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Production components of Jatropha under irrigation and nitrogen fertilization in the semiarid region of Ceará

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A B S T R A C T
Jatropha curcas L. proves to be a promising species, considering its inclusion in the National Program of Biodiesel Production and Use. However, since it has not been genetically improved, agronomic information is still scarce in the literature, especially under conditions of water and nutritional stress. Thus, this field study aimed to evaluate the effects of irrigation depths (735; 963; 1,191; 1,418 and 1,646 mm) and nitrogen fertilization (0; 25; 50 and 75 kg ha^{-1}) on the production of Jatropha plants. Plants under the highest irrigation depth showed the highest values of number of fruits and productivity of fruits, seeds and albumen. Plants under the irrigation depth of 1,191 mm showed the highest values of mean mass of albumen and the ratios between mass of albumen and mass of seeds and between mass of albumen and mass of fruits. Nitrogen fertilization did not influence the production components of Jatropha.

Palavras-chave:
Jatropha curcas L.
irrigação localizada
biodiesel
produtividade

Componentes de produção do pinhão-manso sob irrigação e adubação nitrogenada no semiárido cearense

R E S U M O
O cultivo do pinhão-manso (*Jatropha curcas* L.) se revela promissor ao se considerar sua inserção no Programa Nacional da produção de biodiesel, mas, por ser uma espécie não melhorada geneticamente, suas informações agronômicas ainda são pouco frequentes na literatura, sobretudo em condições de estresse hídrico e nutricional. Face ao exposto, realizou-se este trabalho de campo para avaliar os efeitos de lâminas de irrigação aplicadas, de 735; 963; 1.191; 1.418 e 1.646 mm e adubação nitrogenada aos níveis de 0; 25; 50 e 75 kg ha^{-1} de N na produção das plantas de pinhão-manso. Os maiores valores do número de frutos, produtividade de frutos, sementes e albúmen foram obtidos das plantas irrigadas com a maior lâmina aplicada. Os maiores valores da massa média do albúmen e das relações entre massa de albúmen e de semente e entre a massa de albúmen e do fruto foram obtidos nas plantas irrigadas com a lâmina de 1.191 mm. A adubação nitrogenada não influenciou os componentes de produção do pinhão-manso.

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Introduction

Jatropha (*Jatropha curcas* L.) has emerged as an alternative for the supply of raw material to the production of biodiesel and biokerosene, since it is a perennial species, originated in the South American continent, which produces easy-to-harvest, oil-rich seeds, with properties capable of producing high-quality fuel (Dabdoub et al., 2009).

Jatropha cultivation has expanded not only through private initiatives from commercial plantations, but also through technical-scientific actions of domestication, with continuous scientific and technical experimentation, aiming to transform it from a wild to a cultivated species (Durães & Laviola, 2009; Nery et al., 2013). According to Carvalho et al. (2011), for being a wild species, i.e., it has not been genetically improved, there is still little agronomic information on this crop, especially under conditions of water and nutritional stress.

However, research results show that, in order to obtain high productivity of fruits and seeds, the crop needs water and fertile soils with good physical conditions. Thus, irrigation and the correction of soil acidity and fertility are decisive factors for the success and profitability with this crop (Laviola & Dias, 2008; Chaves et al., 2009; Schiavo et al., 2010; Farias et al., 2011; Oliveira et al., 2012).

Achten et al. (2009) also warn that caution is needed with respect to its unrestrained exploration, because it may be an obstacle for the achievement of the real potential of the crop, since science needs to be timely applied.

The possibility of using Jatropha oil for biodiesel production opens broad perspectives for the increase of cultivation areas in the Northeast semiarid region (Drumond et al., 2010). According to Jiang & Zhang (2002), the low water availability is one of the most important environmental factors in the regulation of growth, development and yield of seeds and oil in oil crops.

In semiarid regions, low rainfalls and low-fertility soils constitute the main factors responsible for the low yields of many crops used for the extraction of vegetable oil destined to biodiesel production (Carvalho et al., 2013). Given the above, this study aimed to evaluate the effects of increasing irrigation depths and levels of nitrogen fertilization on the production variables of Jatropha in the semiarid region of Ceará, Brazil.

Material and Methods

The experiment was carried out from September 2008 to February 2010, in the experimental area of the Bandeira Farm of the Agroempresa Brasil Ecodiesel, located in the municipality of Crateús-CE, Brazil (05° 23' 25" S; 40° 57' 38" W; 717 m). The climate of the region is BSw`h`, hot semiarid, with rainy season from February to May and mean annual rainfall of 786.7 mm, temperature of 27.1 °C and relative air humidity of 74% (1971-2000).

