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Irrigation water salinity and nitrogen doses affect the cultivation of castor bean (*Ricinus communis* L.) at different phenological stages

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Abstract

The high population growth in the last years, combined with the deterioration in quality and decrease in quantity of water resources, has made the use of saline water in agricultural activities necessary. This study aimed to evaluate growth and yield of castor bean plants cv. 'BRS Energia', as a function of electrical conductivity of irrigation water and nitrogen fertilization under different water management strategies. The experiment was carried out in field conditions in a Regolithic Neosols Eutrophic with sandy loam texture in the municipality of Pombal, Paraíba, Brazil.The experimental design consisted of randomized blocks in a 5×2×2 factorial with three replications, testing five levels of electrical conductivity of irrigation water ECw (0.3, 1.2, 2.1, 3.0 and 3.9 dS m^{-1}), two nitrogen doses (100 and 160 mg kg^{-1}) and two management strategies of use of saline water as (a) the use of low salinity water (0.3 dS m^{-1}) during the vegetative stage, and later on use of water with different saline levels; and (b) the use of water of different ECw levels throughout the entire crop cycle. The results showed that use of saline water, regardless of the management strategy, affects growth and yield of the cv. 'BRS Energia' which is more sensitive to saline stress when irrigated with saline water throughout the entire cycle. The N doses did not influence the evaluated growth and yield variables. Irrigation with water caused alterations in the content and yield of oil. Water with electrical conductivity of 2.1 dS m^{-1} may be utilized in cultivation of castor bean cultivar 'BRS Energia'.

Keywords: BRS Energia; saline stress; water scarcity; mineral nutrition; *Ricinus communis* L.
Abbreviations: DAS_days after seeding; ECw_electrical conductivity of water; MHSPR_mass of a hundred seeds of the primary raceme; MSPR_mass of seeds of the primary raceme; NL _number of leaves; OCPR_oil content of primary raceme; OYPR_oil yield of seeds of the primary raceme; PH_plant height; PTP_Percentage of threshing; SD_stem diameter;TLPR_total length of primary raceme; ECse_ electrical conductivity of the soil saturation extract; ECd _electrical conductivity of drainage water.

Introduction

In northeast Brazil, especially in semiarid areas, the occurrence of high temperatures, low rainfalls, uneven distribution of rains and intense evaporation in most months of the year is common. Hence, the practice of irrigation is the best way to guarantee safe agricultural production (Nobre et al., 2011). In addition, it should be pointed out that the quality of the irrigation water in this region varies too much, both in geographic (spatial) and temporal (seasonal) terms, being common the occurrence of water sources with high salinity levels (Bezerra et al., 2010). In agriculture, the use of water and/or soils with salt problems can limit plant growth and yield, because of the reduction in the osmotic potential of the soil solution, which may cause ionic toxicity, nutritional imbalance or both, due to the excessive accumulation of certain ions, especially chloride and sodium, in plant tissues (Flowers, 2004). However, plant response to salinity is a complex phenomenon, because the tolerance to salinity varies among species and cultivars, which depends on some other factors, such as type and concentration of salts, exposure time, phenological stage and edaphoclimatic factors, as well as the interaction between them (Ashraf and Harris, 2004). Among the socioeconomically important crops for the semiarid region, castor bean (*Ricinus communis* L.) stands out, because of its xerophilic and heliophilic characteristics, besides its good adaptation to different conditions of soil and management. It is a rustic crop, with a fast growth, high yield and expressive oil content in seeds (Marinho et al., 2010). Castor bean oil contains 90% of ricinoleic acid, which gives singular characteristic to the oil, serving as raw material for the industrial sector in more than 700 industrialized products (Gonçalves et al., 2005). Quantitative and qualitative depletion of water resources has led to the search for alternatives for a more efficient water use and rational use of waters considered of low quality, since the use of saline waters in agriculture is almost obligatory in semiarid regions (Alves et al., 2011).

Therefore, some studies (Pinheiro et al., 2008; Zhou et al., 2009; Li et al., 2010; Severino et al., 2012) report the effect of irrigation using water with different salinity levels on the cultivation of castor bean. However, these studies are limited to the use of different salinity levels and new studies are necessary, especially to verify the effects of nitrogen fertilization and the use of saline water in different crop phenological stages to identify the stage(s) with higher tolerance to saline stress.

In addition, it is important to take into consideration the nutritional aspects using nitrogen in the cultivation of plants under saline stress, since this macronutrient performs important physiological functions in the formation of oragnic compounds, especially amino acids, proteins, coenzymes, nucleic acids, vitamins, chlorophylls, among others (Chaves et al., 2011). In this context, Silva et al. (2008) reported that nitrogen fertilization, besides promoting plant growth, can mitigate the deleterious effects of high salt concentrations on crop growth and yield, since the accumulation of these solutes increase the osmotic adjustment capacity of plants and increase their resistance to water and salt stresses.

The lack of data on castor bean growth and yield, when cultivated under different nitrogen doses and in different phenological stages, justifies the verification of its tolerance to saline water to define the chances for this crop to be used as an option in semiarid regions in northeast Brazil. Thus, this study aimed to evaluate growth and yield of castor bean, cv. 'BRS Energia', under different ECws, nitrogen fertilizations and management strategies to use saline water.

