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Effects of planting density on vegetative growth and production components of jatropha (*Physic nut* L)

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Abstract

Planting configuration is a management factor that influences production. Despite its importance for the establishment of commercial plantations of jatropha, the best planting configuration is still unknown, since its optimal planting density varies widely according to the climate and soil conditions of each region. This study aimed to determine the best planting configuration for jatropha cultivated in the Agreste region of Paraíba, Brazil. An experiment was set up in a randomized block design with 4 replicates. The treatments consisted of 4 different planting configurations: 2 m × 2 m (2,500 plants ha^{-1}), 3 m × 2 m (1,666 plants ha^{-1}), 3 m × 3 m (1,111 plants ha^{-1}), and 4 m × 3 m (833 plants ha^{-1}). The experimental plot (16 m × 16 m) had a minimum of 4 rows and 5 plants row^{-1} for the widest spacing (4 m × 3 m) and a minimum of 7 rows and 7 plants row^{-1} for the narrowest spacing (2 m x 2 m). The mean values of plant height, leaf area, number of fruits per plant, number of seeds per plant, number of fruiting branches per ha, number of fruits per ha, number of bunches per ha and production of seeds per ha were significantly influenced by planting density in dense plantations. The highest seed production per ha was obtained at a density of 2,500 plants ha^{-1} (narrowest spacing).

Keywords: *Jatropha curcas* L; spacing; production.
Abbreviations: S: _Sum of bases; T_Cation exchange capacity; V_Saturation of bases; OM_Organic matter; LA_Leaf area, PH_plant height, SD_stem diameter, NVB/pl_number of vegetative branches per plant, NVB/ha_number of vegetative branches per ha, NFB/pl_number of fruiting branches per plant, NFB/ha_number of fruiting branches per ha, NInf/pl_number of inflorescences per plant, NInf/ha_number of inflorescences per ha, NF/pl_number of fruits per plant, NF/ha_number of fruits per ha, NBunch/pl_number of bunches per plant, NBunch/ha_number of bunches per ha, NS/pl_number of seeds per plant, NS/ha_number of seeds per ha, Prod/pl_production of seeds per plant, Prod/ha_production of seeds per ha, Σ_sum of leaf area, *L*_midrib length, *W*_leaf width.

Introduction

Jatropha (*Jatropha curcas* L.) is a perennial oilseed plant in the Euphorbiaceae family native to the Americas, which is grown mainly in India, Africa, and Central America (Laviola et al., 2012). It is found in almost all intertropical regions, occurring at a larger scale in tropical and temperate regions and at a smaller scale in cold regions (Colodetti et al., 2011). Its seed production usually starts in the first cultivation year, but commercial production only starts in its second year and becomes stable from the fourth or fifth year on (Drumond et al., 2010; Silva et al., 2012). Jatropha yield is highly variable, so its production technology needs to be improved. One cultural practice that can be carefully managed for high yields without increasing production costs, is the use of high planting density (Horschutz et al., 2012; Sharma et al., 2012).
In general, production can be increased by maximizing the photosynthetic efficiency of the cultivated plants, especially by improving the interception of photosynthetically active radiation through a more efficient conversion of the intercepted radiation into dry matter and through the partitioning of photoassimilates to the reproductive organs (Marchão et al., 2005). For jatropha, improving radiation interception through plant configuration is one of the most important management practices to enhance yield.