The total area of the experiment was equal to 3,750 m^2 (75 x 50 m). The experiment was set in a randomized block design, using a split-plot scheme, and the treatments consisted of the combinations of five irrigation depths (plots) and four levels of nitrogen (N) fertilization (subplots), totaling 20 treatments with three replicates.

The experimental plots (250 m^2 - 25 x 10 m) consisted of 4 subplots (60 m^2 - 6 x 10 m) with two plant rows in a spacing of 3 x 2 m, totaling 10 plants per row. Each block had an area of 1,250 m^2 (25 x 50 m). In the subplot, only one plant row was used for the evaluations and the other one was used as a common border row between subplots. The last plants on each side of the evaluated plant row were also considered as border plants, i.e., out of 10 plants in each subplot, only the 3 central ones were used for evaluations.

Five irrigation depths were applied and defined from the daily evaporation measured using a Class A pan (ECA), with the following treatments: L_1 = 50%; L_2 = 75%; L_3 = 100%; L_4 = 125% and L_5 = 150% of ECA, which, together with the effective rainfall, resulted in the applied water depths of 735.53, 963.30, 1,191.03, 1,418.82 and 1, 646.60 mm, respectively.

N fertilization was performed according to the recommendation of the Laboratory of Soils and Water of the Soil Science Department of the Federal University of Ceará (UFC). The applied doses were 0, 50, 100 and 150% of the total recommended (50 kg ha^{-1} of N), corresponding to 0, 25, 50 and 75 kg ha^{-1} of N, with 40% of each dose in the form of urea (45% of N) and 60% as ammonium sulfate (21% of N and 24% of S). Phosphorus (P) and potassium (K) fertilization was the same for all treatments with doses of 50 kg ha^{-1} of P_2O_5, as single superphosphate (18% of P_2O_5; 16% of Ca^{2+} and 8% of S) and 50 kg ha^{-1} of K_2O, as potassium chloride (60% of K_2O).

Hydro-physical and chemical characterization of the soil for the layer of 0-0.20 m (Table 1) was performed using samples randomly collected in the experimental area. Basal and topdressing fertilizations, throughout the crop cycle, were based on the results of chemical analysis.

The soil preparation in the area cultivated with Jatropha consisted of plowing and a mechanical crosswise harrowing.

Table 1. Physical-hydraulic and chemical characterization of the soil in the experimental area

Parameter	Unit	Layer (m) 0-0.20
Hydro-physical		
Coarse Sand	g kg^{-1}	615
Fine Sand	g kg^{-1}	307
Silt	g kg^{-1}	49
Clay	g kg^{-1}	29
Natural Clay	g kg^{-1}	17
Soil Bulk Density	kg dm^{-3}	1.54
Soil Particle Density	kg dm^{-3}	2.66
Total Porosity	%	41
Field Capacity*	%	13.24
Permanent Wilting Point*	%	5.27
Available Water Content	%	7.97
Textural Class		Sand
Chemical		
Organic Matter	g kg^{-1}	5.17
Calcium	$cmol_c$ dm^{-3}	1.40
Magnesium	$cmol_c$ dm^{-3}	1.40
Calcium + Magnesium	$cmol_c$ dm^{-3}	2.80
Aluminum	$cmol_c$ dm^{-3}	1.00
Potassium	mg dm^{-3}	31.00
Phosphorus	mg dm^{-3}	5.00
Sodium	mg dm^{-3}	3.00
pH		4.50

* The water contents at field capacity and permanent wilting point were determined using the volumetric ring method at the potentials of -0.010 MPa and -1.5 MPa, respectively

In addition, soil liming with approximately 2 t ha^{-1} of limestone and a basal fertilization with 240 g $plant^{-1}$ of NPK (8-30-20) were performed, according to the soil chemical analysis (Table 1) and the recommendations for the crop adopted by the 'Agroempresa Brasil Ecodiesel' at the Bandeira Farm.

The water used for irrigation came from a deep well located beside the experimental area, which was analysed and classified as C_1S_1, with no restrictions for irrigation purposes.

After the rainy season of 2009, at the end of July (194 days after transplanting), pruning was performed in order to standardize all the plants at a height of 0.3 m, and then the treatments with irrigation depths and N fertilization started.

