Volumen 32, Nº 3. Páginas 91-99
IDESIA (Chile) Junio-Agosto, 2014

Physiology, growth and yield of castor bean under salt stress and nitrogen doses in phenophases

Fisiología, crecimiento y rendimiento de semilla de ricino bajo estrés salino, según dosis de nitrógeno en fenofases

Geovani Soares de Lima[1], Reginaldo Gomes Nobre[2], Hans Raj Gheyi[3], Lauriane Almeida dos Anjos Soares[1], Alexsandro Oliveira da Silva[4]*

ABSTRACT

High population growth during the last decades and reduced water resources, both in quantity and quality, have made necessary the use of saline water in agricultural activities. This study was conducted to evaluate the influence of irrigation with water of varying salinity in different phenological phases associated with nitrogen fertilization on the physiology, growth and yield of castor bean cv. BRS Energia. Research was carried out in lysimeters under field conditions in Pombal-PB, Brazil, from September 2011 to January 2012. A completely randomized block design arranged in a 5x2x2 factorial design was adopted, 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 strategies of management of water salinity: 1) irrigation with low salinity water during the vegetative stage and application of different salinity levels in the reproductive phase and 2) irrigation with different ECw levels throughout the crop cycle, and two nitrogen doses (100 and 160 mg N kg^{-1} soil). Leaf (DML) and stem (DMS) dry matter and the number of fruits (NFruPC) and seeds (NSeePC) of the primary cluster were evaluated. Irrigation with ECw exceeding 0.3 dS m^{-1} affected DML and DMS negatively. The greatest accumulation of dry matter was observed in plants which were not irrigated with saline water in the initial development phase. Irrigation with saline water caused changes in gas exchange of the castor bean plant, with varying effects according to the management strategy adopted. The nitrogen dose of 160 mg N kg^{-1} soil increased DMS. Different ECw levels negatively affected production, regardless of the development stage. No significant interaction effect was observed among the factors studied and the variables evaluated.

Key words: *Ricinus communis* L., salinity, nitrogen.

RESUMEN

El alto crecimiento de la población durante las últimas décadas y la disminución de los recursos hídricos, tanto en cantidad como en calidad, han hecho el uso necesario de agua salina en las actividades agrícolas. Esta investigación se realizó para evaluar la influencia del riego con agua salina en las diferentes fases fenológicas en ricino cv. Energía BRS. La investigación se realizó bajo las condiciones de campo en Pombal-PB, Brasil, desde septiembre de 2011 a enero de 2012. El diseño experimental fue de bloques completos al azar, dispuestos en un diseño factorial 5x2x2 y fue adoptada con tres repeticiones. Se consideraron cinco niveles de conductividad eléctrica del agua de riego (ECw = 0,3 ; 1,2 ; 2,1 ; 3,0 y 3,9 dS m^{-1}); dos estrategias de gestión de la salinidad del agua (riego con agua de baja salinidad durante la etapa vegetativa y la aplicación de diferentes niveles de salinidad en la fase reproductiva y riego con diferentes niveles de ECw en todo el ciclo de cultivo) y dos dosis de nitrógeno (100 y 160 mg de N kg^{-1} suelo). Se evaluó materia seca de hojas (DML) y el tallo (DMS); número de frutos (NFruPC) y número de semillas (NSeePC) del racimo principal. El riego con ECw superior a 0,3 dS m^{-1} afectó negativamente a DML y DMS. La mayor acumulación de materia seca se observó en las plantas que no fueron irrigados con aguas salinas en la fase inicial de desarrollo. El suministro de nitrógeno en dosis de 160 mg N kg $^{-1}$ suelo aumentó el DMS. No se observó efecto interactivo significativo entre los factores y las variables estudiadas.

Palabras clave: *Ricinus communis* L., salinidad, nitrógeno.

1 Center for Technology and Natural Resources, Federal University of Campina Grande, Campina Grande PB Brazil.
2 Center for Agrifood Science and Technology, Federal University of Campina Grande, Pombal PB Brazil.
3 National Senior Visiting Professor (CAPES), Nucleus for Soil and Water Engineering, Federal University of Recôncavo of Bahia, Cruz das Almas BA Brazil.
4 Center for Science and Agrifood Science and Technology, Federal University of Campina Grande, Pombal PB Brazil.
* Author for correspondence: hans@pq.cnpq.br

Fecha de Recepción: 6 Enero, 2014.
Fecha de Aceptación: 2 Junio, 2014.