The ideal spacing for jatropha is still unknown and depends on genotype, propagation method, soil fertility, climate conditions in the region, level of technology applied, weed control, topography, plantation longevity, etc. (Jimu et al., 2009; Huse Santosh et al., 2011). All these factors have a direct influence on the correct selection of planting densities for jatropha, which range from 833 to 10,000 plants ha^{-1} in various regions worldwide (Huse Santosh et al., 2011; Horschutz et al., 2012; Sharma et al., 2012). The available spacing recommendations are based almost exclusively on those for other crops, which can decrease the production of the system. According to the literature, denser plantations increase jatropha yield (Behera et al., 2010; Sharma et al., 2012). In Brazil, Horschutz et al. (2012) observed that, in the first cultivation year, there were no significant differences in the growth and production variables of jatropha plants at spacings of 2 m × 3 m, 2 m × 4 m, 3 m × 3 m, 3 m × 4 m, 4 m × 4 m, 5 m × 3 m, and 5 m × 4 m. On the other hand, Ghosh et al. (2007) recommend the use of narrower spacing (3 m × 2 m), for higher yield and oil content in the seeds. Similarly, under rainfed conditions in India, Sharma et al. (2012) recommend narrow spacing (1.7 × 1.5 m and 1 × 1 m) for higher seed production and oil content.

In the Agreste region of Paraíba, there are no consistent reports in the literature on the best planting configuration for the cultivation of jatropha. This study aimed to define the best planting configuration for jatropha cultivated in the Agreste region of Paraíba, Brazil.

Results and Discussion

Growth and yield variables

Plant height, leaf area, number of fruits per plant, number of seeds per plant, number of fruiting branches per ha, number of fruits per ha, number of bunches per ha, and production of seeds per ha were influenced by the evaluated planting densities (Tables 2, 3, and 4).

In general, vegetative growth was influenced by the evaluated planting densities, because plant height and leaf area are the most representative variables of plant growth. Mineral demands are usually higher in denser plantations due to the creation of an environment with high competition for water, light, and nutrients in the space occupied by the plant, resulting in faster growth than in plants in less dense plantations (Scarpare Filho and Kluge, 2001).

The plant height and leaf area of jatropha evaluated 14 months after seedling emergence showed a quadratic response, with maximum values of 171.9 cm and 8994.60 cm^2, respectively, for densities of 1,475 and 1,337 plants ha^{-1}, respectively (Fig 1A and B). In general, at a density of 1,475 plants ha^{-1} or more, plant height was reduced by about 24%. On the other hand, leaf area decreased sharply at a density of 1,337 plants ha^{-1} or more. The lowest leaf area (3855.6 cm^2) was observed at a planting density of 2,500 plants ha^{-1}, a reduction of 57.13% from the maximum leaf area value. The decreases in plant height and leaf area are probably related to the reduction in the photosynthetic capacity in response to shading, which decreases the production of photoassimilates and their redistribution for the formation of new tissues and plant growth (Marchão et al., 2005). The number of fruits per plant showed the same tendency observed for plant height and leaf area (Figure 1C). Increased planting density decreased the number of fruits per plant, and its maximum value (30.9) was observed at a planting density of 1,300 plants ha^{-1}. The average number of fruits per plant ranged from 30.9 to 22.2 at planting densities of 1,300 and 2,500 plants ha^{-1}, respectively. According to these results, fruit production decreased by 28% with the increase in planting density. Leaf area may have influenced the number of fruits per plant, since the production of photoassimilates was hampered at the highest planting densities, which may have reduced the translocation of photoassimilates to sink organs. Therefore, the transport of nutrients and water to this growth region reduces the development of production components, leading to a lower production of fruits per plant. According to Reddy et al. (2012), the economically important crop parts may react to the pressure of a large population, after competition starts, through a decrease in fruit number and size and/or seed production. The decrease in the number of seeds per plant (Fig 1D) observed at the high planting densities evaluated can also be attributed to the reduction in photosynthetic capacity as a response to shading, which reduces fruit filling and development (Morais et al., 2008). The highest number of seeds per plant (107) was observed at a planting density of 833 plants ha^{-1}, indicating that less dense plantations can be more productive with respect to this variable. On the other hand, the minimum value of 66.68 seeds $plant^{-1}$ was observed at the narrowest spacing (2,500 plants ha^{-1}), a decrease of 37.6% for this variable. High planting densities also reduced the number of seeds per plant. This can be partially explained by the intraspecific competition of jatropha plants for environmental factors, especially light, which may have determined fruit filling and seed formation. This suggests that a higher number of plants per row (narrower spacing) can reduce the availability of photoassimilates, which should be directed to production components.