A localized drip irrigation system (PLASTO®) was used, with service pressure of 200 kPa and nominal flow rate of 8 L h^{-1}, with emitters spaced 2 m apart, one for each plant at a distance of 0.10 m from the stem.

The irrigation depths applied in the treatments were controlled through valves according to the daily irrigation time, based on the evaporation measured in the Class A pan, as in Eq. 1.

$$Ti = \frac{\left(f \cdot ECA \cdot L_R \cdot L_p \cdot Fc\right)}{Ei \cdot Q_E} \tag{1}$$

where:

Ti - irrigation time, h;
f - adjustment factor according to the treatments;
ECA - evaporation measured in the Class A pan, mm d^{-1};
L_R - space between plant rows, m;
L_P - space between plants, m;
Fc - soil cover factor, dimensionless;
Ei - irrigation efficiency, dimensionless (adopted value of 90%, obtained from field evaluations of the system used); and
Q_E - emitter flow rate per plant, L h^{-1}.

The analysed variables were:

- Number of fruits (NF), obtained by the individual count of fruits in all harvested bunches of each plant;
- Mean mass of fruits (MMF), quantified by the ratio between the production per plant and the number of fruits;
- Mean mass of seeds (MMS) and Mean mass of albumen (MMA), obtained using a precision scale (0.01 g). Then, the ratio between MMS/MMA and the total number of seeds per plant were obtained;
- Productivity of fruits (PRODFH), quantified by Eq. 2:

$$PRODFH = \frac{PRODFP \cdot \left(\frac{10.000}{AP}\right)}{1.000} \tag{2}$$

where:

PRODFP - productivity of fruits, g $plant^{-1}$; and
AP - area of the plant, m^2.

- Productivity of seeds (PRODSH) and Production of albumen (PRODAH), quantified by Eqs. 3 and 4, respectively;

$$PRODSH = \frac{PRODSP \cdot \left(\frac{10.000}{AP}\right)}{1.000} \tag{3}$$

where:

PRODSP - productivity of seeds, g $plant^{-1}$;

$$PRODAH = \frac{PRODAP \cdot \left(\frac{10.000}{AP}\right)}{1.000} \tag{4}$$

where:

PRODAP - productivity of albumen, g $plant^{-1}$;

- Ratio between mass of albumen and mass of seeds (RMAMS) and ratio between mass of albumen and mass of fruits (RMAMF), in %, determined by Eqs. 5 and 6, respectively;

$$RMAMS = \frac{MMA}{MMS} \cdot 100 \tag{5}$$

$$RMAMF = \frac{\left(MMA \cdot NSF\right)}{MF} \cdot 100 \tag{6}$$

where:

NSF - number of seeds per fruit; and
MF - mass of the fruit, g.

The results were subjected to analysis of variance by F test and the data regarding irrigation depths and N fertilization were subjected to regression analysis. In the regression analysis, the equations that best fitted the data were chosen based on the significance of the regression coefficients at 0.01 and 0.05 probability level by F test and on the highest coefficient of determination (R^2). Variance and regression analyses were performed in electronic spreadsheets (Excel), using the software Assistat 7.5 Beta (Silva & Azevedo, 2008).

Results and Discussion

According to the analysis of variance (Table 2), except for the number of fruits and the mass of albumen, which responded to the effects of irrigation depths, none of the Jatropha production components responded significantly to the effects of the interaction between irrigation depths or the isolated effects of the N doses.

With respect to fertilization, similar results were obtained by Fernandes et al. (2013), working with different sources of fertilization, who observed no significant effect in any of the studied production components in the first crop cycle.

The statistical analysis of number of fruits and mass of fruits, seeds and albumen, is shown in Table 2.

The increase in the irrigation depths stimulated the production of fruits per plant (Figure 1). The values increased from 52.63 to up to 86 fruits, which represents an increment of 63.4% between plants under the lowest (735 mm) and the

Table 2. Summary of the analysis of variance for the number of fruits per plant (NF), mean mass of fruits (MMF), mean mass of seeds (MMS) and mean mass of albumen (MMA)

Source of variation	DF	Mean square NF (fruit plant^{-1})	MMF (g)	MMS (g)	MMA (g)
Irrigation depths (L)	4	2,506.07940**	0.00749^{ns}	0.00092^{ns}	0.07301**
Nitrogen levels (N)	3	186.84959^{ns}	0.00837^{ns}	0.00070^{ns}	0.00294^{ns}
Interaction L x N	12	136.27668^{ns}	0.00783^{ns}	0.00112^{ns}	0.00273^{ns}
Block	2	28.87848^{ns}	0.00281^{ns}	0.00331**	0.00038^{ns}
Residue (L)	8	160.33671	0.00707	0.00032	0.00280
Residue (N)	30	134.22718	0.00637	0.00084	0.00254
CV (L)	(%)	21.02	2.86	2.44	10.82
CV (N)	(%)	19.23	2.71	3.95	10.30