Introduction

Growing demands in energy in Brazil and worldwide have reduced over the years the availability of conventional fuel resources. Moreover, these sources have produced negative effects on the environment and on society as a whole. Several studies have been conducted in recent years to identify alternative and renewable sources of primary materials for competitive production, aiming at the progressive replacement of petroleum-derived mineral fuels (Fernandes Neto *et al*., 2008).

The castor bean (*Ricinus communis* L.), a species with high potential, has always been considered an important source of oil. Oil extracted from its seeds is the most viscous of vegetal oils and is the only glyceride which is soluble in alcohol. It is the prime matter for the manufacture of biodiesel with diversified industrial uses. Consequently, the crop of the castor bean is of high economical and strategic relevance for Brazil (Azevedo & Lima, 2001).

The area in which the castor bean crop is grown includes several edaphoclimatic variations. In certain regions, as in the semiarid stretches of northeastern Brazil, rainfall is less than the crop's requirement or precipitations are irregular throughout the year (Mattos Junior *et al*., 2005). The introduction of irrigation and fertilization technologies is mandatory so that the crops can grow and develop and express genetically their productive potential (Oliveira *et al*., 2010).

In addition to climatic conditions, irrigation water quality varies enormously in the region in geographical and seasonal terms. The occurrence of water sources with high salt concentrations is not rare (Bezerra *et al*., 2010).

High concentrations of soluble salts in the soil not only decrease its water potential, but may also cause toxic effects in plants, particularly functional disorders and damage in their metabolism (Silva *et al*., 2003). However, the use of saline water in agriculture may be conditioned to crop tolerance and to management of irrigation and fertilization practices to avoid environmental impacts, with consequent benefits to agriculture and society.

Fertilization is considered within all management techniques as one of the main technologies to increase productivity and profits (Marinho *et al*., 2010). Nitrogen is a nutrient of vital importance for plant development, since it is one of the constituents of the plant's structure and part of the composition of amino acids, proteins, enzymes, RNA, DNA, ATP, chlorophyll and others (Marschner, 1995).

This study evaluated the formation of biomass and the production of castor bean cv. BRS Energia irrigated with varying levels of water salinity in different phenological phases and in two nitrogen doses.

Material and methods

The experiment was performed during September, 2011 to January, 2012 in drainage lysimeters in the experimental area of the Agro-food Science and Technology Center of the Federal University of Campina Grande (CCTA/UFCG) Pombal-PB, Brazil, geographic coordenates 6°48'16" S; 37°49'15" W and mean altitude of 144 m.

A completely randomized block design was employed with a 5 x 2 x 2 factorial scheme and three replications. Treatments consisted of five levels of electrical conductivity of irrigation water – ECw (0.3 -control; 1.2; 2.1; 3.0 and 3.9 dS m^{-1}), two management strategies of use of saline water: 1) irrigation with low salinity water (0.3 dS m^{-1}) during the vegetative phase, ending with the onset of the flower budding in 90% of the plants and the start of flowering, and application of different saline levels (1.2 to 3.9 dS m^{-1}) in the reproductive phase (flowering and fructification) and 2) irrigation with different ECw levels during the whole crop cycle), and two doses of nitrogen being fertilization (100 and 160 mg N kg^{-1} soil), the lower dose according to recommendations proposed by Novais *et al*. (1991).

Irrigation water of different salinity levels was obtained by dissolving sodium chloride (NaCl) in tap water of local supply. The quantity to be added was calculated according to the equation proposed by Rhoades *et al.* (2000): C (mg L^{-1}) = 640 x ECw (dS m^{-1}), where ECw was a pre-established level. In the preparation of saline water the initial ECw was taken into consideration.

Seeds of the castor bean cultivar BRS Energia were used. The crop has a 120-150-day cycle, semi-dehiscence fruits cultivar, oil content in seeds 48% on average and productivity of approximately 1800 kg ha^{-1} (Silva *et al*., 2009).

Drainage lysimeters of 100 L capacity were filled with 2.0 kg pebbles (number zero), which covered the bottom, plus 107.8 kg non-saline and non-sodic soil (sandy loam) without clods collected from the municipality of Pombal– PB, Brazil. The physical and chemical characteristics of the soil (Table 1) were determined at the Soil and Plant Nutrition Laboratory of CCTA/UFCG, following methodologies recommended by Claessen (1997). Holes in the bottom of the lysimeters allowed follow-up of drained water volume and calculation of water consumed by the plant.

