Australian Journal of Crop Science
AJCS

AJCS 10(4):452-459 (2016) ISSN:1835-2707
DOI: 10.21475/ajcs.2016.10.04.p6946x

Response of jatropha to organic and phosphate fertilization under irrigated conditions

Rosiane de Lourdes Silva de Lima[1*], Silvanete Severino da Silva[1†], Carlos Alberto Vieira Azevedo[1], José Marcelo Cordeiro Possas[1], José Dantas Neto[1], Ronaldo do Nascimento[1]

[1]Federal University of Campina Grande, Academic Unit of Agricultural, Engineering, Campina Grande, CEP 58.109-970, Paraíba, Brazil

***Corresponding author: limarosiane@yahoo.com.br**
[†]This paper was extracted from the thesis of the second author, which is part of postdoctoral research project of the first author.

Abstract

Jatropha (*Jatropha curcas* L.) is a perennial species that requires expressive amounts of nutrients in order to produce satisfactorily. An experiment was conducted using pots, arranged in a randomized block design, with four replicates and one plant per plot, in order to evaluate different fertilization recommendations (phosphate fertilizer and cattle manure) based on soil analysis. The treatments consisted of a 4 x 4 factorial scheme, which represented 4 recommendations of organic fertilization [absence of organic fertilization (0 t ha^{-1}), recommended dose (4 t ha^{-1}), 1.5 times the recommended dose (6 t ha^{-1}) and 2 times the recommended dose (8 t ha^{-1})] and 4 recommendations of phosphate fertilization [absence of phosphate fertilization (0 kg ha^{-1}), recommended dose (90 kg ha^{-1}), 1.5 times the recommended dose (135 kg ha^{-1}) and 2 times the recommended dose (180 kg ha^{-1}). One hundred and eighty days after seedlings were transplanted to the pots, growth variables and production components were measured. Plant height, number of branches, stem diameter, leaf area, number of inflorescences, number of fruits, number of bunches, number of fruits per bunch, mass of fruits, number of seeds per fruit, number of seeds per plant and total mass of seeds per plant were influenced by the fertilization recommendations. The recommendation of organic and phosphate fertilization suggested by the laboratory of soil analysis (4 t ha^{-1} of organic matter and 90 kg ha^{-1} of phosphorus) was insufficient to obtain productive plants. The isolated use of organic matter in fertilization of jatropha promotes positive effects on growth variables and production components. The application of 1.5 the dose of organic matter recommended by the laboratory of soil analysis, corresponding to 6 t ha^{-1} of cattle manure, isolated, or associated with 135 kg ha^{-1} of P, is sufficient to supply the nutritional demand for N and P in the first cultivation cycle. Phosphate fertilization associated with organic fertilization significantly influenced plant height, number of branches, stem diameter, leaf area, number of seeds per plant and total mass of seeds of jatropha plants.

Keywords: *Jatropha curcas* L.; fertilization recommendation; cattle manure
Abbreviations: S_Sum of bases; T_Cation exchange capacity; V_Saturation of bases; OM_Organic matter; DAT_Days after transplant ; LA_Leaf area , Σ_sum of leaf area; *L*_Midrib lenght; W_leaf width; PH_ Plant height , NLB_Number of leaves per plant, NBP_Number of branches per plant , SD_Stem diameter; LA_Leaf area (%); ns_Not significant; DF_Degree of freedom; C.V_Coefficient of variation; NIP_Number of inflorescences per plant; NFP_Number of fruits per plant; NBP_Number of bunches per plant; NFB_Number of fruits per bunch; MMF_Mean mass of fruits; NSF_Number of seeds per fruit: NSP_Number of seeds per plant; MSP_Mass of seeds per plant.