(**) Significant at 0.01 and (*) at 0.05 probability level; (^{ns}) not significant at 0.05 probability level by F test

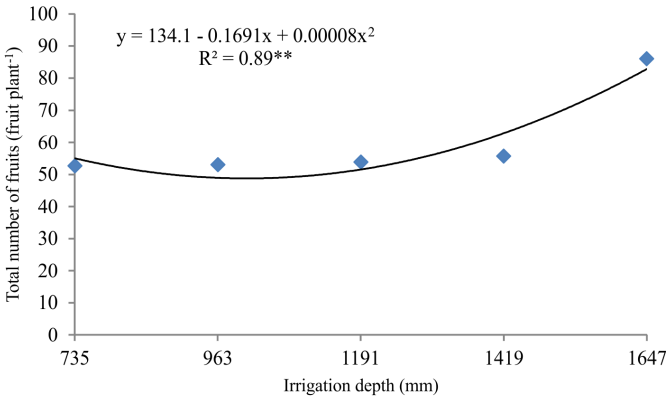

Figure 1. Number of fruits of Jatropha as a function of irrigation depths

highest (1,646 mm) irrigation depths, respectively. Similar behavior was observed by Silva et al. (2011) in Jatropha plants irrigated with wastewater, with an increase of 648.8% in the mean number of bunches between plants in the treatments with 0.25 and 1.25 of replenishment of evapotranspiration.

The values of mean mass of albumen (MMA) were virtually constant for the different irrigation depths, except for 1,191 mm, which promoted the highest MMA (0.63 g), reaching an expressive difference compared with the others, i.e., about 38.46% higher.

The equation chosen to express the behavior of MMA in response to the different irrigation depths (R^2 = 0.51) is represented by Eq. 7:

$$y = 0.2788 + 0.0014x - 0.0000006x^2 \qquad (7)$$

where:

y - mean mass of albumen, g; and

x - irrigation depth, mm.

The treatments with irrigation depths below or above the total evaporation of the Class A pan, showed MMA values similar to reference values while the most expressive value was obtained for the irrigation depth corresponding to 1,191 mm.

In the treatments with water deficit, the reduction in the growth of fruits, seeds and shells can be justified by the stomatal closure, which favors metabolic changes that cause the plant to adapt to the new conditions and adjust the osmotic flow, thus reducing the assimilation of chlorophyll (Nóbrega, 2010).

As with the production components, productivity variables did not respond to the interaction between irrigation depths and N fertilization or to the isolated effects of N fertilization, but all the variables were significantly influenced by irrigation depths (Table 3).

Similar result was obtained by Oliveira et al. (2012), who observed no significant effect of K fertilization on the productivity of Jatropha seeds. However, irrigation depths influenced this production factor.

The increase in irrigation depths stimulated the total production of fruits, seeds and albumen, as shown in Figure 2.

The production of fruits of Jatropha increased from 258.72 to 417.07 kg ha^{-1}, an increment of 61.2% between plants subjected to the lowest and the highest irrigation depths (Figure 2A). The behavior of the plants is in agreement with the results observed by Silva et al. (2011), who claimed that, as plants adapt to the environmental conditions, the number of fruits will increase and, therefore, the productivity will also increase. Silva (2010) claimed that Jatropha plants demand higher volume of water available in the soil (close to field capacity), in order to better express its production potential and reach higher productivity.

According to Lima et al. (2012), the production of fruits by this crop occurs from the first to the second year of development and stabilizes around the fourth year, lasting for up to forty years. However, this effect can only be reached with the maintenance of soil management, rainfall and irrigations favorable to plant growth.

For the production of seeds, the increment from the lowest to the highest irrigation depth corresponded to 61.86%, with values of 167.13 and 270.51 kg ha^{-1} (Figure 2B); in the same conditions, the total production of albumen ranged from 100.92 to 166.43 kg ha^{-1}, corresponding to an increase of 64.92% (Figure 2C). Similarly, Silva et al. (2011) observed that plants showed a continuous production, especially those under conditions of adequate water availability.

