Influence of irrigation and nitrogen fertilization on the characteristics of seeds of Jatropha

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Abstract

Agronomic information on the cultivation of Jatropha plants (Jatropha curcas L.) in the field is still uncommon 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 characteristics of seeds of Jatropha. Nitrogen fertilization did not influence the production components of Jatropha. The seeds have an elongated aspect, where the length is always greater than the width and thickness. The highest values of seed thickness obtained in plants under the lowest irrigation depth. Plants under the highest irrigation depth showed the highest values of seed length, total number of seeds per plant and productivity of seeds.

Keywords: *Jatropha curcas* L., biodiesel, productivity.

1. Introduction

The species Jatropha curcas belongs to the family Euphorbiaceae, which is widely distributed in tropical and subtropical areas with potential for the production of biodiesel. This species has several attributes, such as: fast growth, easy propagation, perennial plant, cultivated in areas of low and high precipitation, low cost of seeds and high oil content (Sujatha et al., 2008; Nunes et al., 2009).

According to Santos et al. (2011), the species belonging to the euphorbiae family are excellent examples of the high capacity for obtaining oil, through organic matter, for the production of biodiesel, highlighting the physic nut (Jatropha curcas L.) and the castor bean (Ricinus communis L.). Where Jatropha curcas L. is being considered an agricultural option for the Northeast region of Brazil for being a native species, demanding in insolation and with strong resistance to drought, being a culture that can be developed in family properties, contributing to the income of the owners rural areas.

However, the lack of technical and scientific knowledge about the species, especially in conditions of water and nutritional stress, generates a demand for research that makes the implantation of Jatropha possible as an agricultural crop in the country and in the world (Arruda et al., 2004; Pimenta et al., 2014 and Carvalho et al., 2015b).

Since water is a limiting factor for the expansion of agriculture, especially in arid and semi-arid regions, it is necessary to apply water artificially with the use of irrigation, making it necessary to correctly manage irrigation where are identified the depths water ideal for obtaining a balanced production of the crops to be irrigated (Carvalho et al., 2011b; Carvalho et al., 2015a).

In addition, well-conducted fertilization allows significant productivity gains in most cultivated plants. It is a production factor that can be managed at a low investment cost, but it needs to be conducted technically to avoid unnecessary use of certain nutrients that can cause unnecessary expenses and in certain cases even reduce productivity (Carvalho et al., 2011a).

In view of the scarcity of information on the cultivation of physic nut and the importance of using irrigation and nitrogen fertilization, this work aimed to evaluate the characteristics of irrigated Jartropha seeds cultivated with different doses of nitrogen fertilization.

2. Material and Methods

The experiment was carried out 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 ºC and relative air humidity of 74% (1971-2000).

The total area of the experiment was 3,750 m2 (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 (Figure 1).

Figure 1. General view of the jatropha experiment in the field.

The experimental plots 250 m^2 (25 x 10 m) and consisted of 4 subplots of 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: L1 = 50%; L2 = 75%; L3 = 100%; L4 = 125% and L5 = 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 applied 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).

Physical-hydraulic 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.

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

Parameter	Unit	Layer (m) 0-0.20
Physical-hydraulic		
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

The soil preparation in the area cultivated with Jatropha consisted of plowing and a mechanical crosswise harrowing. 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 (Table 2), with no restrictions for irrigation purposes.

Table 2. Chemical characterization of water in the experimental area

Parameter	Unit	Quantity
	Cations	
Calcium (Ca^{2+})	$mmol_c\ L^{-1}$	0.19
Magnesium (Mg^{2+})	$mmol_c\ L^{-1}$	0.16
Sodium (Na^{+})	$mmol_c\ L^{-1}$	0.17
Potassium (K^{+})	$mmol_c\ L^{-1}$	0.10
Sum	$mmol_c\ L^{-1}$	0.63
	Anions	
Chloride (Cl^{-})	$mmol_c\ L^{-13}$	0.42
Sulfate (SO_4^{2-})	$mmol_c\ L^{-1}$	0.01
Bicarbonate (HCO^{3-})	$mmol_c\ L^{-1}$	0.20
Carbonate (CO_3^{2-})	$mmol_c\ L^{-1}$	-
Sum	$mmol_c\ L^{-1}$	0.63
EC (Electric Conductivity)	$dS\ m^{-1}$	0.062
SAR (sodium adsorption ratio)		0.42
pH		6.8
Dissolved solids	$Mg\ L^{-1}$	62
Classification		C_1S_1

After 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.

$$Ti = \frac{(f * ECA * L_R * L_p * Fc)}{(Ei * Q_E)} \quad (1)$$

where:

Ti – irrigation time, h;

f – adjustment factor according to the treatments;

ECA – evaporation measured in the Class A pan, mm d^{-1};

LR – space between plant rows, m;

LP – 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

QE – emitter flow rate per plant, L h^{-1}.

