute less for emitting less compounds in the combustion process, mainly CO_2 and the

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Production process is cleaner than with fossil fuels.Brazil is the country with the greatest potential for biofuel production because it has vast expanses of arable land, plenty of water, and soil and climate diversity that enables the exploitation of various species adapted to different climates and biomes (Freitas et al., 2011).

Biodiesel production in Brazil is based only on one raw material, namely soybean, which represents 73.92%. Beef suet, cotton and other fat materials contribute 21.21, 2.45 and 2.42% of the production, respectively (Matos et al., 2014). It is thus necessary to diversify the source of raw material used in biodiesel production through introduction of potential species like *Jatropha curcas* L.

J. curcas is an oil-producing plant of the Euphorbiaceae family, popularly known as physic nut. It is a fast-growing shrub, able to initiate production from the seventh month of planting, remaining productive for approximately 40 years (Dias et al., 2007). *J. curcas* has various favorable attributes enabling its commercial exploitation, like fast growth, easy propagation, perennial plant, high oil content (between 33 and 38%) and quality, evidencing its high economic potential (Sujatha et al., 2008).

J. curcas is considered as a rustic, drought-resistant plant, suitable for the most diverse soil and climate conditions, surviving in marginal lands of low natural fertility (Arruda et al., 2004). The plant grows in various soil types, including sandy, stony, saline, alkaline and rocky soils, which, nutritionally and physically speaking, limit the full development of the roots (Carvalho et al., 2011).

Despite high adaptability and rusticity, one may presume that the highest genetic potential is exploited in adequate fertilization conditions. Well-performed fertilization makes significant productivity gains possible in most cultivated plants. Although it is a rustic plant, higher seed productivity is obtained with use of fertilizers and soil pH correction (Carvalho et al., 2011; Freitas et al., 2012; Mohapatra et al., 2011; Laviola and Dias, 2008).

Among essential nutrients for the growth and production of *J. curcas*, we may highlight phosphorus and nitrogen for affecting the initial growth and the establishment of the plant, the vegetative development and the seed productivity. According to Freiberger et al. (2014), phosphate fertilization is as limiting to the growth and establishment of *J. curcas* as fertilization with all other nutrients, in the seedling phase. Nitrogen is the nutrient the plant requires in the greatest quantity (Laviola and Dias, 2008). It is considered as the main nutrient for the development of the plant, as it is directly involved in growth and photosynthetic activity (Freitas et al., 2012).

In order that *J. curcas* become competitive with other oil-producing plants on the Brazilian energy stage, aspects related to the productivity of the plant need to be elucidated, since the species lacks basic agronomic information (Fernandes et al., 2013).

The present study aimed at identifying the correct nitrogen and phosphate fertilization for the maximum productivity of *J. curcas* plants.

MATERIALS AND METHODS

Experimental design

The study was carried out in the experimental field of the State University of Goiás, Ipameri Campus (latitude 170° 43' 19"S, longitude 480° 09' 35"W, Altitude 773 m), Ipameri, Goiás, Brazil. This region has basically two well defined seasons: the wet season, from October to April, and the dry season, from May to September.

Three-year-old clones of *J. curcas* plants were used at a spacing of 4 × 2 m. The clones come from plant populations naturally found in the State of Goiás. After analysis of the soil classified as Oxissol, pH correction was performed in accordance with technical recommendations for the species (Dias et al., 2007). The chemical analysis of the soil gave the following values: pH 5.55, 4.3% of O.M., 0.0 mg dm^{-3} of P, 129 mg dm^{-3} of K, 0.10 $cmol_c$ dm^{-3} of Al, 6.5 $cmol_c$ dm^{-3} of Ca, 29 $cmol_c$ dm^{-3} of Mg, 84.8% of V, 35.90 $cmol_c$ dm^{-3} of S and 42.33 $cmol_c$ dm^{-3} of CEC. The experiment was set up as a random block design, in a 4 × 2 factorial arrangement, with four doses of nitrogen (0, 100, 200 and 300 kg/ha), two doses of phosphorus (0 and 50 kg/ha), five replications and two-plant slot. All plants were fertilized with the same amount (50 kg/ha) of potassium chloride, following recommendations of Laviola and Dias (2008).

The nitrogen fertilization were divided in three equal applications in the days 10/30/2013, 30/11 / 2013 and 01/05/2014. The phosphate and potash fertilizers were applied in its entirety on 08/20/2013. Fertilization was made in semicircle following the crown projection, 20 cm away from the stem.