Among the production components per hectare (yield components), significant differences were observed in the number of fruiting branches, number of bunches, number of fruits, and production of seeds (Tables 2, 3, and 4). As planting density increased, there were significant increases in the number of fruiting branches (Fig 2A) and number of fruits per ha (Fig 2B) up to limits of 6,300 and 54,015, respectively, at planting densities of 2,265 and 2,212 plants ha^{-1}, respectively. The lowest values for both variables were observed at a planting density of 833 plants ha^{-1}. Despite the higher number of fruits per ha with higher planting density, there was a slight reduction in the number of fruits and seeds per plant (Fig 1C and D) as planting density increased. These results suggest that high planting density stimulated the production of hormones and the formation of reproductive structures. However, because of the high metabolic demand for photoassimilates, the amount of carbohydrates produced by the plants was not sufficient for the fixation of flowers and formation and filling of seeds, due to possible shading and a reduction in the photosynthetic rate.

The number of bunches per ha and production of seeds per ha (Fig 2C and D) increased linearly as planting density increased, in contrast to the previously discussed production variables, which decreased at high planting densities. The highest number of bunches was observed at the highest planting density (2,500 plants ha^{-1}). On the other hand, seed production ranged from 60.29 to 116.8 kg ha^{-1} at planting densities of 833 and 2,500 plants ha^{-1}, respectively, which indicates that high planting density can be a viable strategy to increase jatropha production. Although the decrease in the number of seeds per plant was substantial at the highest planting densities studied (narrowest spacing), the production remained higher at the lowest densities (widest spacing). Increases in jatropha yield at higher planting densities were also observed by Behera et al. (2010), Harika et al. (2012), Jimu et al. (2009), and Sharma et al. (2012). Although the yield obtained in this study was low compared with those reported in the literature, it should be pointed out that production data are for 14-month-old plants, corresponding to the beginning of the first cycle. According to Drumond et al. (2010) and Laviola and Dias (2008), jatropha plants begin to produce satisfactorily only in the second or third year of cultivation, and the production in the first cycle is not significant. These results indicate the need for further studies on the second, third, and fourth cultivation years of jatropha plants at high planting density for more consistent information on the best planting configuration. In general, these results indicate that a higher number of plants per unit of area, that is narrower spacing, might be essential to maintain adequate yields in jatropha plants.

Table 1. Soil chemical characteristics in the area under jatropha cultivation. Lagoa Seca-PB, Brazil, 2014.

pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SB	H + Al	T	V	Al^{3+}	P	OM
1:2.5	Sorption Complex ($mmol_c dm^{-3}$)							%	$mmol_c$ dm^{-3}	mg dm^{-3}	g kg^{-1}
6.3	5.8	3.3	3.8	1.8	14.7	16.7	31.4	46.8	2.0	15.4	11.7

SB – Sum of bases; T – Cation exchange capacity; V – Base saturation; OM – Organic matter.