Introduction

Jatropha (*Jatropha curcas* L.) is a perennial oilseed species native from Tropical America (Freiberg et al., 2014) and the oil produced in its seeds has been investigated as an alternative in the biodiesel production chain (Lopes and Steidle Neto, 2011; Raja et al., 2011; Bello and Agge, 2012). According to the literature (Freire et al., 2011; Hussein et al., 2012; Freiberg et al., 2014), this oilseed plant is responsive to fertilization and require large amounts of nutrients (Laviola and Dias, 2008) to grow and produce satisfactorily. Usually, the fertilizer doses recommended for basal and topdressing fertilizations vary according to plant phenological stage (Pereira et al., 2011), soil fertility and water and environmental conditions (Mohaptra and Panda, 2011). However, there is no information available in the literature on the fertilizer doses that promote significant increases in jatropha growth and production, which makes the system not very productive and inefficient. Studies on the fertilization of this species have increasingly expanded. In general, it is recommended to apply doses of fertilizers recommended for other crops, and it is necessary to test recommendations based on results of soil analysis, which can widely vary according to the studied environment. One of the promising alternatives for jatropha fertilization is the use of organic material, like cattle manure (Sop et al., 2011; Schulz et al., 2012) and oilseed cakes (Ghosh et al., 2007), or through the application of mineral nitrogen (Prates et al., 2011), phosphate (Carvalho et al., 2013) and potassium (Freiberg et al., 2014) fertilizers, which can be used individually or associated with organic fertilizers (Hussein et al., 2012). The limitations for the availability of nutrients, such as N and P, in the beginning of the vegetative growth can result in restrictions for the formation of the root system and shoots (Silva et al., 2009), as well as for the crop reproductive stage (Pereira et al., 2011). According to Laviola and Dias (2008), P is the most limiting nutrient for initial growth and root system development, as well as for the formation of leaves and fruits of this oilseed crop. Although some studies indicate that phosphate fertilization is essential for the development and increase in fruit yield of jatropha, there is no consensus on the most adequate dose, because most recommendations are based on those established for other crops. Many recommendations of phosphate and organic fertilization have been cited in the national and international literature. Carvalho et al. (2013) recommend the use of 50 kg ha^{-1} of P in order to guarantee good plant development in the first cultivation year under irrigated conditions in Brazil. In India, under rainfed conditions and sub-humid local climate, Patolia et al. (2007) recommend the application of 30 kg ha^{-1} of P_2O_5, as single superphosphate for jatropha cultivation, while Mohaptra and Panda (2011) recommend the use of 100 g $plant^{-1}$ of P, under annual rainfall of 300 mm and sandy soil with low contents of organic matter. In Iran, Akbarian et al. (2010) recommend the application of 120 kg ha^{-1} of P, under rainfed conditions. For the basal fertilization, under rainfed conditions in the *agreste* region of Paraíba, Brito et al. (2013) recommend the application of 54 g $hole^{-1}$ of P, while Pereira et al. (2011), in a soil classified as dystrophic Red Yellow Latosol, also under rainfed conditions, recommend the application of 150 g $hole^{-1}$ of P_2O_5 for higher production in jatropha plants. Under pot conditions in the *agreste* region of Paraíba, Freire et al. (2011) reported that the P dose of 70 kg ha^{-1} promoted improvements on vegetative growth and yield components of jatropha plants cultivated in a sandy loam soil. On the other hand, Sousa et al. (2011) observed that the dose of 200 g $plant^{-1}$ associated with irrigation promoted satisfactory results on the production. Freiberg et al. (2014) found that the P dose of 57 mg dm^{-3} promoted adequate conditions for the initial growth of jatropha plants. Dose of 55 mg dm^{-3} of P pot^{-1} was the best recommendation of phosphate fertilization for obtaining vigorous plants in a Quartzarenic Neosol with low contents of organic matter, according to Souza et al. (2011). With respect to the recommendation of organic fertilization for jatropha, Ghosh et al. (2007) recommend the application of 3 t ha^{-1} of jatropha cake in sandy soils under rainfed conditions. On the other hand, Prates et al. (2012) recommend the use of 11 t ha^{-1} of sewage sludge as the source of organic matter in order to obtain well-nurtured and productive plants. According to Sop et al. (2011), the application of 500 g $hole^{-1}$ of cattle manure is an excellent recommendation of fertilization for jatropha cultivated under rainfed conditions. Hussein et al. (2012) recommend the dose of 5 kg $plant^{-1}$ of cattle manure in order to obtain vigorous and productive plants. For Fernandes et al. (2013), the use of 12 kg $hole^{-1}$ of cattle manure guarantees good production. In experiments conducted in pots, Schulz et al. (2012) recommended the dose of 200 L m^{-3} of cattle manure for the full growth of jatropha plants. This study aimed to evaluate the effects of different recommendations of organic and phosphate fertilization suggested according to the soil analysis on the vegetative growth and production components of jatropha plants cultivated in pots and irrigated.

Results and Discussion

Growth variables

Plant height, number of branches, stem diameter and leaf area of jatropha plants cultivated in pots and irrigated were significantly influenced by the joint application of cattle manure and single superphosphate (Table 2). It is evident that the organic matter provided adequate contents of nutrients and that the addition of P contributed significantly to plant development. Plant height, number of branches per plant, stem diameter and leaf area were influenced by the joint application of cattle manure and single superphosphate, according to the recommendation of the laboratory of soil analysis, and showed linear and quadratic responses (Fig 2A, B, C and D). Plant height showed linear response for all the studied combinations of organic matter and P. Considering the results for the recommended doses (4 t ha^{-1} of organic matter and 90 kg ha^{-1} of P_2O_5) and 2 times the recommended doses (8 t ha^{-1} of organic matter and 180 kg ha^{-1} of P_2O_5), the mean values of plant height increased from 67.9 cm to 98.8 cm. There was an increment of 5.15 in plant height for each unit increase in the doses of cattle manure. On the other hand, in comparison to the absence of fertilizer (0 t ha^{-1} of organic matter and 0 kg ha^{-1} of P_2O_5), there was an increase of about 7.23 in relation to the highest dose of organic matter (8 t ha^{-1}). For Ghosh et al. (2007), the recommendation of 3 t ha^{-1} of jatropha cake in sandy soils is sufficient for obtaining plants with adequate vegetative growth. The number of branches per plant was also influenced by the evaluated recommendations of organic and phosphate fertilization (Fig 2B). For the absence of P and the dose of 90 kg ha^{-1} of P_2O_5, the number of branches per plant showed quadratic responses to the recommendations of fertilization, and its mean value (4 branches $plant^{-1}$) was observed for the mean dose 6.6 t ha^{-1} of cattle manure. Similar results were reported by Arruda et al. (2013), who observed that the application of 150 g $plant^{-1}$ of organic matter promoted substantial increases in branching and, consequently, in production, since the inflorescences appear on the tips of the branches grown in the current year.