On 02/20/2014 and 02/21/2014 the following evaluations were made: number of branches, plant height, stems diameter, leaf area, crown diameter, total chlorophyll and carotenoids, phosphorus and nitrogen leaf content. Seed productivity was analyzed between 04/05/2014 and 06/10/2014.

Morpho-agronomic characteristics

Plant height, stem diameter and crown diameter were measured using graduated ruler and digital pachymeter. The evaluation of the number of branches was made through counting. To evaluate the leaf area, we used a graduated (cm) tape measure, measuring width and length of the totally expanded leaf (between the 3^{rd} and 5^{th} pair of leaves). Then we calculated the leaf area following the recommendations of Severino et al. (2007). Seed productivity was evaluated through harvesting and threshing of the fruits of each plant and weighing of the seeds.

Nitrogen, phosphorus and potassium content in the leaves were determined in the Soil Science Laboratory of the Federal University of Viçosa, Viçosa, Minas Gerais, Brazil. Nitrogen was determined using the Kjeldahl method with sulfuric acid digestion. To determine phosphorus contents, dry and ground plant material was submitted to nitric-perchloric digestion (Johnson and Ulrich, 1959).

Physiological characteristics

To determine the total chlorophyll concentration (photosynthetic pigments), leaf disks of known area were removed and placed in glasses with dimethyl sulfoxide. Subsequently, extraction of the samples was performed in a bain-marie at 65°C for 1 h. Aliquots were removed for spectrophotometric reading at 490, 646 and 663 nm. Chlorophyll *a* (Cl *a*), chlorophyll *b* (Cl *b*) and total carotenoid contents were determined following the equation proposed by Wellburn (1994).

Table 1. Summary of the analysis of variance of the plant height, stem and crown diameter, number of branches and leaf area of physic nut plants cultivated under different doses of nitrogen and phosphorus.

Variation source	DOF	Mean squares				
		Height (m)	Stem diameter (mm)	Crown diameter (m)	Nr. branches	Leaf area (cm^2)
Block	4					
P	1	0.028^{ns}	74.6^{ns}	0.02^{ns}	62.3^{ns}	7.70^{ns}
N	3	0.22^{*}	299.9^{ns}	0.22^{ns}	37.0^{ns}	1834.2^{*}
N x P	3	0.033^{ns}	83.8^{ns}	0.02^{ns}	45.1^{ns}	537.4^{ns}
Error	28	0.87	1942.5	0.09	61.6	331.2
CV (%)		7.9	7.8	10.9	16.7	10.3
Treatments		**Averages**				
- N - P		2.50	120.4	2.89	47.4	179.7
- N + P		2.64	129.1	2.78	46.8	167.8
100 N - P		2.88	136.8	2.74	46.0	174.6
100 N + P		2.85	129.5	2.67	52.4	154.1
200 N - P		2.56	132.9	2.91	41.5	164.2
200 N + P		2.77	136.4	2.81	46.8	174.4
300 N - P		3.01	138.2	3.02	49.0	194.6
300 N + P		2.95	143.1	3.10	46.2	205.8

*Significant at 5% probability; ns = not significant by F test.

Statistical procedures

Analyses of variance (ANOVA) were performed following the random block design with a factorial arrangement of 4 × 2 (four doses of nitrogen: 0, 100, 200 and 300 kg/ha and two doses of phosphorus: 0 and 50 kg/ha) and five blocks. Regression analysis for the quantitative variables was made using software SISVAR 5.3 (Ferreira, 2011).

RESULTS AND DISCUSSION

Statistical analysis of the data showed that there was no significant interaction between nitrogen and phosphorus doses (Tables 1 and 2). Thus, the nitrogen doses interfere with the analyzed variables regardless of the phosphorus doses. The factors are thus independent and, in this case, were studied separately. The plant height and leaf area showed significant differences in function of the nitrogen doses (Table 1).

Leaf concentrations of carotenoids (Car), total chlorophylls (total Cl) and nitrogen (N) in the leaves showed no significant variation in relation to the nitrogen and phosphorus doses applied to the soil (Table 2). However, phosphorus leaf concentration showed significant variation in relation to phosphorus doses applied to the soil. Seed productivity showed significant variation in function of the nitrogen doses.

The maximum points were 81.6 kg nitrogen to get 1483 kg ha^{-1} of *J. curcas* seeds. We observed that as nitrogen doses were incremented, there was an increase in plant height (Figure 1), and that phosphorus leaf concentration was lower in the treatments with applications of more phosphorus to the soil. Productivity and leaf area showed quadratic variations in relation to the nitrogen doses.