The analysed variables were:

Mean mass of seeds (MMS), in grams, obtained using a precision scale (0.01 g).

Seed length (SL), in mm, was measured with the aid of a digital caliper, measuring the longitudinal distance of the seed.

Seed width (SW), in mm, was measured with the aid of a digital caliper, measuring the equatorial distance from the seed.

Seed thickness (ST), in mm, was measured with the aid of a digital caliper, measuring the polar distance of the seed.

Mean number of seeds per fruit (MNSF), in seeds fruit-1, was determined by Eq. 2.

$$MNSF = \frac{TNS}{TNF} \quad (2)$$

Where: MNSF is the mean number of seeds per fruit, in seeds fruit-1; TNS is the total number of seeds; TNF is the total number of fruits.

Mean mass of seeds in the fruit (MMSF), in g $fruit^{-1}$, was determined by equation 3.

$$MMSF = MMS.MNSF \quad (3)$$

Where: MMSF is the mean mass of seeds in the fruit, in g $fruit^{-1}$; MMS is the mean mass of seeds, em g; MNSF is the mean nunber of seeds per fruit, in seeds $fruit^{-1}$.

Ratio between mass of seed and mass of fruit (RMSMF), in %, was determined by equation 4.

$$RMSMF = \frac{(MMS.NSF)}{MF}.100 \quad (4)$$

Where: RMSMF is the ratio between mass of seed and mass of fruit, in %; MMS is the mean mass of seeds, em g; NSF is the number of seeds per fruit and MF is the mass of fruit, em g.

Total number of seeds per plant (TNSP), in seeds $plant^{-1}$, was determined by counting the number of seeds in each plant.

Productivity of seeds (PRODS), in kg ha^{-1}, was determined by equation 5.

$$PRODS = \frac{PRODSP.\left(\frac{10000}{AP}\right)}{1000} \quad (5)$$

Were: PRODS is the productivity of seeds, in kg ha^{-1}; PRODSP is the production of seed per plant, in gram; AP is the area of the plant in m²

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 7.7 (Silva & Azevedo, 2016).

3. Results and Discussion

The statistical analysis of mean mass of seed, seed length, seed width, seed thickness and mean number of seeds per fruit, is shown in Table 3.

Table 3. Summary of the analysis of variance for mean mass of seeds (MMS), seed length (SL), seed width (SW), seed thickness (ST) and mean number of seeds per fruit (MNSF)

Source of Variation	DF	Mean Square				
		MMS (g)	SL (mm)	SW (mm)	ST (mm)	MNSF (seeds fruit^{-1})
Irrigation depths (L)	4	0.00092^{ns}	0.10903^{*}	0.01449^{ns}	0.02422^{**}	0.00415^{ns}
Linear regression	1	-	0.07656^{*}	-	0.01806^{*}	-
Quadratic regression	1	-	0.03159^{ns}	-	0.00244^{ns}	-
Cubic regression	1	-	0.00306^{ns}	-	0.00056^{ns}	-
Nitrogen levels (N)	3	0.00070^{ns}	0.00588^{ns}	0.00667^{ns}	0.00362^{ns}	0.01126^{ns}
Interaction L x N	12	0.00112^{ns}	0.03168^{ns}	0.00920^{ns}	0.00615^{ns}	0.00708^{ns}
Block	2	0.00331^{**}	0.00573^{ns}	0.00702^{ns}	0.00175^{ns}	0.01472^{ns}
Residue (L)	8	0.00032	0.02614	0.01703	0.00340	0.00593
Residue (N)	30	0.00084	0.02439	0.00643	0.00480	0.01051
CV (L)	(%)	2.44	0.87	1.16	0.65	2.97
CV (N)	(%)	3.95	0.84	0.71	0.78	3.95

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

According to the analysis of variance (Table 3), except for seed length and the seed thickness, which responded to the effects of irrigation depths, none of the Jatropha seeds characteristics responded significantly to the effects of the interaction between irrigation depths or the isolated effects of the N doses.

The maximum and minimum values of seed mass observed in this experiment were 0.79 and 0.72 grams per seed. These values are much higher than those observed by Heller (1996), who obtained values of 0.575 and 0.417 grams per seed. The results found in this experiment were very close to the maximum limit found by Peixoto (1973) and Rocha et al. (2008) which was 0.8 grams per seed. With regard to the general mean value of 0.73 grams per seed, it is slightly higher than that found by Santos et al. (2011) who obtained an mean mass of 0.694 g.