Results and Discussion

Effect of irrigation water salinity and nitrogen doses on growth variables

According to analysis of variance (Table 2), significant effect of water salinity was observed on all analysed variables. For the factor 'water management strategies', there was significant effect only on plant height and stem diameter, while no significant effect was found for the nitrogen doses and the interaction between factors on any analysed variable.

Different water salinity levels interfered negatively with the number of leaves of castor bean plants, cv. 'BRS Energia', at 60 days after sowing (DAS) and a quadratic response was found through the regression analysis (Fig 1). The highest number of leaves (on average, 49.87 leaves) was estimated, when plants were irrigated with ECw of 0.3 dS m^{-1}. From this level on, the NL decreased and a reduction of 30.68% was found for plants receiving the highest saline level (3.9 dS m^{-1}), compared with the ones receiving 0.3 dS m^{-1}. According to Oliveira et al. (2009), the decrease in NL in plants under saline stress occurs because of the lower water availability, causing morphological and anatomical changes, which include reduction of NL in order to maintain a high water potential in plant. In studies on castor bean cultivated in protected environment, Silva et al. (2008) also verified that irrigation water salinity level caused progressive reduction in NL, with decreases of 9.9% and 7.5% per unit of ECw for the cultivars 'BRS Paraguaçu' and 'BRS Energia' at 80 DAS, respectively.

Increments in ECw reduced plant height linearly. According to the regression equation (Fig 2A), there was a reduction of 3.67% per unit increase in ECw. In other words, plants subjected to irrigation with ECw of 3.9 dS m^{-1} had decrease of 7.48 cm in comparison with plants under the lowest saline level. The decrease in plant growth, in terms of height, was observed in plants under saline stress. It may be explained by the decrease in the osmotic potential of the soil solution, besides the possible ionic toxicity, nutritional imbalance or both, as a result of the excessive accumulation of certain ions in plant tissues (Khan and Panda, 2008). Likewise, plants tend to close their stomata to reduce water losses through transpiration, resulting in a lower photosynthethic rate and contributing to a reduction in the growth of plants under such stress (Flowers, 2004). Alves et al. (2012) evaluated the effects of varying irrigation water salinity (from 0.4 to 4.4 dS m^{-1}) and nitrogen fertilization doses on the growth of castor bean, cv. 'BRS Energia'and found a reduction of 9.68% in PH with per unit increase of ECw at 40 DAS.

Plant height was affected significantly by the management strategies of saline water use (Fig 2B). Castor bean plants had greater growth in PH (53.84 cm) when irrigated with low-salinity water during vegetative stage and later with water of high salinity levels, compared with the ones irrigated with saline water during all the development cycle (50.48 cm). The lower increase of PH in plants irrigated with saline water during entire crop cycle probably occurred due to exposure of plants to the stress at the phenological stage (vegetative phase), in which their metabolic activities are maximal (Larcher, 2000). According to these results, castor bean PH is differently affected by the salinity level of the irrigation water, depending on their developmental stage.

According to the regression equation (Fig 3A), there was a linear decrease in stem diameter of castor bean plants, cv. 'BRS Energia', of 6.15% per unit increase of ECw. The behavior of this variable, as a function of the increase in water salinity level, can be evaluated through the regression model, in which a reduction of 5.15 mm (22.16%) was observed between the highest (ECw = 3.9 dS m^{-1}) and the lowest (ECw = 0.3 dS m^{-1}) salinity level of the irrigation water. This harmful effect was caused by the increase in salinity, which decreased the osmotic potential of the soil solution, making the roots water absorption difficult, combined with the fact that Na^{+} and Cl^{-} were accumulated in the leaves, prevailing both in the irrigation water and in the soil. As a consequence, they might have negatively influenced physiological processes, inhibiting meristematic activity and cell elongation, leading to reduction in plant growth. Santos et al. (2013), in a field experiment with the same cultivar, also verified linear decreasing effect of ECw on SD at 65 DAS, with a reduction of 6.88% with per unit increase of ECw.

The intensity of the effect of the different water salinity levels on SD varied significantly between water management strategies (Fig 3B). The use of water with low salinity level (0.3 dS m^{-1}) at initial developmental stages promoted higher growth in SD (on average, 20.91 mm) compared to plants irrigated with saline water during the entire cycle, i.e., from its beginning to the yield formation (Fig 3B), in which there was an average decrease of 1.31 mm in SD, compared with plants subjected to the first management practice. This behavior demonstrates the sensitivity of castor bean plants, cv. 'BRS Energia', to saline stress at initial developmental stage (vegetative phase) and confirms the previously mentioned hypothesis of Larcher (2000), on plant height. Thus, the decrease in SD as a function of the exposure time to saline stress reflects the negative effect of both osmotic and ionic components, which are inseparable in the saline stress.

Table 1. Physical and chemical characteristics of the soil used in the experiment.