Under natural conditions, nutritional stress can cause irreversible damage in *J. curcas*. High adaptability to soil and climate variations of *J. curcas*, besides maintenance of the growth under nutrition stress condition can represent expansion of the agricultural frontier by getting economic return in areas until then inappropriate, as later discussed.

The lack of significant interaction between doses of nitrogen and phosphorus shows that these factors acted separately on the analyzed variables. Regardless of supplied nitrogen and phosphorus doses, the plants behaved similarly as for plant growth (stem and crown diameters and number of branches). However, plant height increased linearly with the nitrogen doses, showing that heavy fertilizations with this nutrient can intensify plant growth, more specifically plant height. The increment in the vegetative growth of *J. curcas* is a common effect of treatments with increasing nitrogen doses (Oliveira and Beltrão, 2010; Freitas et al., 2012). Competition for assimilates between the growth and the filling of seeds may have contributed to a lower productivity of plants submitted to high doses of nitrogen. Under such circumstances, the larger leaf area of plants under high doses of nitrogen may be related to higher photosynthetic activity in function of the higher demand for assimilates. According to Freitas et al. (2012), the photosynthesis of *J. curcas* plants increases linearly with the doses of nitrogen. These authors used doses from 50 to 350 kg ha^{-1} of urea.

Seed productivity did not increase proportionally to the

Table 2. Summary of the analysis of variance of carotenoids (Car), total chlorophylls (total Cl), nitrogen (N), phosphorus (P) leaf concentrations and productivity of physic nut plants cultivated under different doses of nitrogen and phosphorus.

Variation source	DOF	Mean squares				
		Car (g kg^{-1})	Total Cl (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	Productivity (kg ha^{-1})
Block	4					
P	1	0.002^{ns}	0.38^{ns}	0.42^{ns}	0.73*	109341^{ns}
N	3	0.001^{ns}	0.09^{ns}	4.31^{ns}	0.17^{ns}	158013*
N × P	3	0.006^{ns}	0.19^{ns}	11.30^{ns}	0.07^{ns}	32942^{ns}
Error	28	0.007	0.15	7.04	0.17	45412
CV (%)		20.7	7.8	8.8	16.8	14.6
Treatments		**Averages**				
- N - P		0.36	2.09	29.3	2.5	1414.6
- N + P		0.33	2.38	31.0	2.1	1544.2
100 N - P		0.35	2.08	28.6	2.6	1655.4
100 N + P		0.34	2.58	31.8	2.6	1737.3
200 N - P		0.32	2.32	31.1	2.7	1226.6
200 N + P		0.32	2.13	28.4	2.3	1562.5
300 N - P		0.30	2.33	30.1	2.5	1313.1
300 N + P		0.39	2.53	28.7	2.2	1344.2

*Significant at 5% probability; ns = not significant by F-test.