On the other hand, when the P dose of 90 kg ha^{-1} was associated with the recommended doses of organic matter (0, 2, 4, 6 and 8 t ha^{-1}), the critical point of the organic fertilizer for this variable (5 branches $plant^{-1}$) occurred when 6.1 t ha^{-1} of cattle manure was applied. From this dose of organic fertilizer on, there was a slight decrease for this variable. With respect to the joint action of the recommended dose of P (135 kg ha^{-1}) and the doses of 0, 2, 4, 6 and 8 t ha^{-1} of organic matter, there was a linear response for the combinations of fertilizers. For the association with the highest P dose (180 kg ha^{-1}), there were increments of about 0.39 for each ton of organic matter applied. Stem diameter showed a response similar to that of plant height, except for the combination between the highest P dose (180 kg ha^{-1}) and the recommended doses of organic matter (0, 2, 4, 6 and 8 t ha^{-1}) (Fig 2C). The maximum point (5.09 mm) was obtained when 5.2 t ha^{-1} of organic matter were applied. In general, stem diameter increased as the recommended doses of organic fertilization increased. The application of N, either organic or mineral, was expected to promote satisfactory results for plant growth, particularly for stem diameter, since it participates in the composition of membranes and acts directly in plant structure as a component of amino acids involved in metabolism and growth. The low N supply of the lowest recommendations of organic and phosphate fertilization caused low values of leaf area of jatropha plants, evaluated at 180 days after emergence (Fig 2D). Leaf area showed linear response for most combinations of fertilization, except for the P dose of 90 kg ha^{-1} associated with doses of 0, 2, 4, 6 and 8 t ha^{-1} of organic matter, for which it showed quadratic response. The maximum leaf area (684.738 cm^2) was observed for the application of 6.2 t ha^{-1} of cattle manure combined with the P dose of 90 kg ha^{-1}. Usually, the deficiency of N causes a decrease in production and leaf area, since the vegetative growth is impaired (Maffeis et al., 2000; Silva et al., 2009). According to

Table 1. Chemical characteristics of the soil used for jatropha cultivation.

pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	S	H + Al	T	V	Al^{3+}	P	OM
1:2.5	Exchangeable complex of the soil ($mmol_c\ dm^{-3}$)							%	$mmol_c\ dm^{-3}$	$mg\ dm^{-3}$	$g\ kg^{-1}$
6.3	0.58	0.33	0.38	0.18	12.1	14.0	3.14	20	0.2	1.54	1.17

S – Sum of bases; T – Cation exchange capacity; V – Saturation of bases; OM – organic matter.

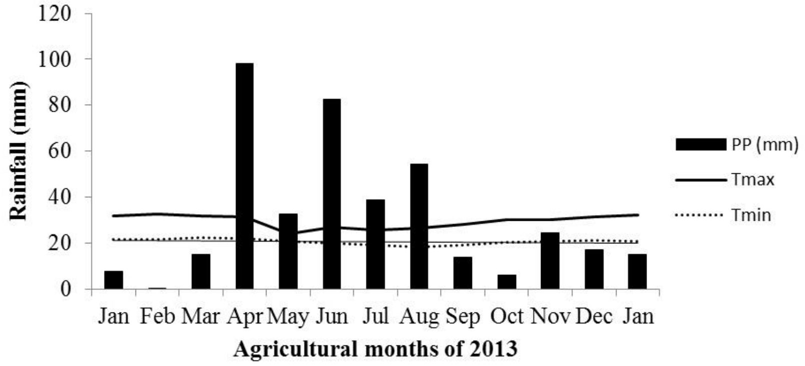

Fig 1. Mean rainfall and temperature between January 2013 and January 2014 in Campina Grande, PB, Brazil. Source: INSA, 2014.

Table 2. Plant height (PH), number of leaves per plant (NLP), number of branches per plant (NBP), stem diameter (SD) and leaf area (LA) of jatropha in response to different recommendations of organic and phosphate fertilization.

Mean Square						
Souce of Variation	DF	PH	NLP	NBP	SD	$LA_{30\%}$
Organic matter (OM)	3	13509.3**	1628.3^{ns}	102.4**	10.3**	2644461.0**
Phosphorus (P)	3	230.7*	527.4^{ns}	8.6**	0.8**	23424.7*
OM x P	9	255.1**	75.3ns	1.5*	0.2**	15023.4*
Block	3	238.4*	2264.2^{ns}	0.3^{ns}	0.1^{ns}	2542.5^{ns}
Residue	45	47.3	812.0	0.9	0.1	5673.9
C.V	-	8.2	22.1	25.4	5.2	15.7

**significant at 1%, * significant at 5%, ns = not significant, DF = degrees of freedom, CV = coefficient of variation.

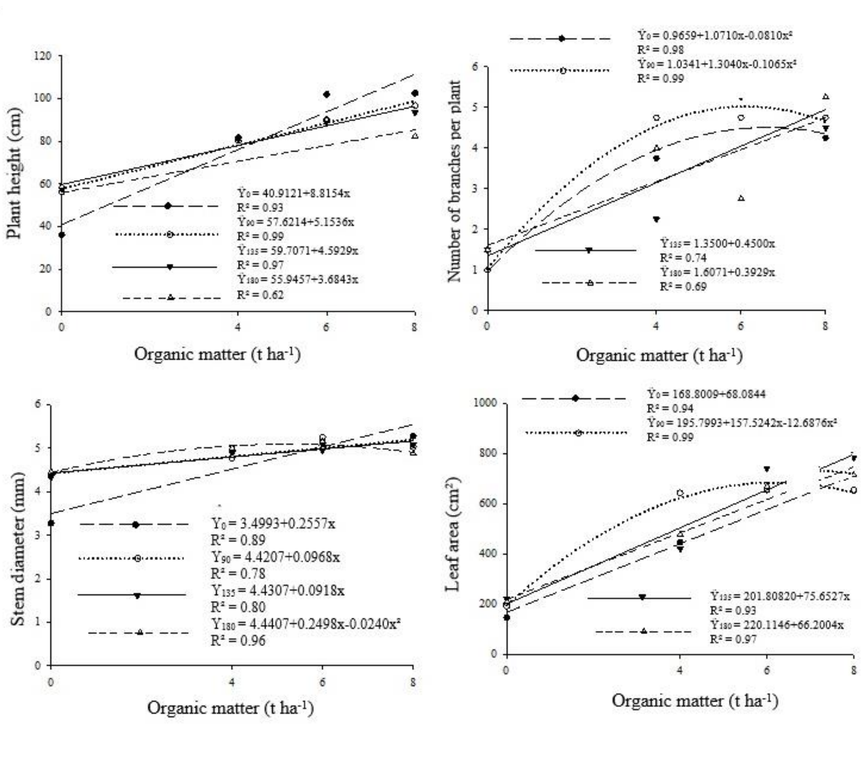

Fig 2. Plant height (A); number of branches per plant (B); stem diameter per plant (C), and foliar area per plant (D) of jatropha plants grown in pots in response to the joint application of organic matter and phosphorus. Campina Grande, PB, Brazil, 2014.