Bulk Density	Total Porosity	Water Content (%)		Available Water	Exchange Complex				pH_{sp}	EC_{se}
					Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		
($kg\ dm^{-3}$)	(%)	0.33 atm	15.0 atm	(%)	..............($cmol_c\ kg^{-1}$)…...........				-	($dS\ m^{-1}$)
1.34	48.26	18.01	9.45	8.56	3.95	3.70	0.37	0.43	5.01	0.09

Ca^{2+} and Mg^{2+} extracted with 1 mol L^{-1} KCl at pH 7.0; Na^{+} and K^{+} extracted with 1 mol L^{-1} NH_4OAc at pH 7.0; pH_{sp} - pH of the saturation paste; EC_{se} – electrical conductivity in the saturation extract.

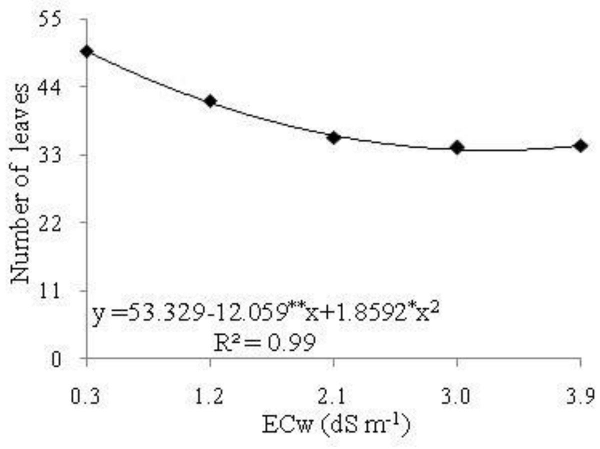

Fig 1. Number of leaves of castor bean plants as a function of the electrical conductivity of the irrigation water – ECw at 60 days after seeding.

Table 2. Summary of analysis of variance for number of leaves (NL), plant height (PH) and stem diameter (SD) of castor bean plants irrigated with increasing levels of water salinity under different water management strategies and nitrogen doses.

Sources of Variation	DF	Mean Square		
		NL	PH	SD
Saline Level (SL)	4	534.98^{*}	106.01^{*}	51.83^{**}
Linear Regression	1	1755.67^{**}	336.84^{*}	190.10^{**}
Quadratic Regression	1	381.00^{*}	34.97^{ns}	4.78^{ns}
Nitrogen Doses (ND)	1	156.81^{ns}	12.24^{ns}	0.33^{ns}
Management Strategies (MS)	1	46.81^{ns}	169.68^{*}	25.70^{*}
Interaction (SL*ND)	4	64.90^{ns}	14.19^{ns}	3.79^{ns}
Interaction (MS*SL)	4	17.81^{ns}	23.16^{ns}	1.95^{ns}
Interaction (MS*ND)	1	64.90^{ns}	50.05^{ns}	1.48^{ns}
Interaction (MS*SL*ND)	4	49.66^{ns}	75.71^{ns}	3.21^{ns}
Block	2	4.46^{ns}	41.79^{ns}	4.78^{ns}
Residue	38	68.09	33.34	3.26
CV (%)		21.04	11.07	8.92

ns, **, * respectively non-significant, significant at $p < 0.01$ and $p < 0.05$

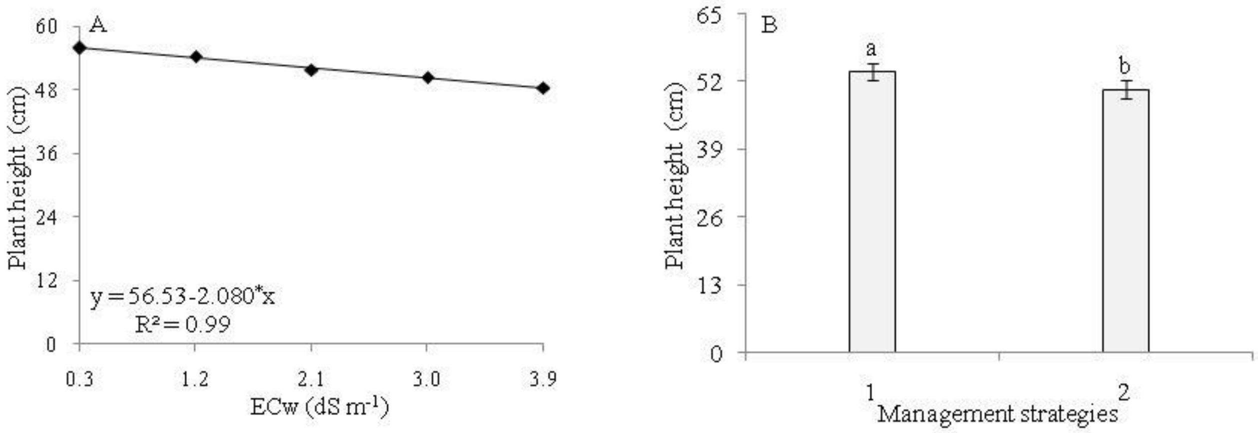

Fig 2. Plant height of castor beans as a function of electrical conductivity of irrigation water – ECw (A) and management strategies of saline water usage (B) at 60 days after seeding. Saline water management strategies: 1- irrigation with low-salinity water during the vegetative stage followed by irrigation with increasing ECw levels in the subsequent phases of yield formation; 2. Irrigation with different salinitye water in entire crop cycle.