Oliveira et al. (2012) observed that the productivity of Jatropha plants under irrigation depth corresponding to 120% of ECA was 69% higher compared with non-irrigated plants, reaching maximum seed productivity of 192 kg ha^{-1}.

The importance of irrigation in the production of Jatropha is shown in the data of Drumond et al. (2007) for the region of Petrolina-PE, with plant spacing of 2 x 2 m, in which the mean productivity of fruits (871 kg ha^{-1}) for irrigated plants

Table 3. Summary of the analysis of variance for the production of fruits ha^{-1} (PRODFH), production of seeds ha^{-1} (PRODSH) and production of albumen ha^{-1} (PRODAH)

Source of variation	DF	Mean square PRODFH (kg ha^{-1})	PRODSH (kg ha^{-1})	PRODAH (kg ha^{-1})
Irrigation depths (L)	4	56,055.51888**	23,805.20461**	9,022.63740**
Nitrogen levels (N)	3	5,067.74366^{ns}	2,269.45446^{ns}	963.25549^{ns}
Interaction L x N	12	3,191.78384^{ns}	1,340.62244^{ns}	541.61765^{ns}
Block	2	1,026.86621^{ns}	464.63013^{ns}	230.70339^{ns}
Residue (L)	8	4,532.74532	2,040.26713	777.66346
Residue (N)	30	5,067.74366	1,431.19018	567.21862
CV (L)	(%)	22.79	23.62	23.66
CV (N)	(%)	19.51	19.79	20.21

**Significant at 0.01 and (*) at 0.05 probability level; ^{ns}Not significant at 0.05 probability level by F test

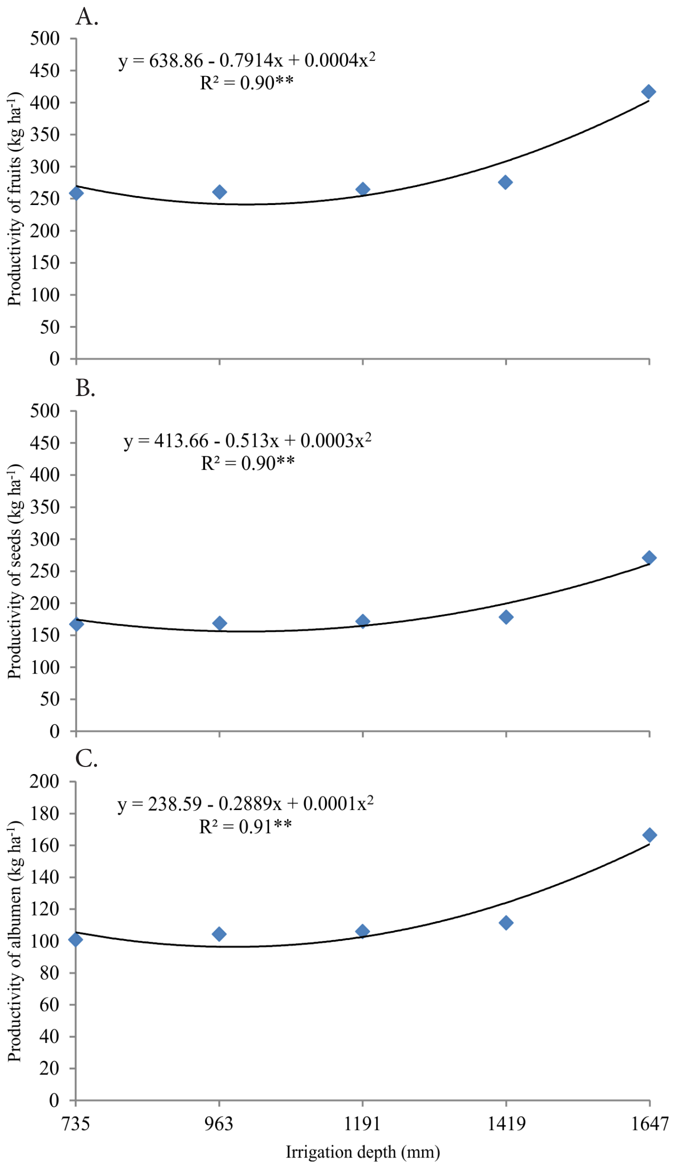

Figure 2. Productivity of fruits (A), seeds (B) and albumen (C) of Jatropha plants per hectare as a function of irrigation depths

was 3.5 times higher compared with non-irrigated plants (246 kg ha^{-1}), and Evangelista et al. (2011), who concluded that the irrigated treatment was superior to the non-irrigated one, with seed productivity of 236.2 and 83.87 kg ha^{-1}, respectively.