Table 3. Number of inflorescences per plant (NIP), number of fruits per plant (NFP), number of bunches per plant (NBP) and number of fruits per bunch (NFB) of jatropha in response to different recommendations of organic and phosphate fertilization.

Mean Square					
Souce of Variation	DF	NIP	NFP	NBP	NFB
Organic matter (OM)	3	1.7^{ns}	626.9^{**}	143.8^{**}	12.6^{**}
Phosphorus (P)	3	0.6^{ns}	34.0^{ns}	2.8^{ns}	0.7^{ns}
OM x P	9	0.5^{ns}	38.8^{ns}	6.3^{ns}	1.6^{ns}
Block	3	0.3^{ns}	21.2^{ns}	2.9^{ns}	0.5^{ns}
Residue	45	0.3	22.6	4.3	0.7
C.V	-	196.3	3307.0	676.3	81.2

**significant at 1%, * significant at 5%, ns = not significant, DF = degrees of freedom, CV = coefficient of variation.

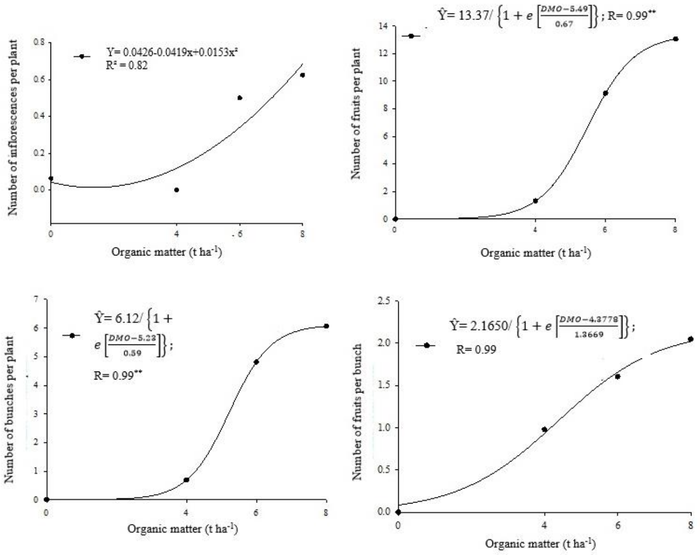

Fig 3. Number of inflorescences per plant (A), number of fruits per plant (B), number of branches per plant (C), and number of fruits per branch (D) of jatropha plants in response to different amounts of organic and phosphate fertilizers. Campina Grande, PB, Brazil, 2014.

Table 4. Number of inflorescences per plant (NIP), number of fruits per plant (NFP), number of bunches per plant (NBP) and number of fruits per bunch (NFB) of jatropha in response to different recommendations of organic and phosphate fertilization.

Mean Square					
Souce of Variation	DF	MMF	NSF	NSP	MSP
Organic matter (OM)	3	3903.2^{**}	25.3^{**}	4868.1^{**}	1759.9^{**}
Phosphorus (P)	3	585.4^{ns}	0.4^{ns}	736.3^{*}	262.3^{*}
OM x P	9	443.1^{ns}	0.4^{ns}	615.8^{*}	213.8*
Block	3	600.4^{ns}	0.5^{ns}	603.9^{ns}	287.2^{*}
Residue	45	180.2	0.5^{ns}	254.4	86.2
C.V	-	69.5	39.1	73.9	71.5

**significant at 1%, * significant at 5%, ns = not significant, DF = degrees of freedom, CV = coefficient of variation.

Marschner (2012), N promotes alterations in plant morphology, so that, under conditions of high N supply, there is an increase in leaf area, because this nutrient increases leaf curvature and significantly interferes with light interception and photosynthesis rate. Since cattle manure is a source of nutrients, especially N, the addition of organic matter, combined with irrigation, was expected to provide adequate amounts of nutrients to the soil solution and to the absorption by plants. Because N is a macronutrient highly mobile in the phloem with high capacity of redistribution inside plants (Lima et al., 2011), its deficiency usually results in gradual chlorosis of older leaves and decrease of plant growth (Freiberg et al., 2014), which reflects in early maturation and loss of yield and fruit quality. Jatropha shows a high growth rate (Laviola and Dias, 2008) and N is essential for the assimilation of carbon and formation of new plant organs, because it participates in its structure as a component of amino acids, proteins, enzymes, RNA, DNA, ATP and other molecules (Marschner, 2012). P has also a high mobility in the phloem and distribution in jatropha plant tissues (LIMA et al., 2011). It is one of the most required minerals for jatropha cultivation especially during the initial growth stage (Freiberg et al., 2014). In fact, phosphorus is part of the plant structure as it is part of membranes (phospholipids), RNA, DNA, ATP, and carbohydrate esters, as well as of several key metabolic molecules that accelerate the formation of roots and contribute to the symbiotic fixation of N (Malavolta et al., 1997). According to Laviola and Dias (2008), during the first years of jatropha cultivation P should be supplied in greater amounts than the accumulated by the plants. In fact, more than 50% of the P supplied during fertilizer application is fixed by the sandy fraction of the soil, limiting its availability for the plants. Limited P availability at the start of the vegetative cycle may restrict crop development. Plants do not recover from such deficiencies even when P is supplied at adequate levels later (Lima et al., 2011). As to P, this mineral