Fertilization used 162.5 g simple superphosphate, 12 g K_2SO_4 and 2.5 kg (equivalent to 2.5%) vermicompost per pot. After its accomodation in the lysimeter, soil was irrigated to field capacity with respective water according to treatment. Nitrogen fertilization was partitioned, with 1/3 at planting and 2/3 divided into four equal applications by fertigation at 10-day intervals starting at 25 days after sowing (DAS), as 33.34 g mono-ammonium phosphate and 8.88 g urea per pot in a treatment of 100 mg N kg^{-1}soil).

Ten seeds were sown equidistantly at a depth of 0.02 m on September 28, 2011. A first thinning occurred after 22 DAS and only three of the most vigorous plants were left per pot; further thinnings occurred at 30 and 40 DAS, leaving only one plant in the pot.

Soil was maintained at field capacity with daily irrigation. The volume of water to be applied was calculated by the difference between water applied in previous irrigation minus volume of drainage, plus an average of 10% leaching fraction.

The effects of treatments on castor bean plants were evaluated at 67 DAS by determining leaf temperature (T_{leaf}), CO_2 assimilation rate (*A*) and stomata conductance (gs). Dry biomass of leaves (DML), dry biomass of stem (DMS), number of fruits (NFruPC) and seeds (NSemPC) in the primary cluster were analyzed at 120 DAS. T_{leaf}, *A* and gs were determined by an IR portable apparatus for gas exchange analysis (LCPro+from ADC Bio Scientific Ltd). The dry mass of plants was determined by separating plant parts (stem and leaves) which were placed in paper bags, identified and placed in a forced-air oven at 65 °C for 72 hours to determine DMS and DML. Harvest of primary clusters was conducted manually when 90% of fruits were physiologically mature. Exposure of seeds to sun completed drying. After drying, the number of fruits and seeds in the primary cluster were determined.

Data were submitted to analysis of variance using SISVAR-ESAL. Regression analysis for factor ECw levels was performed when significant; Tukey's test was used to compare means at 0.05 probability level for the phenological phases and nitrogen doses.

Results and discussion

Regression analysis between salinity (ECw) and leaf temperature (Figure 1A) showed that increase in salinity of irrigation water produced a quadratic response resulting in maximum values of T_{leaf} (32.14 °C) when plants were irrigated with ECw of 2.4 dS m^{-1} and lowest T_{leaf} (31.30 °C) obtained in plants irrigated with water at ECw = 0.3 dS m^{-1}. It is noteworthy that one of the primary mechanisms for the reduction of water loss by plants under saline and/or water stress conditions is reduced stomata opening. According to Machado *et al*. (2005), this is the main mechanism involved in the regulation of leaf temperature. Smaller stomata apertures occur due to decrease in transpiration and increase in temperature of the leaf tissue. The results obtained in this study agree with those reported by Sousa *et al*. (2012), who evaluated gas exchange in *Jatropha curcas* under saline conditions in a protected environment. They reported a leaf temperature increase of 1.57% per unit increase of ECw due to increase in salinity levels of irrigation water varying from 0.6 to 3.0 dS m^{-1}.

Figure 1B shows a significant effect on leaf temperature due to management strategies of use of saline water. Irrigation with saline water during the entire crop cycle of the castor bean plant reduced

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

Density	Total porosity	Water content (%)		Available water	Exchangeable cations				pH_{ps}	ECse
					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 KCl 1 mol L^{-1} pH 7.0; $Na^{+}$and K^{+} extracted by NH_4OAc 1 mol L^{-1} pH 7.0; pH_{PS} - pH saturation paste; CE_{es} – electrical conductivity of the saturation extract.