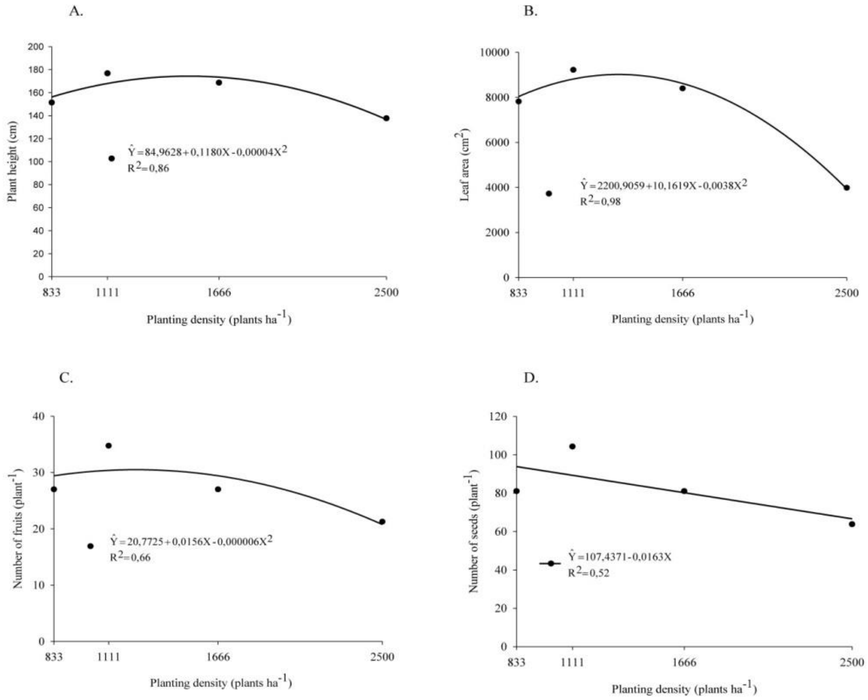

Fig 1. Plant height (A), leaf area (B), number of fruits per plant (C) and number of seeds per plant (D) of 14-month-old jatropha plants at different planting densities. Lagoa Seca-PB, Brazil, 2014.

Table 2. Summary of analysis of variance for plant height (PH), stem diameter (SD), leaf area (LA), and number of vegetative branches per plant (NVB/pl) and per ha (NVB/ha) of 14-month-old jatropha plants at different planting densities. Lagoa Seca-PB, Brazil, 2014.

Mean Square						
Source of Variation	DF	PH	SD	LA	NVB/pl	NVB/ha
Planting density (PD)	3	1229.4^{**}	405.4739^{ns}	21546341.5^{*}	0.250000^{ns}	5918263.5^{ns}
Block	3	38.14^{ns}	49.0156^{ns}	262374.5^{ns}	0.750000^{ns}	4201378.5^{ns}
Residue	9	25.29	91.4600	2130423.4	0.750000	3708239.5
LR	1	1146.30^{**}	431.0808^{ns}	44235931.6^{**}	0.107033^{ns}	17035384.6^{ns}
QR	1	2042.73^{*}	696.5970^{ns}	19340998.9^{ns}	0.029264^{ns}	203266.7^{ns}
CV (%)	-	4.57	11.68	19.85	17.92	22.55

DF – Degree of freedom; LR – linear regression; QR – quadratic regression; **significant at 1%; * significant at 5%; ns = not significant.

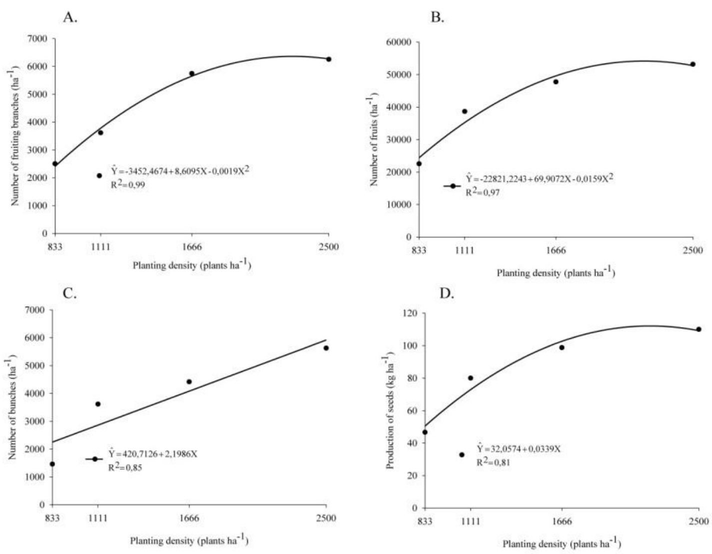

Fig 2. Number of fruiting branches per ha (A), number of fruits per ha (B), number of bunches per ha (C) and production of seeds (D) of 14-month-old jatropha plants at different planting densities. Lagoa Seca-PB, Brazil, 2014.