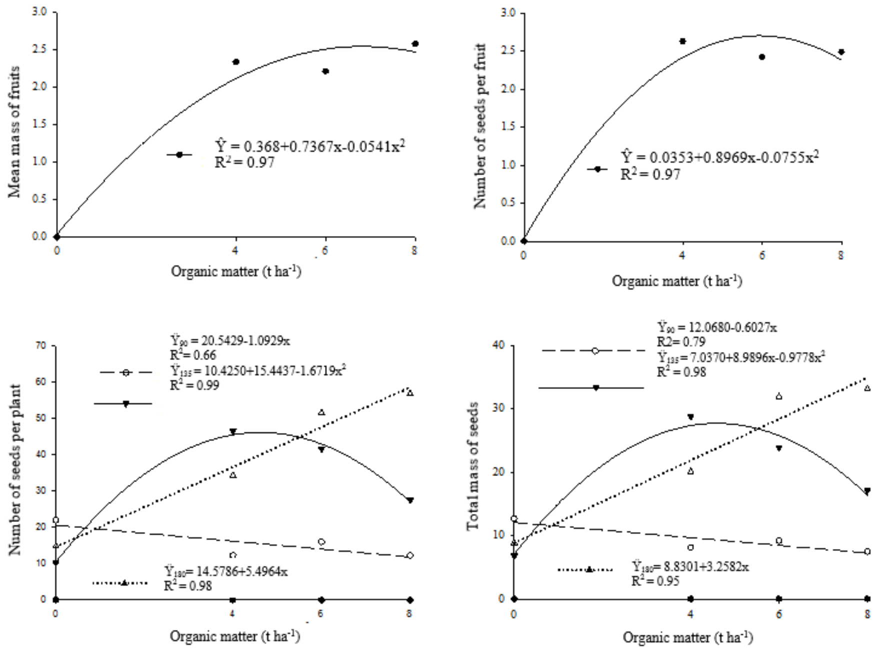

Fig 4. Mean mass of fruits per plant (A), number of seeds per fruit (B), number of seeds per plant (C), and total mass of seeds per plant (D) of jatropha plants in response to different amounts of organic and phosphate fertilizers. Campina Grande, PB, Brazil, 2014.

is also highly mobile in the phloem and is intensively redistributed (Lima et al., 2011) in jatropha tissues, for being one of the most required minerals, especially in its initial growth stage (Freiberg et al., 2014). P is part of plant structure in the composition of membranes (phospholipids), RNA, DNA, ATP and esters of carbohydrates, besides many key molecules in its metabolism, responsible for accelerating the formation of roots and assisting symbiotic N fixation (Malavolta et al., 1997). According to Laviola and Dias (2008), the supply of P to jatropha in the first years of cultivation must be higher than the amount accumulated by the plant, since more than 50% of P supplied through fertilizations is fixed by soil clay fraction, which limits its availability to plants. The limitations in P availability in the beginning of the vegetative cycle can result in restriction to crop development, from which plants do not recover later, even if the P supply is increased to adequate levels (Araújo and Machado, 2006).

Yield variables

The number of inflorescences per plant showed a quadratic response for the tested doses of organic matter (Fig 3A) and the lowest value was observed at the dose of 1.36 t ha^{-1} of cattle manure. On the other hand, the highest value (0.68 inflorescences plant^{-1}) was observed at the dose of 8 t ha^{-1} of cattle manure. The application of N sources was expected to promote satisfactory results on the reproductive structures of the plants, since this macronutrient stimulates the formation and development of floral and fruit buds and is responsible for higher vegetation, as well as for the increase in the contents of proteins (Malavolta et al., 1997). The application of 8 t ha^{-1}, which corresponds to 4.8 kg plant^{-1} of cattle manure, promoted results similar to those obtained by Arruda et al. (2013) and Fernandes et al. (2013), who verified that the doses of 15 and 12 kg plant^{-1} of cattle manure promoted higher number of inflorescences in jatropha plants cultivated in pots and irrigated. The production variables number of fruits per plant and number of bunches per plant (Fig 3B and D) showed a sigmoid response, with the highest values between the doses of 6 and 8 t ha^{-1} of cattle manure. The lowest values for these two production components occurred between the recommended dose (4 t ha^{-1}) and 1.5 times the recommended dose (6 t ha^{-1}) of organic fertilization. Higher number of fruits and bunches was observed by Arruda et al. (2013) and Fernandes et al. (2013) through the application of 12 and 15 kg hole^{-1} of cattle manure. Proportionally, these authors used, on average, 3 to 3.5 times the amounts applied in this study. These results suggest that jatropha is responsive to organic fertilization, particularly to the application of cattle manure. Possibly, for concentrating expressive amounts of macro and micronutrients and for gradually supplying these minerals, organic matter is an excellent option for the fertilization of jatropha, especially in farms close to livestock production centers, where cattle manure can be obtained by farmers at lower prices. This reduces production costs, due to both the improvement of soil physical and chemical properties and the supply of nutrients. The different recommendations of organic fertilization significantly influenced the production components mass of fruits and number of seeds per fruit. On the other hand, the isolated application of P, and combined with doses of organic matter, promoted significant response for the variables number of seeds per plant and mass of seeds per plant, respectively (Table 4). As observed for the variable number of inflorescences per plant, a quadratic response was found for the production variables mean mass of fruits and number of seeds per fruit, with the increase in the recommended doses of organic matter. Since cattle manure is a potential source of N, its adequate supply probably promoted alterations in plant morphology, increasing leaf area and facilitating the light interception for photosynthesis (Marschner, 2012). The mean mass of fruits (Fig 4A) showed a quadratic response, with maximum value of 2.5 g for the application of 6.8 t ha^{-1} of organic matter. In general, the increase in mass of fruits of jatropha was correlated with the recommended doses of the organic fertilizer. The same tendency was observed for the number of seeds per fruit (Fig 4B), which showed quadratic response until the dose of 5.9 t ha^{-1} of cattle manure. The number of seeds per fruit depends on the amount of photoassimilates produced in the leaves and transported to the drains, such as seeds in formation. These results can be explained by the fact that these nutrients are highly mobile in the phloem and are redistributed to younger organs (Malavolta, 2006). In this stage of fruit formation, the presence of adequate amounts of macro and micronutrients is essential in the soil solution, especially N and P, because they participate directly in the formation of amino acids and proteins, as well as in the composition of fatty acids, which are the main product of jatropha seeds. Probably, for the cultivation under low fertility conditions, represented in this study by the absence of organic and phosphate fertilization, and partially by the dose recommended according to the soil analysis, the processes of fruiting, fruit development and seed filling were seriously hampered, because the best results occurred for the conditions of medium fertility, represented by the application of 1.5 times the recommended doses (6 t ha^{-1} of organic matter and 135 kg ha^{-1} of P).