Table 3. Summary of analysis of variance for total length (TLPR), mass of seeds (MSPR), mass of a hundred seeds (MHSPR), oil content (OCPR), oil yield (OYPR) of seeds of the primary raceme and threshing percentage of the primary raceme (PTP) of castor bean plants irrigated with increasing salinity levels under different management strategies of use of saline water and nitrogen doses

Source of Variation	DF	Mean Square					
		TLPR	MSPR	MHSPR	OCPR	OYPR	PTP
Saline Levels (SL)	4	268.04**	4870.24**	60.36*	50.06*	4321.22**	736,00**
Linear Regression	1	945.84**	16103.84**	224.07*	117.11*	15235.10**	1624,54**
Quadratic Regression	1	4.50^{ns}	1624.72*	4.43^{ns}	8.93^{ns}	711.04*	250,80^{ns}
Nitrogen Dose (ND)	1	230^{ns}	175.41^{ns}	58.33^{ns}	6.24^{ns}	56.12^{ns}	48,85^{ns}
Management Strategies (MS)	1	21.00^{ns}	3.22^{ns}	8.03^{ns}	9.48^{ns}	671.96*	25,97^{ns}
Interaction (SL*ND)	4	72.79^{ns}	529.33^{ns}	3.11^{ns}	6.42^{ns}	371.02^{ns}	178,72^{ns}
Interaction (MS*SL)	1	146.81^{ns}	261.51^{ns}	6.04^{ns}	8.35^{ns}	374.08^{ns}	136,96^{ns}
Interaction (MS*ND)	4	95.50^{ns}	145.86^{ns}	1.95^{ns}	3.52^{ns}	5.54^{ns}	148,87^{ns}
Interaction (MS*SL*ND)	4	156.36^{ns}	68.75^{ns}	9.62^{ns}	11.90^{ns}	73.63^{ns}	245,79^{ns}
Block	2	27.21^{ns}	84.63^{ns}	86.85*	18.37^{ns}	161.37^{ns}	192,35^{ns}
Residue	42	54.10	190.81	23.13	11.98	242.86	93,34
CV (%)		17.86	20.49	20.05	7.18	19.80	14,69

ns, **, * respectively non-significant, significant at p<0.01 and p< 0.05

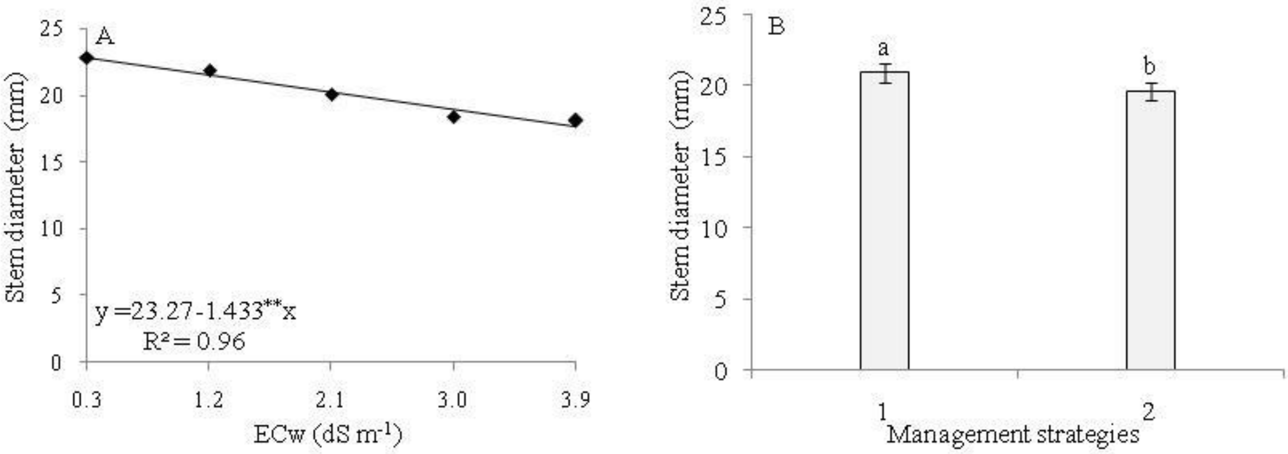

Fig 3. Stem diameter of castor bean plants as a function of electrical conductivity of irrigation water – ECw (A) and management strategies of use of saline water (B) at 60 days after seeding. Saline water management strategies: 1- irrigation with low-salinity water during the vegetative stage followed by irrigation with increasing ECw levels in the subsequent phases of yield formation; 2. Irrigation with different salinity water in entire crop cycle.