Table 3. Summary of analysis of variance for number of fruiting branches per plant (NFB/pl) and per ha (NFB/ha), number of inflorescences per plant (NInf/pl) and per ha (NInf/ha), and number of fruits per plant (NF/pl) and per ha (NF/ha) of 14-month-old jatropha plants at different planting densities. Lagoa Seca-PB, Brazil, 2014.

Mean Square							
Source of Variation	DF	NFB/pl	NFB/ha	NInf/pl	NInf/ha	NF/pl	NF/ha
Plant density (PD)	3	0.500000^{ns}	12507961*	0.395833^{ns}	2311207.^{ns}	122.8^{ns}	71755304^{ns}
Block	3	0.833333^{ns}	2269447.0^{ns}	0.229167^{ns}	623824.2^{ns}	19.50^{ns}	977507^{ns}
Residue	9	0.444444	730553.72	0.395833	950912.2	19.22	58635533.6
LR	1	0.762264^{ns}	32531895**	1.074657^{ns}	5541205^{ns}	191.9^{ns}	17382128^{ns}
QR	1	0.730160^{ns}	4808582.1^{ns}	0.020189^{ns}	1088368^{ns}	52.35^{ns}	3396751.3^{ns}
CV (%)	-	22.22	18.88	37.28	39.69	15.94	18.91

DF – Degree of freedom; LR – linear regression; QR – quadratic regression; **significant at 1%; * significant at 5%; ns = not significant

Table 4. Summary of analysis of variance for number of bunches per plant (NBunch/pl) and per ha (NBunch/ha), number of seeds per plant (NS/pl) and per ha (NS/ha), and production of seeds per plant (Prod/pl) and per ha (Prod/ha) of 14-month-old jatropha plants at different planting densities. Lagoa Seca-PB, Brazil, 2014.

Mean Square							
Source of Variation	DF	NBunch/pl	NBunch/ha	NS/pl	NS/ha	Prod/pl	Prod/ha
Planting density (PD)	3	1.562500^{ns}	12296938.0^{ns}	1105.5^{ns}	6.4579**	0.000508^{ns}	3074.86*
Block	3	1.062500^{ns}	3537656.16^{ns}	175.50^{ns}	879756963.0^{ns}	0.000075^{ns}	418.83^{ns}
Residue	9	0.451389	1513220.38	173.00	52771980.3	0.000069	251.23
LR	1	0.002959^{ns}	31336239.8**	1727.8^{ns}	15643912938.7**	0.001001^{ns}	7448.8**
QR	1	1.501973^{ns}	3232176.61^{ns}	471.21^{ns}	3057076569.5^{ns}	0.000157^{ns}	145.24^{ns}
CV (%)	-	27.56	32.55	15.94	18.91	14.81	18.91

DF – Degree of freedom; LR – linear regression; QR – quadratic regression; **significant at 1%; * significant at 5%; ns = not significant.

Materials and Methods

Location and crop plant

The experiment was carried out under field conditions for 14 months at the experimental unit of the State Company for Agricultural Research (EMEPA) in the municipality of Lagoa Seca in the microregion of Campina Grande in the Agreste of Paraíba, Brazil (7°9′28″ S, 35°52′24″ W; 630 m). According to Thornthwaite (1948), the climate in the region is Aw, rainy tropical with a summer dry season. The experiment was carried out in a homogeneous area with a predominance of soil classified as Eutrophic Quartzarenic Neosol of sandy loam texture. The soil showed slight acidity; low availability of Ca, Mg, and P; low base saturation; high content of Al^{3+}; and moderate content of organic matter (Table 1). According to the results of the soil analysis, acidity correction was necessary. In order to repair the deficiency of Ca and Mg and increase soil pH, 2 t ha^{-1} of dolomitic limestone was applied to the entire area. Sixty days after liming, organic and mineral fertilizers were distributed in the holes before planting the seeds according to the studied spacings. As a reference recommendation for all the treatments, 120, 90, and 60 kg ha^{-1} of N, P, and K, respectively, were applied as urea, triple superphosphate, and potassium chloride, respectively. Nitrogen fertilization was divided into 3 applications, 1 basal and 2 topdressings 30 and 60 days after seedling emergence. To improve soil physical properties, 4 t ha^{-1} of cattle manure was applied in accordance with the recommendation of the Laboratory of Soil and Water Analyses of Embrapa Cotton.