The increase in the irrigation depths stimulated the seed length (Figure 2). The values increased from 18.60 to up to 18.79 mm, which represents an increment of 1.08% between seeds of plants under the lowest (735 mm) and the highest (1,646 mm) irrigation depths, respectively.

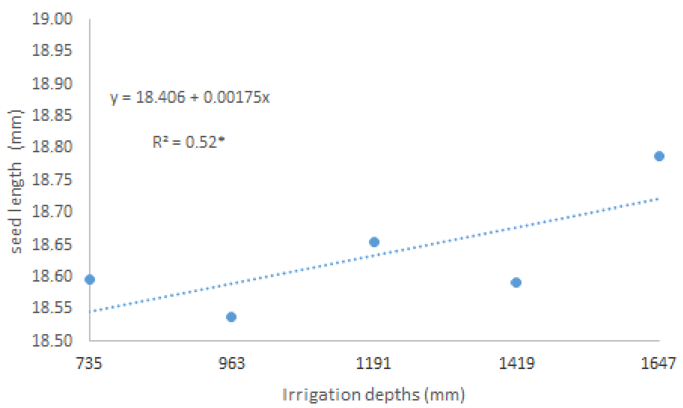

Figure 2. Jatropha seed length, depending on the water depth.

Linear equation (Figure 2) may also be used to express the behavior of seed length a as function of the different irrigation depths for its simplicity, though with value of R2 = 0.52.

The mean value of the seed length for the irrigation depth obtained in this experiment was 18.63 mm. This mean value observed for the jartropha seed length is higher than the mean values of 18.09 mm obtained by Santos et al. (2012), of 17.50 mm obtained by Pimenta et al. (2014), of 16.20 mm obtained by Nunes et al. (2009).

Similar values for seed length were reported by Dantas et al. (2007), in which their values were around 10 mm to 20 mm.

Regarding the seed width, an mean value of 11.24 mm was observed in this experiment, which is higher than the values found by Santos et al. (2012), Pimenta (2014) and Nunes (2009), which were 10.85, 10.90 and 10.7 mm, respectively.

The growing irrigation depths provided an inverse effect on seed thickness when compared to the length seed, i.e., with the addition of the irrigation depths, the thickness values dropped, resulting in a decreasing linear regression (Figure 3).

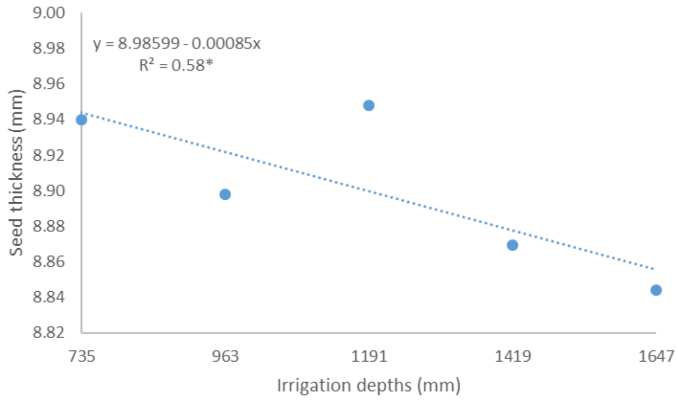

Figure 3. Jatropha seed thickness, depending on the water depth.

The seed thickness values decreased from 8.94 to up to 8.84 mm, which represents a decrease of 1.13% between seeds of plant under the lowest (735 mm) and the highest (1,646 mm) irrigation depths, respectively.

Linear equation (Figure 3) may also be used to express the behavior of seed thickness a as function of the different irrigation depths for its simplicity, though with value of R2 = 0.58.

The mean value of the seed thickness obtained in this experiment was 8.90 mm. This value is higher than that found by Santos et al. (2011) with 8.64 mm, by Pimenta et al. (2014) with 8.70 mm and by Nunes et al. (2009) with 4.70 mm.

It was also observed that due to the fact that the length is always greater than the width and thickness, the seeds presented an elongated aspect, as observed by Dantas et al. (2007), Nunes et al. (2009), Santos et al. (2011) and Pimenta et al. (2014).

With regard to the mean number of seeds per fruit, there was no influence of irrigation depths or nitrogen doses, an mean number of 2.6 seeds per fruit was obtained, where 5.61% of the fruits presented 1 seed, 28.14% of the fruits had 2 seeds, 66.14% of the fruits had 3 seeds and only 0.12% had 4 seeds.

According to the analysis of variance (Table 4), except for the total number of seeds per plant and the productivity of seeds, 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.