It is evident that the amount of organic matter represented by 1.5 times the recommended dose (6 t ha^{-1}) was sufficient for obtaining satisfactory results of production components. The highest number of seeds per fruit was observed for the dose of 5.9 t ha^{-1} of organic matter, while the lowest value was observed in plants without fertilization. This result can be explained by the fact that jatropha shows high growth rate and N is the most required nutrient for the formation of leaves and the supply of the metabolic requirements of fruits (Laviola and Dias, 2008), since it is essential for the assimilation of carbon and formation of new organs in plants (Taiz and Zeiger, 2004). As to the production components number of seeds per plant and total mass of seeds per plant (Fig 4C and D), there were interactive effects between organic and phosphate fertilization. In general, when the P doses of 90, 135 and 180 kg ha^{-1} were isolated and the recommended doses of organic matter (0, 4, 6 and 8 t ha^{-1}) varied, there was a quadratic response for the association between the P dose of 135 kg ha^{-1} and the four doses of organic matter for both analyzed variables. For the other combinations, there was linear increase for the P dose of 180 kg ha^{-1} and a linear decrease for the P dose of 90 kg ha^{-1} with the increase in the doses of organic matter, for both studied variables. This means that the joint application of the P dose recommended by the laboratory and all the recommended doses of organic matter fertilization did not promote adequate results for these production variables. In the literature, there are no results explaining the lack of response of these variables to the combinations of 135 kg ha^{-1} of P and the tested doses of organic fertilizer.

Although the application of the recommended doses of phosphate fertilization tested in this study was not significant, it is evident that the organic matter provided adequate amounts of essential nutrients for jatropha growth and development, which indicates that the use of P combined with organic matter may be unnecessary in the first cultivation year. According to Freiberg et al. (2013), the demand for P is not expressive in the first year of cultivation, gradually increasing from the second and third production years on. However, Laviola and Dias (2008) recommend P application in the first two years of jatropha, in order to guarantee good growth and development. It should be pointed out that the recommendations of these authors refer to studies performed using only mineral fertilization and not the association between P and organic matter. The number of seeds per plant is a yield component that represents plant production. According to the observed results (Fig 4C), the highest production of seeds (58.5) was observed for the dose of 8 t ha^{-1} of cattle manure associated with the P dose of 180 kg ha^{-1}, which corresponds to 2 times the doses recommended by the laboratory of soil analysis for both fertilizers. On the other hand, for the application of 135 kg ha^{-1} of P inside all the tested doses of organic matter, the number of seeds increased until the dose of 4.6 t ha^{-1} of cattle manure. Doses above the critical point significantly reduced the production of seeds.

The production component total mass of seeds (Fig 4C) showed a response similar to that of number of seeds per plant. For the doses of 135 kg ha^{-1} of P and 4.59 t ha^{-1} of organic matter, the total mass of seeds reached 27.6 g $plant^{-1}$. The increase in mass of seeds was directly related to the recommendations of fertilization. Higher values of mass of seeds were obtained when plants were cultivated under high fertility conditions, represented by the joint application of 8 t ha^{-1} of cattle manure and 180 kg ha^{-1} of P. Unfavorable results for mass of seeds were obtained when the P dose of 90 kg ha^{-1} was associated with the four recommended doses of organic matter.

Materials and Methods

Location and tratments used in this study

The experiment was carried out in an open area of the Academic Unit of Agricultural Engineering at the Federal University of Campina Grande-PB, Brazil (07°15'18'' S; 35°52'28'' W; 550 m). The climate of the region, according to Köppen's classification, is Csa, mesothermal sub-humid with dry and hot drought period (4 to 5 months) and rainy period from autumn to winter (Coelho and Soncin, 1982). The data of precipitation and temperature in the cultivation area are shown in Fig 1. The experiment was set in a randomized block design, with four replicates and one plant per plot. The treatments consisted of a 4 x 4 factorial scheme with two factors: 4 recommendations of organic fertilization [absence of fertilization (0 t ha^{-1}), recommended dose (4 t ha^{-1}), 1.5 times the recommended dose (6 t ha^{-1}) and 2 times the recommended dose (8 t ha^{-1})] and 4 recommendations of phosphate fertilization [absence of fertilization (0 kg ha^{-1}), recommended dose (90 kg ha^{-1}), 1.5 times the recommended dose (135 kg ha^{-1}) and 2 times the recommended dose (180 kg ha^{-1})]. The recommended doses of organic and phosphate fertilization was determined according to the contents of organic matter and P in the soil. Organic matter and P were supplied using cattle manure and single superphosphate, respectively.