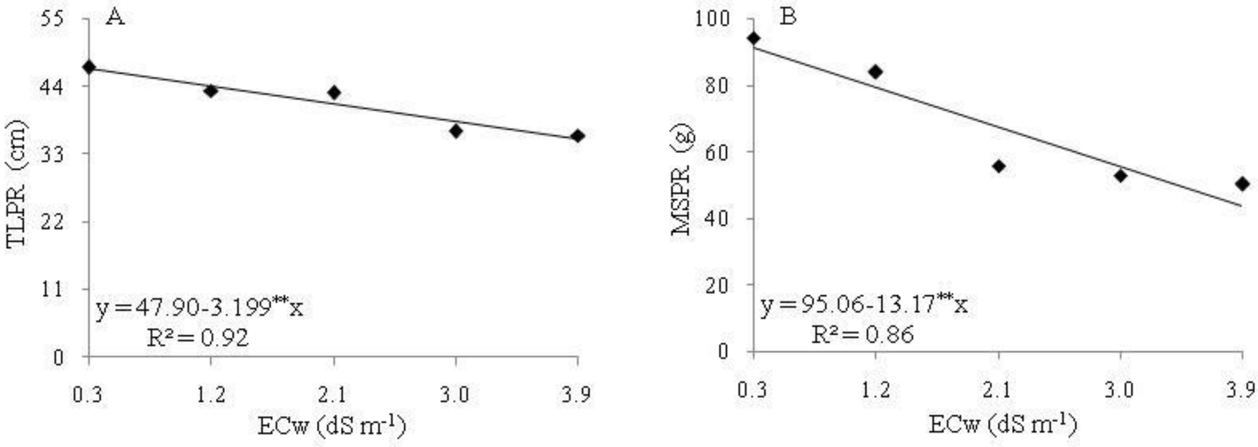

Fig 4. Total length – TLPR (A) and mass of seeds – MSPR (B) of the primary raceme of castor bean plants as a function of electrical conductivity of irrigation water – ECw.

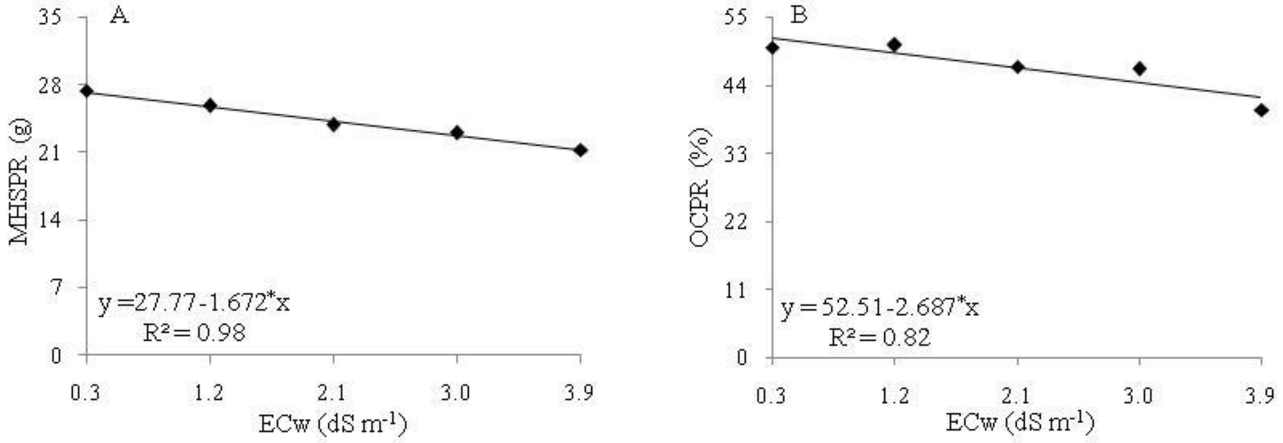

Fig 5. Mass of a hundred seeds – MHSPR (A) and oil content – OCPR (B) of seeds of the primary raceme of castor bean plants as a function of electrical conductivity of irrigation water – ECw.

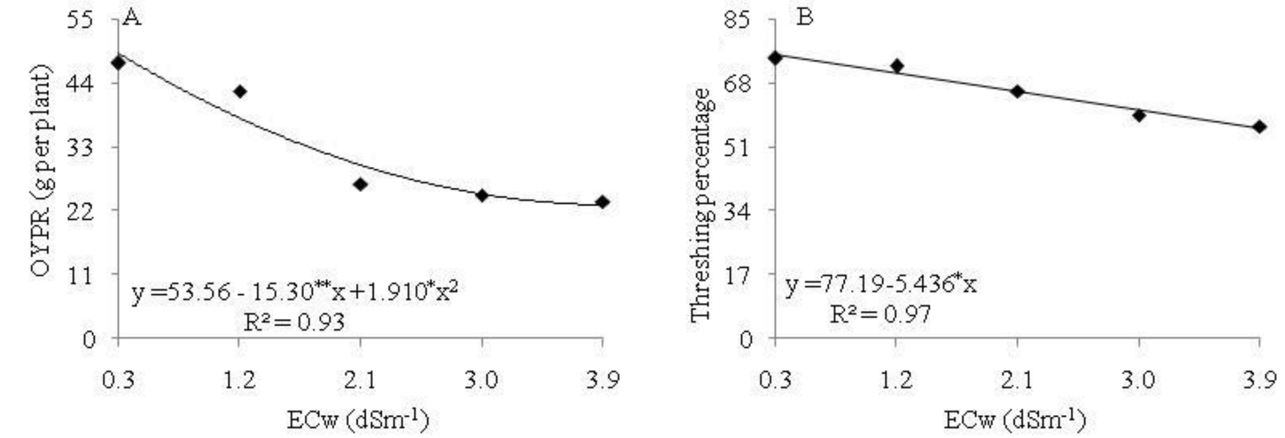

Fig 6. Oil yield of seeds of the primary raceme – OYPR (A) and threshing percentage (B) of castor bean plants as a function of electrical conductivity of irrigation water – ECw.