Table 4. Summary of the analysis of variance for mean mass of seeds in the fruit (MMSF), ratio between mass of seed and mass of fruit (RMSMF), total number of seeds per plant (TNSP), and productivity of seeds (PRODS)

Source of Variation	DF	Mean Square			
		MMSF (g fruit^{-1})	RMSMF (%)	TNSP (seeds plant^{-1})	PRODS (kg ha^{-1})
Irrigation depths (L)	4	0.00294^{ns}	0.16370^{ns}	17,308.44956**	23,805.20461**
Linear regression	1	-	-	12,930.85640**	18,728.98729**
Quadratic regression	1	-	-	7,244.73754**	9,820.37315**
Cubic regression	1	-	-	2,531.59921*	2,830.30152*
Nitrogen levels (N)	3	0.00449^{ns}	0.27214^{ns}	1,709.18585^{ns}	2,269.45446^{ns}
Interaction L x N	12	0.00567^{ns}	0.56969^{ns}	899.14007^{ns}	1,340.62244^{ns}
Block	2	0.00172^{ns}	0.16370^{ns}	76.95032^{ns}	464.63013^{ns}
Residue (L)	8	0.00430	0.36627	1,245.54107	2,040.26713
Residue (N)	30	0.00468	0.47745	881.60948	1,431.19018
CV (L)	(%)	3.45	0.94	22.55	23.62
CV (N)	(%)	3.59	1.07	18.97	19.79

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

With respect to fertilization, similar results were obtained by Carvalho et al. (2013), Fernandes et al. (2013) and Carvalho et al. (2015), working with different sources of fertilization, who observed no significant effect in any of the studied growth and production components in the first crop cycle.

The increase in the irrigation depths stimulated the total number seeds per plant (Figure 4). The values increased from 136.49 to up to 224.31 seeds, which represents an increment of 64.3% between plants under the lowest (735 mm) and the highest (1,646 mm) irrigation depths, respectively.

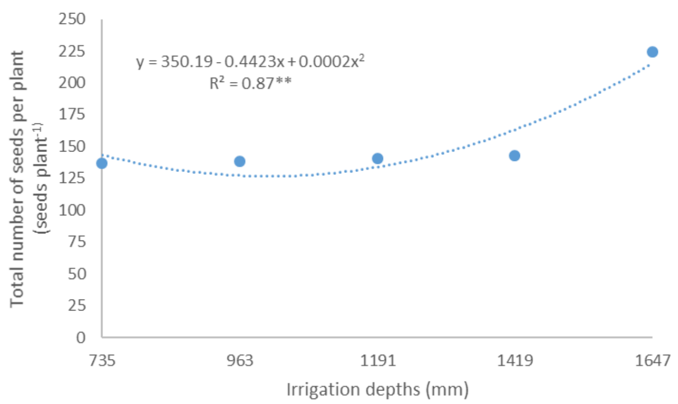

Figura 4. Total number of seeds per plant as a function of irrigation depths.

The production of seeds of Jatropha increased from 167.13 to 270.51 kg ha^{-1}, an increment of 61.86% between plants subjected to the lowest and the highest irrigation depths (Figure 5). Similarly, Silva et al. (2011) and Carvalho et al. (2015b) observed that plants showed a continuous production, especially those under conditions of adequate water availability.

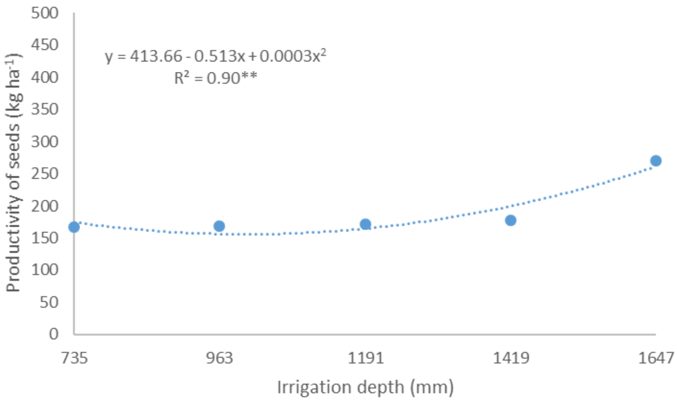

Figura 5. Productivity of seeds of Jatropha plants per hectare as a function of irrigation depths.

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 seeds of Jatropha is shown in the data of 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) and Carvalho et al (2015b).

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 (Carvalho et al., 2013) and production (Carvalho et al., 2015b).

4. Conclusions

Nitrogen had no effects on the characteristics of seeds of Jatropha.

The seeds have an elongated aspect, where the length is always greater than the width and thickness.

The highest values of seed thickness obtained in plants under the lowest irrigation depth.

Plants under the highest irrigation depth showed the highest values of seed length, total number of seeds per plant and productivity of seeds.

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