The experiment was conducted in pots with capacity for 150 L of substrate, which were filled with the material of a soil classified as Quartzarenic Neosol Eutrophic of sandy loam texture, collected from the layer of 0-30 cm in the district of São José da Mata, Campina Grande-PB, Brazil. The soil and the cattle manure were chemically analyzed for the determination of the requirements of organic matter and P, at the Laboratory of Soil and Water Analyses of the Federal University of Campina Grande, and the results are shown in Table 1. The cattle manure used in the experiment showed contents of 10.2, 2.0, 12.4, 6.6, 4.2 and 2.5 g kg^{-1} for N, P, K, Ca, Mg and S, respectively. According to the results of the soil analysis, there was no need for acidity correction or presence of sodium salts. For the distribution of the recommended fertilizer doses in the cultivation area, the pots were filled with 50% of soil and 50% of a mixture containing soil, cattle manure and P, according to the pre-established treatments. Then, the pots were irrigated, using water from the local supply system, and brought to field capacity for the determination of the irrigation depths, which were defined by the difference between retained and drained volumes. Plants were irrigated and the water consumption for the entire cultivation period (180 days) was equal to 6,120 L.

The experiment was installed in April 2013, in a spacing of 3 x 2 m. Seedlings were produced in 288-dm^{-3} plastic tubes, filled with the commercial substrate Plantmax. In order to guarantee the germination of the seedlings, the recipients were daily irrigated until complete emergence. After emergence, the seedlings were irrigated according to the water demand and to the climatic conditions of the environment.

Thirty days after emergence, the seedlings were transplanted to the definitive recipients containing the treatments. Plants were irrigated at the end of the afternoon in an interval of three days, defined according to the difference between the retained and drained water volumes. During the experiment, the following cultural practices were performed: manual removal of weeds, superficial scarification of the soil every two irrigations and weekly sprayings, for the preventive control of insects and fungal diseases.

Measurements

Plant growth was evaluated 180 days after transplantation (DAT), through the measurement of plant height, stem diameter, number of leaves, leaf area and number of branches per plant. During the flowering period, the following production components were measured: number of inflorescences per plant, number of fruits per plant, number of bunches per plant, number of fruits per bunch, mass of fruits per plant, number of seeds per plant, number of seeds per bunch and total mass of seeds per plant.

Plant height was measured in the stem, considering the distance from the basis to the apex of the plant and stem diameter was measured at 5 cm from the soil surface. For the number of leaves, all the fully expanded leaves with length equal to or higher than 3 cm were considered. Leaf area was estimated in 30% of the total number of leaves per plant using Equation 1, proposed by Severino et al. (2007).

$$LA = \Sigma\, 0.84\, (L + W)^{0.99} \qquad (1)$$

where,
- LA: leaf area (cm^2);
- Σ: sum of leaf area;
- L: midrib length (cm); and
- W: leaf width (cm).

Data analysis

The obtained data were subjected to analysis of variance by F test. When significant, the data were analyzed through linear and quadratic polynomial regressions using the statistical program SISVAR-ESAL (Ferreira, 2003). Maximum and/or minimum points of the regression equations were estimated through the derivative of "Y" with respect to "X".

Conclusions

Plant height, number of branches, stem diameter, leaf area, number of inflorescences, number of fruits, number of bunches, number of fruits per bunch, mass of fruits, number of seeds per fruits, number of seeds per plant and total mass of seeds per plant were influenced by the recommendations of fertilization; The recommendation of organic and phosphate fertilization suggested by the laboratory of soil analysis (4 t ha^{-1} of organic matter and 90 kg ha^{-1} of phosphorus) was insufficient for the development of productive plants; The isolated use of organic matter in the fertilization of jatropha promotes positive effects on growth variables and production components. The application of 1.5 times the dose of organic matter recommended by the laboratory of soil analysis, which corresponds to 6 t ha^{-1} of cattle manure, isolated, or associated with 135 kg ha^{-1} of P, is sufficient to supply the nutritional requirements of N and P in the first cultivation year; Phosphate fertilization associated with organic fertilization significantly influenced plant height, number of branches, stem diameter, leaf area, number of seeds and total mass of seeds of jatropha plants.

Acknowledgements

The authors would like to thank the Brazilian Council for Scientific research and Development (CNPq) for the grant to the first author (EDITAL MEC/CAPES and MCT/CNPq/FINEP N^o 28/2010 – PNPD/CNPq/UFCG.

References

Akbarian MM, Modafebehzadi N, Bagheripour MA (2010) Study of fertilizer (NPK) effects on yield and triglycerides in Jatropha **(***Jatropha curcas L.***)**. Plant Ecophysiology. 2:169-172.

Arruda RL, Queiroz PA, Costa NV, Araiva AS, Erasmo EAL (2013) Evaluation of the initial growth of *Jatropha curcas* L. under different doses of phosphorus applied to the base. J Biotec Biodivers. 4: 378-389

Araújo AP, Machado CTT (2006) Fósforo. In: Fernandes, MS. (Ed.). Plant Mineral Nutrition. Viçosa, MG: Sociedade Brasileira de Ciência do Solo. p. 253-280.

Bello EI, Agge M (2012) Biodiesel production from ground nut oil. JETEAS. 3: 276-280.