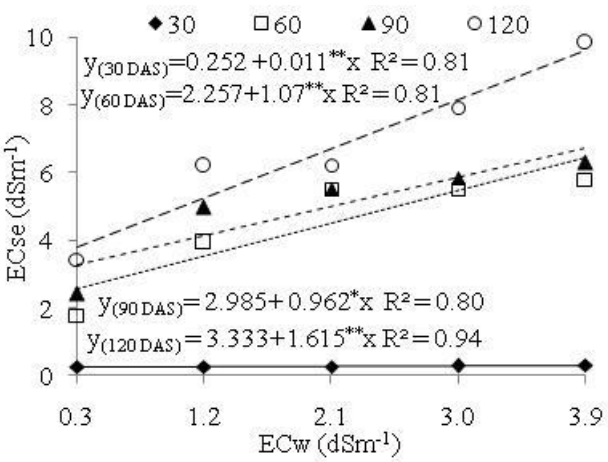

Fig 7. Electrical conductivity of saturation extract of the soil (ECse) under castor bean cultivation irrigated with saline water at 30, 60, 90 and 120 days after seeding.

Effect of irrigation water salinity and nitrogen doses on yield variables

Through the variance analysis (Table 3), it is observed that there was significant effect of the factor water salinity levels on total length of primary raceme (TLPR), mass of seeds of the primary raceme (MSPR), mass of a hundred seeds of the primary raceme (MHSPR), oil content (OCPR), yield of seeds (OYPR) and percentage of threshing (PTP). There was no significant effect on any of the analysed variables due to application of nitrogen doses and saline water management strategies, as well as the interaction between factors.

The TLPR was negatively influenced by the ECw levels according to the regression equation (Fig 4A), which shows a linear reduction of 6.67% per unit increase of ECw. Also, plants subjected to ECw of dS m-1 had a reduction of 11.51 cm (24.04%) in TLPR, compared with the ones irrigated with water of 0.3 dS m^{-1}.

The MSPR data also fitted to the linear regression model (Fig 4B) and, according to the regression equation, there was a decrease of 13.85% in MSPR per unit increase in ECw, which corresponds to a reduction of 50.29 g (49.87%) in MSPR of plants subjected to ECw of 3.9 dS m^{-1}, compared with the ones receiving 0.3 dS m^{-1}. Plants with the highest TLPR (46.94 cm) also had the highest seed production (90.86 g per plant), i.e., as TLPR decreased, the mass of seeds in the raceme also decreased (Fig 4A and B). Similar results were also observed by Silva et al. (2008), studying the cultivars 'BRS Energia' and 'BRS Paraguaçu', who found that higher irrigation water salinity reduces the average seed mass.

The reduction in TLPR and MSPR can be related to the delay in the net carbon assimilation rate during flowering and fruiting stages, associated with the osmotic effects and the accumulation of potentially toxic ions in plant tissues, especially Na^+ and Cl^-, the low capacity for osmotic adjustment of this crop and the reduction in total water potential caused by the increase in saline concentration (Assis Júnior et al., 2007).

Similarly to TLPR and MSPR, the increase in salinity levels in the irrigation water negatively influenced MHSPR. According to the regression equation (Fig 5A), the effect was linear. There was a decrease of 6.02% in MHSPR per unit increase of ECw, i.e., a reduction of 6.01 g (21.67%) in plants irrigated with a salinity level of 3.9 dS m^{-1} compared with the ones receiving irrigation water of 0.3 dS m^{-1} electrical conductivity. According to Leonardo et al. (2007), there is a reduction in water availability to plants under saline conditions due to a decrease in the total soil water potential. Thus, salinity imposes a higher energy expenditure on plant water absorption, which decreases crop yield as a consequence. Lima et al. (2012), conducted a field experiment with castor bean, cv. 'BRS Energia', and verified a linear negative effect of ECw on the mass of seeds in the secondary raceme, with a reduction of 17% per unit increase of ECw.