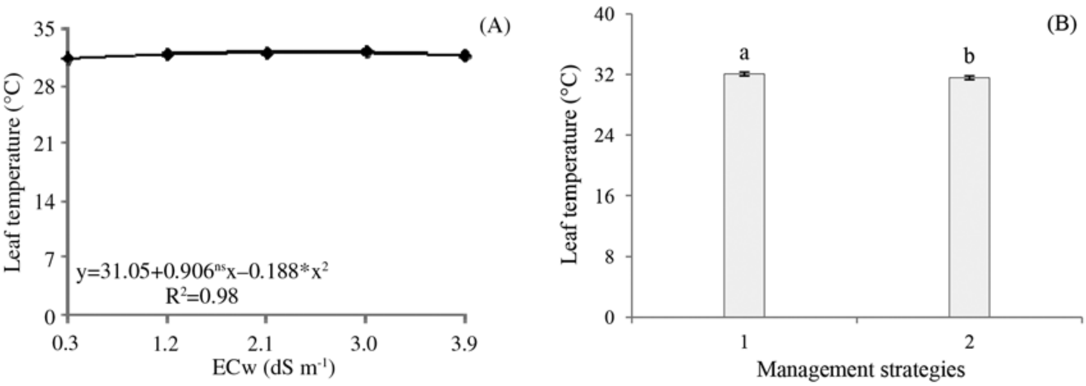


Figure 1. Leaf temperature of castor bean as a function of electrical conductivity of irrigation water - ECw (A) and management strategies of use of saline water (B) at 67 days after sowing.

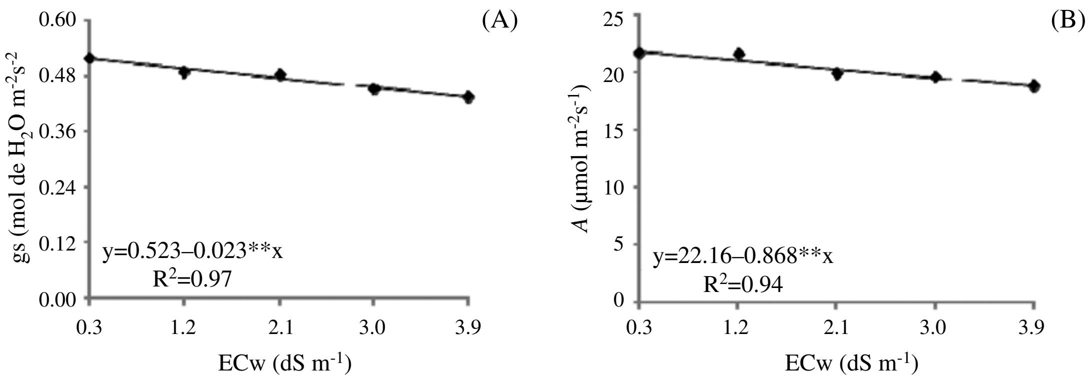


Figure 2. Stomata conductance – gs (A) and CO_2 assimilation rate (B) of castor bean as a function of electrical conductivity of irrigation water – ECw 67 days after sowing.

leaf temperature significantly. However, when plants were irrigated with low salinity water during the vegetative phase and with increasing levels of salinity during the fruit formation phase they showed higher leaf temperature. It is important to note that plants with highest leaf temperature were those irrigated with water of low salinity during the first phase of development. Since they had greater stomata conductance (Figure 2A), a temperature decrease occurred in the leaf blade. The closing of the stomata and the consequent reduction in normal flow of CO_2 (Figure 2B) towards the site of carboxylation were the main causes of reduction of photosynthesis in plants cultivated in saline conditions. As a consequence of stomata closure, the plants manifested higher leaf temperature (Xu *et al*., 1994).

Stomatal conductance was significantly affected by increasing levels of salinity in irrigation water and the linear model was the best fit for the data (Figure 2A); it indicated a 4.39% decrease per unit increase of ECw. Comparison of rates obtained for plants irrigated with water of EC = 3.9 dS m^{-1} with rates of plants irrigated with water at 0.3 dS m^{-1} shows a 15.83% reduction in stomatal conductance in the former. Decrease in stomatal conductance and consequently the reduction in CO_2 assimilation rate in response to increase in the salinity of irrigation water may be due to the osmotic effect coupled with soluble salt accumulation in the soil and the reduction of hydraulic conductivity of the roots caused by increased suberization and lignification of the vascular tissues of plant roots under saline stress (Neves *et al*., 2009). Soares *et al*. (2013) also reported a decrease in stomatal conductance and recorded a 4.85% decrease per unit increase in ECw when they evaluated gas exchange in the castor bean plant cv. BRS Energia irrigated with saline water and doses of nitrogen fertilization.

Table 2. Summary of analysis of variance with regard to the leaf temperature (Tleaf), CO2 assimilation rate (A) and stomata conductance (gs) of castor bean plants irrigated with water of different salinity under two management strategies of use of saline water and two doses of nitrogen.