Brito KSA, Laime EMO, Suassuna JF, Fernandes PD, Oliveira DCS (2013) Growth and production of Jatropha (*Jatropha curcas* L.) as a function of sources and doses of organic matter. Eng Amb. 10: 134-142.

Carvalho CM, Viana TVA, Marinho AB, Lima Júnior LA, Valmir Júnior M (2013) Jatropha: growth under different conditions of irrigation and fertilization in the northeastern semiarid. AGRIAMBI. 17: 487-496.

Coelho MA, Soncin NB (1982) Geografia do Brasil. São Paulo: Moderna, 368 p.

Fernandes JD, Chaves LHG, Dantas JP, Silva JRP (2013) Phenology and production of jatropha when grown with different sources of fertilisation**.** Rev Ciênc Agron. 44: 339-346.

Ferreira, P. V (1996) 2nd. Experimental statistics applied to agronomy. Maceió: Edufal, 606p.

Freiberger MB, Guerrini IA, Castoldi G, Pivetta LG (2014) Phosphorus fertilization on the early growth and nutrition of physic nut seedlings. R Bras Ciênc Solo. 38:232-239.

Freire EA, Nascimento NV, Lima VLA (2011) Initial growth of *Jatropha curcas* submitted to phosphorus fertilization. T&CA. 5: 21-24.

Ghosh A, Patolia JS, Chaudhary DR, Chikara J, Rao SN, Kumar D, Boricha GN, Zala A (2007) Response of *Jatropha curcas* under different spacing to *Jatropha* de-oiled cake, FACT seminar on *Jatropha curcas* L. agronomy and genetics, Wageningen, The Netherlands, March 26–28, FACT Foundation, Wageningen (2007) Article no. 8.

Hussein MM, Thalooth AT, Tawfik MM, Mirvat EG, Mohamed MH (2012) Impact of mineral and organic fertilizer on vegetative growth of *Jatropha curcas* L. in sandy soil. Elixir Appl. Botany, 49: 9714-9717.

Laviola BG, Dias LAS (2008) Nutrient concentration in *Jatropha curcas* L. Leaves and fruits and estimated extraction at harvest. Rev Bras Ciênc Solo, 32: 1969-1975.

Lima RLS, Severino LS, Cazetta JO, Azevedo CAV, Sofiatti V, Arriel NHC (2011) Redistribution of nutrients in jatropha leaves through phenological phases. Agriambi, 15:1175–1179.

Lopes DC, Steidle Neto AJ (2011) Potential crops for biodiesel production in Brazil: A review. WJAS, 7: 206-217.

Maffeis AR, Silveira RLVA, Brito JO (2000) Macronutrients and boron deficiencies reflexes on plant growth, production and essential oil in *Eucalyptus citriodora*. Scientia Forestalis, 57: 87-98.

Malavolta E, Vitti GC, Oliveira AS (1997). 2nd. Evaluation of plant nutritional status: principles and applications. Piracicaba: Associação Brasileira para Pesquisa da Potassa e Fosfato, 201 p.

Malavolta, E (2006) Manual of plant mineral nutrition. São Paulo: Agronômica Ceres, 638 p.

Mohapatra S, Panda PK (2011) Effects of fertilizer application on growth and yield of *Jatropha curcas* L. in an Aeric Tropaquept of Eastern India. Not Sci Biol, 3: 95-100.

Marschner H, Mineral Nutrition of higher plants. (2012). 3rd. Publ. Academic Press. San Diego, USA. 651p.

Patolia JS, Ghosh A, Chikara J, Chaudhary DR, Parmar DR, Bhuva HM (2007) Response of *Jatropha curcas* grown on wasteland to N and P fertilization. Proceedings of the FACT Seminar on *Jatropha curcas* L. Agronomy and Genetics, March 26-28, FACT Foundation, Wageningen, The Netherlands, p: 1-10.

Pereira JCS, Fidelis RR, Erasmo EAL, Santos PM, Barros HB, Carvalho GL (2011) Flowering and fruiting of jatropha genotypes under phosphorus doses in the *Cerrado* of the South region of Tocantins. JBB, 2:28-36.

Prates FBS, Lucas CSG, Sampaio RA, Brandão Júnior DS, Fernandes LA, Zuba Júnio GR (2012) Growth of jatropha seedlings in response to single superphosphate and rock-flour fertilization. Rev Cienc Agron, 43:207-213.

Raja SA, Smart DSR, Lee CLR (2011) Biodiesel production from Jatropha oil and its characterization. ISCA, 1:81-87.

Schulz DG, Fey R, Ruppenthal V, Malavasi MM, Malavasi UC (2012) Initial growth of physic nut as a function of sources and doses of organic fertilizers. Cienc. Agrotec., 36: 615-623.

Severino LS, Vale LS, Beltrão NEM (2007) A simple method for measurement of *Jatropha curcas* leaf area. Rev. Ol. Fibros, 11:9-14.

Silva EB, Tanure LPP, Santos SR, Rezende Júnior OS (2009) Visual symptoms of nutrient deficiency in physic nut. PAB, 44:392-397.

Sop TK, Kagambéga FW, Bellefontaine R, Schmiedel V, Thiombiano A (2011) Effects of organic amendment on early growth performance of *Jatropha curcas* L. on a severely degraded site in the sub-Sahel of Burkina Faso. AFS, 86:387-399.

Sousa AEC, Greyi HR, Correia KG, Soares FAL, Nobre RG (2011) Growth and water consumption of physic nut under salt stress and phosphorus levels. Rev. Ciênc. Agron., 42: 310-318.

Souza PT, Silva EB, Grazziotti PH, Fernandes LA (2011) NPK Fertilization on initial growth of physic nut seedlings in quartzarenic neossol. Rev Bras Ciênc Solo, 35: 559-566.