Irrigation water salinity levels negatively affected OCPR of castor bean plants. According to the regression equation (Fig 5B), the linear model indicated a decrease of 5.11% in OCPR with per unit increase of ECw, i.e., a reduction of 18.42% in OCPR of plants irrigated with a salinity level of 3.9 dS m^{-1} compared with plants receiving 0.3 dS m^{-1}. Comparing the deleterious effects of irrigation water salinity on the studied yield variables, in relative terms, MSPR was the most affected. Thus, water salinity and/or soil salinity caused by irrigation with saline water caused damages to many physiological and biochemical processes, such as respiration, photosynthesis, protein synthesis and lipid metabolism. Also, it can take plants to a water stress state with loss of water to the environment and make them suffer with toxicity, a fact that may lead to serious damages to plant growth, development, production and yield (Dias and Blanco, 2010). A reduction in oil content of seeds caused by salinity was also reported by Sousa et al. (2012). They evaluated the influence of irrigation with water of different electrical conductivities and phosphorus doses on yield components of *Jatropha curcas* during the third year of production. These authors observed that saline stress caused linear decrease of oil content of seeds, with a reduction of 14.2% per unit increase of ECw.

Oil yield of castor bean seeds was significantly influenced by the water salinity. According to the regression model (Fig 6A), the data fit the quadratic model. The irrigation with water of 0.3 dS m^{-1} electrical conductivity led to the maximum castor bean oil yield (49.14 g in primary cluster), whereas the lowest value for this variable (22.94 g) was found for plants receiving irrigation water with ECw of 3.9 dS m^{-1}. Analysing the data through the regression equation (Fig 6A), a decrease of 26,20 g per plant in OYPR was observed in plants under high salinity water, compared with the control plants. The results obtained in the present study do not agree with the ones reported by Jellum et al. (1973), who claimed the oil yield is more dependent to genetic background than environment. In this sense, Moshkin (1986) claimed that oil yield in castor bean seeds is a character with low variability, with a coefficient lower than 10%. Despite this high genetic heritability, the castor bean plant subjected to high levels of water salinity (ECw = 3.9 dS m^{-1}) obtained a lower oil yield, which may be related to changes in the expression of genes that promote synthesis of ricinoleic acid.

Following the same trend observed for MSPR and OCPR, the threshing percentage of the primary raceme of castor bean was also negatively affected by the increasing salinity of irrigation water. Quantitatively, according to the regression equation (Fig 6B), a decrease of 7.04% per unit increase in the ECw occurred. That is a reduction of PTP 28.16% in plants irrigated with water of the highest salinity in relation to plants from the control treatment (0.3 dS m^{-1}).The negative effects of salinity on yield components of castor bean was observed through the decrease in PTP (Fig 6B). This could be associated with interference in net assimilation processes of CO_2, translocation of carbohydrates to drain tissues and misuse of energy sources for other processes, such as osmotic adjustment, compatible solutes synthesis, repair of damages caused by salinity and maintenance of basic metabolic processes (Paranychianakis & Chartzoulakis, 2005).

Evolution of salinity in Regolithic Neosols Eutrophic of sandy loam texture irrigated with saline water and nitrogen doses

The accumulation of salts in the soil was expressed through the electrical conductivity of the saturation extract of soil and through regression studies. A linear increase in ECse was observed up to 120 DAS, in which the increments were 0.3; 3.85; 3.47 and 5.81 dS m^{-1} at 30, 60, 90 and 120 DAS, respectively, when plants were submitted to ECw of 3.9 dS m^{-1} in comparison to irrigated with water of 0.3 dS m^{-1} (Fig. 7). It should be noted that even in the lower level of ECw (0.3 dS m^{-1}), the ECse reached to values of 0.26; 1.77; 2.41 and 3.44 dS m^{-1} at 30, 60, 90 and 120 DAS, respectively, indicating that the accumulation of salts in the soil tends to increase with the cultivation time. Further, it can be inferred that the leaching fraction used in the present study (0.10) was not sufficient to control soil salinity. Thus, the reductions observed in growth (NL, PH, SD) and production components (TLPR, MSPR, MHSPR, OCPR, OYPR PTP) in the castor plant were consequence of increase in ECse and due to the osmotic effects of ions.

Materials and Methods

Localization, experimental procedure, treatments and plant material

The experiment was carried out from September 2011 to January 2012 under field conditions in the experimental area of the Center of Science and Technology of Agrifood of the Federal University of Campina Grande (CCTA/UFCG), in the municipality of Pombal, Paraíba, Brazil (6º48'16" S; 37º49'15" W; 144 m).

The experiment was set in a completely randomized block design, in a 5×2×2 factorial scheme, with three replications. The treatments consisted of different levels of electrical conductivity of the irrigation water – ECw (0.3 – control; 1.2; 2.1; 3.0 and 3.9 dS m^{-1}), two management strategies of saline water application: 1– irrigation with low-salinity water (0.3 dS m^{-1}) during the vegetative stage and with different salinity levels in the subsequent stages of yield formation (flowering and fruiting); and 2–irrigation with different ECw throughout the crop cycle; and two doses of nitrogen fertilization (100 and 160 mg kg^{-1} of soil, where the former dose follows the recommendations (Novais et al., 1991).

Plants subjected to the management strategy-1 were irrigated with low salinity water (0.3 dS m^{-1}) only during the vegetative stage (up to the appearance of flower buds in 90% of the plants) on average, 40 days after seeding (DAS) and, after that, plants were irrigated with saline water until the end of the crop cycle. For the management strategy-2, plants were subjected to irrigation with different salinity levels from seeding up to the end of the crop cycle.