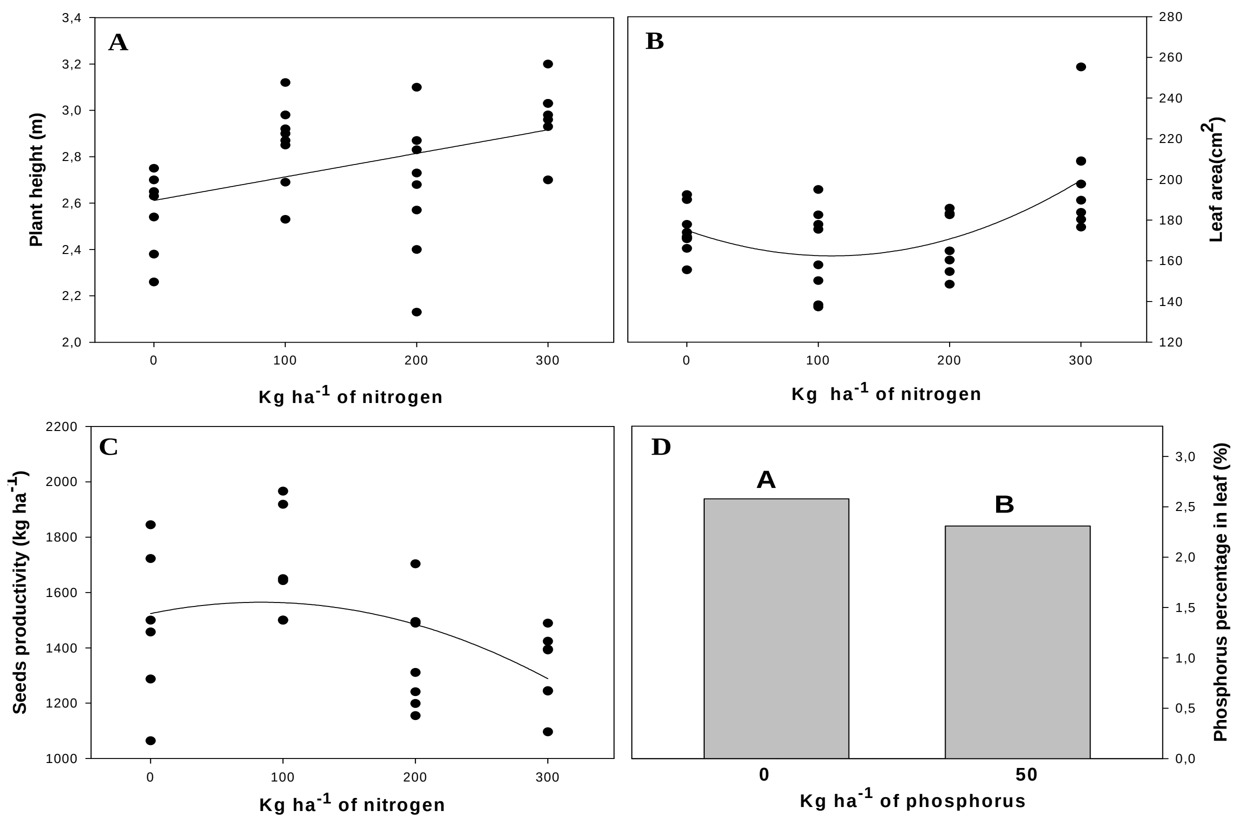

Figure 1. Equations of regression for plant height "A" (Y = 2.61 + 0.0010x, R^2 = 0.81*), leaf area "B"(Y = 174.99 Y - 0.23x + 0.001x^2, R^2 = 0.64*) seed productivity "C" (Y = 1523.76 + 0.98x - 0.006x^2, R^2 = 0.80*) and phosphorus percentage in leaf "D" of *Jatropha curcas* L. plants, fertilized with different doses of nitrogen and phosphorus. Averages followed by the same capital letter do not differ, 5% of probability by F test.

increase of nitrogen fertilization. The maximum seed productivity (1483 kg ha^{-1}) occurred with 81.6 kg ha^{-1} of nitrogen, that is, 65 g of nitrogen per plant. This result corroborates that of Laviola and Dias (2008), who recommended 60 g of nitrogen per plant. Thus, for a 3-year-old plant, cultivated at a spacing of 4 × 2 m, fertilization with 65 g of N is recommended. Heavy fertilizations with amounts of nitrogen fertilizer higher than 65 g per plant intensify plant growth and harm seed productivity. However, subsequent studies with several crop cycles after stabilization of productivity are necessary to get a consistent fertilization recommendation. Studies with plants younger than 5 years show a divergent variation of the vegetative growth and seed productivity (Laviola and Dias, 2008; Freitas et al., 2012; Carvalho et al., 2013). The fertilization of a crop depends on the demands for vegetative and reproductive growth, nutrient supply by the soil and losses in fertilizer (Laviola and Dias, 2008).

Phosphate fertilization incremented productivity and/or growth of *J. curcas* (Freire et al., 2011). *J. curcas* is sufficiently responsive to phosphate fertilization in the initial growth period (Laviola and Dias, 2008; Freiberger et al., 2014), but application of doses from 135 to 200 g of phosphorus per plant shows no significant variation of the vegetative growth (Sousa et al., 2011). In the present study, the application of 40 g per plant did not modify vegetative growth and seed productivity. The liberation of phosphorus by the organic matter of the soil may possibly have contributed to the lack of significance of the analyzed variables. The lower leaf concentration of phosphorus in plants treated with 50 kg ha^{-1} in relation to plants fertilized with phosphorus shows there was no deficiency in the plants that did not get phosphorus and possibly the 50 kg ha^{-1} represented the excess of phosphorus due to the high content of organic matter. However, the high organic matter was not sufficient to meet the demand for nitrogen due to the high demand for *J. curcas* for this nutrient.

Conclusions

We recommend fertilization of 81 kg ha^{-1} (65 g/plant) of nitrogen in 3-year-old *J. curcas* plants cultivated at a spacing of 4 × 2 m. In 3-year-old plantations, soils with organic matter content higher than 4%, phosphate fertilization is not recommended for not increasing seed productivity.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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