Variation source	GL	Mean square		
		T_{foliar}	A	gs
Saline level (S)	4	1.31^{*}	19.42^{*}	0.001^{*}
Linear regression	1	1.27^{ns}	10.89^{*}	0.038^{*}
Quadratic regression	1	3.91^{*}	7.87^{ns}	0.0008^{ns}
Nitrogen doses (N)	1	0.01^{ns}	3.01^{ns}	0.0003^{ns}
Management strategies (MS)	1	3.85^{*}	18.11^{ns}	0.013^{ns}
Interaction (S*N)	4	0.13^{ns}	10.16^{ns}	0.008^{ns}
Interaction (MS*S)	4	0.47^{ns}	10.00^{ns}	0.003^{ns}
Interaction (MS*N)	1	0.38^{ns}	17.73^{ns}	0.118^{ns}
Interaction(MS*S*N)	4	0.19^{ns}	14.59^{ns}	0.063^{ns}
Block	2	9.14^{ns}	11.20^{ns}	0.005^{ns}
Residual	38	0.41	7.32	0.005^{ns}
CV (%)		2.04	13.30	16.31

ns, **, *: not significant, significant at $p < 0.01$ and $p < 0.05$, respectively.

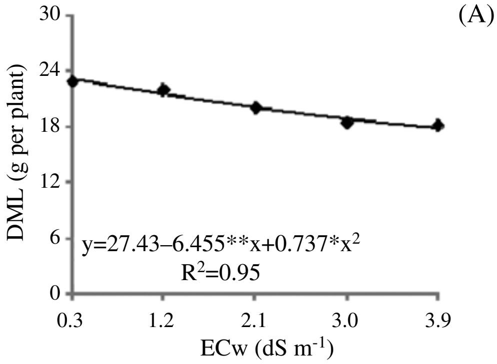
Table 3. Analysis of variance of dry biomass of leaf (DML), dry biomass of stem (DMS), number of fruits (NFruPC) and seeds (NSeePC) in the primary cluster of castor bean cultivated with irrigation water of different salinity levels at harvest (120 days after sowing).

Variation source	GL	Mean square			
		DML	DMS	NFruPC	NSeePC
Saline level (S)	4	301.54^{**}	3717.46^{**}	4317.44^{*}	43705.27^{*}
Linear regression	1	907.96^{**}	14014.90^{**}	15686.53^{**}	158704.13^{**}
Quadratic regression	1	211.36^{*}	64.60^{ns}	1464.38^{ns}	14300.59^{ns}
Nitrogen doses (N)	1	127.55^{*}	430.99^{ns}	84.01^{ns}	1443.26^{ns}
Management strategies (MS)	1	27.14^{ns}	1247.21^{*}	799.35^{ns}	5920.26^{ns}
Interaction (S*N)		1.03^{ns}	399.50^{ns}	1302.05^{ns}	9294.72^{ns}
Interaction(MS*S)	1	7.01^{ns}	85.86^{ns}	1756.64^{ns}	14235.30^{ns}
Interaction (MS*N)	4	1.03^{ns}	5.77^{ns}	3634.81^{ns}	23443.26^{ns}
Interaction (MS*S*N)	4	1.51^{ns}	101.94^{ns}	437.02^{ns}	5575.39^{ns}
Block	2	78.11^{ns}	264.23^{ns}	1276.55^{ns}	14170.55^{ns}
Residue	42	30.47	287.54	802.16	6307.23
CV (%)		30.13	29.20	28.89	29.61

ns, **, *: not significant, significant at $p < 0.01$ and $p < 0.05$, respectively.

Similar to results reported for stomatal conductance, CO_2 assimilation rate (*A*) was also negatively affected by an increase in water salinity. According to the regression equation (Figure 2B), there was a linear reduction in *A* of 3.91% per unit increase in ECw, resulting in 14.10% (3.12 μmol m^{-2} s^{-1}) decrease in CO_2 assimilation rate of plants irrigated with water of 3.9 dS m^{-1} compared to water with ECw of 0.3 dS m^{-1} at 67 DAS. Decrease in CO_2 assimilation rate may have been caused by partial closure of the stomata associated with the osmotic effects of salinity (Wilson *et al*., 2006). However, reduction in photosynthesis rate under saline stress may be related to damage in the photosynthetic apparatus and/or in the CO_2-fixing enzyme system caused by ion toxicity to metabolism rather than to strictly stomatal limitations (Kurban *et al*., 1999). Sousa *et al*. (2012) also observed a similar effect of water salinity while studying gas exchange in *Jatropha curcas* crops with a 6.42% decrease in CO_2 assimilation rate per unit increase in ECw.