In the treatments with the lowest irrigation depth, there was a reduction in the values of the production variables, which was also observed by Evangelista et al. (2009). These authors analysed the productivity of Jatropha under the application of different water depths, calculated based on ECA, and observed a mean value of 192.1 kg ha^{-1} for a water depth equivalent to 120% ECA, with irrigation interval of 3 days, in the first year of cultivation. These authors also claim that the region in which the experiment was carried out has annual rainfall above 1,000 mm, which evidences that Jatropha requires an adequate water availability in the soil.

According to Larcher (2000), the first and most sensitive response to water deficit is the decrease in turgor and, associated with this event, the decrease in the growth process (particularly growth in length). Water deficit compromises cell elongation, because the turgor pressure is not sufficient for cell growth, which becomes slower due to the high concentration of abscisic acid and, consequently, there is a reduction in crop growth and production.

The ratios between mass of albumen and mass of seeds (RMAMS) and mass of albumen and mass of fruits (RMAMF), as the other evaluated variables were not influenced by the interaction between irrigation depths and N fertilization or the isolated effects of N doses. Significant effects were only observed for the irrigation depths (Table 4).

RMAMS and RMAMF become important, because the oil used in the production of biodiesel is extracted from the albumen. These variables can be used to calculate the price of fruits and seeds with shells, if the commercialization is destined to the extraction of oil from the seeds, as well as to determine the obtained amount of material with shells, which will be used as a by-product of the oil extraction, as organic fertilizer etc.

The increase in irrigation depths from 735 mm to up to 1,291 mm increased the RMAMS values from 60.3 to 62.3%, which corresponded to an increment of 3.3% (Figure 3).

This is contrary to the comments of Albuquerque et al. (2009), who claimed that soil water availability interferes with plant production and its deficiency reduces the stomatal opening period and the production of photoassimilates.

Linear equation (Eq. 8) may also be used to express the behavior of RMAMS as a function of the different irrigation depths for its simplicity, though with value of $R^2 = 0.48$):

$$y = -23.748272 + 0.119323x - 0.000049x^2 \quad (8)$$

Table 4. Summary of the analysis of variance for the ratio between mass of albumen and mass of seeds (RMAMS) and between mass of albumen and mass of fruits (RMAMF)

Source of variation	DF	Mean square	
		RMAMS	RMAMF
		(%)	
Irrigation depths (L)	4	8.51691^{*}	581.51416^{**}
Nitrogen levels (N)	3	1.26892^{ns}	31.09032^{ns}
Interaction L x N	12	3.11378^{ns}	16.41360^{ns}
Block	2	4.16100^{ns}	18.18517^{ns}
Residue (L)	8	1.84390	22.71998
Residue (N)	30	1.84662	21.03965
CV (L)	(%)	2.20	11.05
CV (N)	(%)	2.21	10.64

**Significant at 0.01 and (*) at 0.05 probability level; ^{ns}Not significant at 0.05 probability level by F test

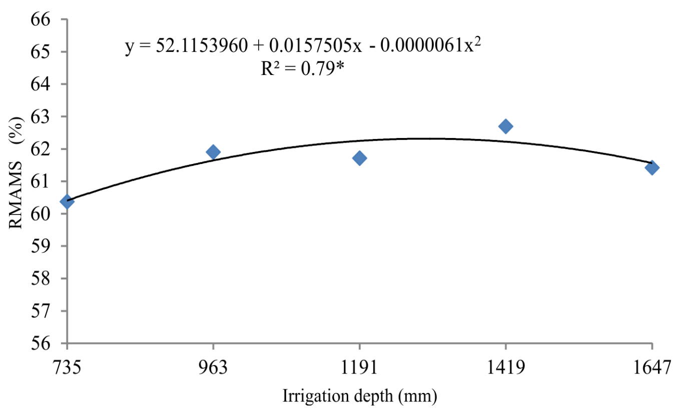

Figure 3. Ratio between mass of albumen and mass of seeds (RMAMS) of Jatropha as a function of irrigation depths

where:

y - ratio between mass of albumen x mass of fruit, %; and

x - irrigation depth, mm.

Conclusions

1. Nitrogen had no effects on the production of Jatropha in the semiarid region of Ceará.

2. The highest values of productivity of fruits, seeds and albumen were obtained in plants under the highest irrigation depth.

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