The different salinity levels used in the irrigation water were obtained by dissolving sodium chloride (NaCl) in water of the local supply system. The quantity of salt was calculated according to the equation of Rhoades et al. (1992); C (mg L^{-1}) = 640 x ECw (dS m^{-1}), where ECw represents the pre-established value of electrical conductivity and C the amount of sodium chloride. Once prepared, the saline water was stored in plastic pots of 200 L capacity It is noteworthy that before every irrigation, measurement of ECw was done with the help of portable conductivity meter.

Establishment and management of the experiment

For the experiment, 100-L plastic recipients adopted as drainage lysimeters were filled with 2.0 kg of crushed stones (No. zero) covering the whole bottom, plus 107.8 kg of non-saline, non-sodic, clod-free soil material (Regolithic Neosols Eutrophic of sandy loam texture) from the municipality of Pombal-Paraíba, Brazil. Physical and chemical characteristics of soil (Table 1) were determined in the Laboratory of Soil and Plant Nutrition of the CCTA/UFCG, according to the methodologies proposed by Claessen (1997). The lysimeters had two openings at the bottom to allow monitoring of volume of water drained and consumed by the crop.

Basal fertilization was performed using 162.5 g of single superphosphate, 12 g of K_2SO_4 and 2.5 kg (equivalent to 2.5%) of vermicompost per recipient. After accommodation in the lysimeters, the soil material was taken to field capacity, using the respective water according to the treatment. Nitrogen application was divided into 5 parts: 1/3 was applied as basal dose and 2/3 divided into 4 equal applications through the irrigation water at an interval of 10, days starting from 25 DAS. In the treatment N1 (100 mg N kg-1 of soil), 33.34 g of monoammonium phosphate and 8.88 g of urea were applied per pot.

On September 28, 2011, castor bean were planted by placing 10 seeds per recipient equi-distantly, at a depth of 0.02 m. At 22 DAS, the first thinning was performed, leaving only three plants per recipient, leaving those with the best vigor. At 30 and 40 DAS, additional thinnings were performed, leaving one plant in each recipient.

The soil was kept at field capacity with daily irrigation, and the volume of water applied in each irrigation was calculated using the concept of water balance, i.e., volume of water applied minus the volume drained in the last irrigation, and adding leaching fraction equivalent to 10%.

Castor bean cultivar 'BRS Energia' was used in the experiment. It has a cycle of 120 to 150 days, with semi-indehiscent fruits, average oil content of 48% in the seeds and yield of approximately 1,800 kg ha^{-1} (Silva et al., 2009).

Traits measured

The following parameters were evaluated at 60 DAS, the number of leaves (NL), plant height (PH) and stem diameter (SD); at 120 DAS, in the primary raceme of castor beans, total length (TLPR), mass of seeds (MSPR), mass of 100 seeds (MHSPR), oil content (OCPR) and oil yield (OYPR). Only completely expanded leaves, with minimum length of 3 cm and with at least 50% of its surface photosynthetically active, were considered while counting the number of leaves. The PH was measured considering the distance between the plant base and the insertion of the primary raceme. The SD was measured 5 cm distant from plant base. The TLPR was measured from the fruit insertion at the base of the raceme to its apex. The racemes were harvested manually, when 90% of the fruits reached physiological maturation, and later on exposed to the sun for three days to complete the drying process. After drying, fruits were manually threshed and then MSPR and MHSPR were determined.

Seed oil content was determined in the Laboratory of Advanced Chemical Technology of Embrapa Cotton, in Campina Grande, Paraíba, Brazil, after drying and correcting moisture to 10% in a non-destructive way, using a nuclear magnetic resonance spectrometer (NMR) H^1 Oxford MQA 7005 (American Oil Chemists' Society, 2000). The OYPR was then estimated using oil content and yield data. The percentage of threshing primary raceme was determined by the ratio between the total mass of seeds per plant (g) and total fruit yield per plant (g) x100.

After 30, 60 and 120 DAS electrical conductivity of the saturation extract of soil (ECse) was estimated on the basis of electrical conductivity of drainage water (ECd) obtained during leaching using the relation (ECse = 0.5 x ECd) recommended by Ayers & Westcot (1994) for medium textured soils.

Statistical analysis

The obtained data were subjected to analysis of variance using F-test; when significant, regression analysis was performed for the factor "ECw levels" and Tukey's test for comparison of means at 0.05 level of probability for the factor "water management strategies and nitrogen doses", using the statistical software SISVAR-ESAL.

Conclusion

The use of saline water in irrigation affects castor bean growth and yield, regardless of the adopted water management strategy. The castor bean cultivar 'BRS Energia' is more sensitive to saline stress at vegetative stage compared with the phase of yield formation. The increase in N dose did not influence castor bean growth and the analysed yield variables. The use of saline water in irrigation, in different development stages, reduced oil content and yield of castor bean plants. Water with electrical conductivity of 2.1 dS m^{-1} may be utilized in cultivation of castor bean cultivar 'BRS Energia' with mean decrease in growth and production components of 15.88 and 20.80%, respectively.

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