The soil preparation was performed by plowing, harrowing, and leveling the experimental area. Jatropha seeds were directly planted in the holes immediately after fertilizer application, and were irrigated until the seedlings reached a height of 10 cm. Localized irrigation was performed using micro-sprinklers (Hadar 7110 – NaanDanJain®) with turbulent flow at a flow rate of 29.0 L h^{-1} at a working pressure of 1.0 bar and wetted diameter of 6.0 m. The micro-sprinklers were positioned 0.25 m from the soil and 0.40 m from the plant stem, using 1 lateral of sprinklers per plant row (one sprinkler per plant).

Irrigation management was based on climatic data, using the Penman-Monteith equation for the calculation of reference evapotranspiration (ETo, mm d^{-1}). For the calculation of crop evapotranspiration (ETc, mm d^{-1}), a crop coefficient of 1.0 (Kc = 1.0) was used. The amount of water applied in the treatments was sufficient to supply crop water demand, with an interval of 4 days. During the experiment, the following cultural practices were performed: manual weeding, superficial scarification of the soil every 2 irrigations, and weekly sprayings for the preventive control of insects and fungal diseases.

Spacing treatments

A randomized block design was adopted with 4 replicates and 6 plants per plot. The treatments consisted of 4 planting densities: 2,500, 1,666, 1,111, and 833 plants ha^{-1}, corresponding to spacings of 2 m × 2 m, 3 m × 2 m, 3 m × 3 m, and 4 m × 3 m, respectively. The experimental plots (16 m × 16 m) had a minimum of 25 and a maximum of 49 plants for the widest (4 m × 3 m) and narrowest (2 m × 2 m) spacings studied, respectively. Only the 2 central rows were considered for the evaluations.

Measurement of traits

From 420 days after seedling emergence on, the following variables were evaluated: plant height, stem diameter, leaf area, and number of vegetative branches (plant^{-1} and ha^{-1}). After the flowering stage, the following production components were evaluated: number of fruiting branches (plant^{-1} and ha^{-1}), number of inflorescences (plant^{-1} and ha^{-1}), number of bunches (plant^{-1} and ha^{-1}), number of fruits (plant^{-1} and ha^{-1}), number of seeds (plant^{-1} and ha^{-1}), and production of seeds (kg ha^{-1}).

Plant height was measured from the base to the apex of the main branch, and stem diameter was measured at 5 cm from the soil surface. Leaf area was estimated for 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).

The numbers of vegetative and fruiting branches, inflorescences, bunches, fruits, and seeds per plant were determined by direct count. The data from all the plots (12 plants per plot) were extrapolated to the total area (hectare) according to the number of plants per ha determined by the spacing of each treatment.

Data analysis

The obtained data were subjected to analysis of variance by an F test and, when significant, linear and quadratic polynomial regressions were performed using the statistical program SISVAR-ESAL (Ferreira, 1996). Maximum and/or minimum points of the regression equations were estimated through the derivative of "Y" with respect to "X".

Conclusions

The mean values of plant height, leaf area, number of fruits per plant, number of seeds per plant, number of fruiting branches per ha, number of fruits per ha, number of bunches per ha, and production of seeds per ha are significantly influenced by planting density in dense plantations.

Grain yield (seed production) is significantly influenced by plant density and the highest values were obtained with a density of 2,500 plants ha^{-1} (narrowest spacing).

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