A significant influence of water salinity level on all variables under analysis was observed (Table 3). In the case of saline water management strategies, there was a significant effect on stem dry biomass, whereas for the factor nitrogen dose a significant effect occurred only for dry leaf biomass. Table 3 shows that for the interactions between the factors



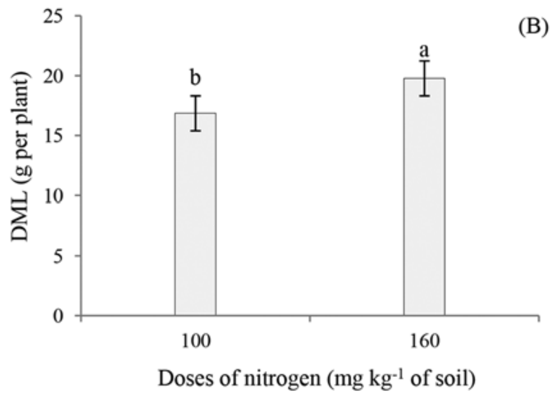


Figure 3. Dry biomass of leaf (DML) of castor bean as a function of electrical conductivity of irrigation water –ECw (A) and nitrogen doses (B) 120 days after sowing.

under analysis, no significant effect occurred for any variable studied. This indicates that castor bean plants had similar behavior in different phonological phases at all saline levels of irrigation water and also at different nitrogen doses.

Regression analysis of dry leaf biomass (Figure 3A) showed that increase in ECw decreased DML significantly. Greater biomass (25.56 g) was recorded for plants irrigated with water of ECw = 0.3 dS m^{-1}. Above this salinity level a decrease occurred; the lowest value (13.46 g) was observed in plants irrigated with water at ECw 3.9 dS m^{-1}. This DML reduction may be related to osmotic and ionic components, both of which are associated with saline stress. Low water availability due to decrease in osmotic potential caused by high soluble salt concentration caused the closing of the stomata with a reduction of CO_2 assimilation and photosynthesis rate, which directly affected the production of biomass (Willadino & Camara, 2004). Cavalcanti *et al.* (2004) studied the effects of irrigation water salinity on the initial growth of the castor bean plant and reported that the biomass of the aerial parts decreased linearly with an increase in ECw above 0.7 dS m^{-1}, with a relative decrease of 6.0% per unit increase of ECw.

Figure 3B shows that the accumulation of DML in plants with 100 mg N kg^{-1} soil was significantly less than with 160 mg N kg^{-1} soil. In fact, the higher dose of N provided a 14.72% increase in DML production compared to plants fertilized with the recommended dose (100 mg N kg^{-1} soil). Under saline stress conditions, an increase in the accumulation of DML is a highly relevant factor since an increase in carbohydrates and energy will be available for the development of the crop. Furthermore, the observed increase in DML produced by an increase in N dose is due to functions of nitrogen in the plants, since the nutrient has an important structural function and participates in many organic compounds such as amino acids, proteins, proline and others which are vital for plant production (Silva *et al.,* 2008). Nobre *et al.* (2013) in their study on the same cultivar under similar conditions reported a 12.47 g increase in the dry biomass of the aerial parts of plant with increasing levels of nitrogen (from 50 to 150 mg N kg^{-1} soil).

Similar to DML, the dry biomass of the stem (DMS) of the castor bean plant was also negatively affected by increase in irrigation water salinity. Regression studies (Figure 4A) showed that there was a linear 14.40% decrease in DMS per unit increase of ECw, resulting in a decrease of 51.87% (43.2 g) in DMS of plants irrigated with water of 3.9 dS m^{-1} compared to plants irrigated with ECw of 0.3 dS m^{-1} at 120 DAS. Reduction in DMS due to increase in water salinity probably occurred because of an increase in the osmotic pressure of soil solution triggered by accumulation of soluble salts and to the reduced availability of water for the plants. This phenomenon influenced division and elongation of cells by inhibiting their growth due to the diversion of energy for their adaptation to saline stress. This fact resulted in a decrease in dry matter production with consequences on the metabolic energy costs associated with the adaptation to salinity and decrease in carbon gains (Azevedo Neto & Tabosa, 2000). Our results concur with those obtained by Soares et al. (2013), who analyzed the effect of different saline levels associated with

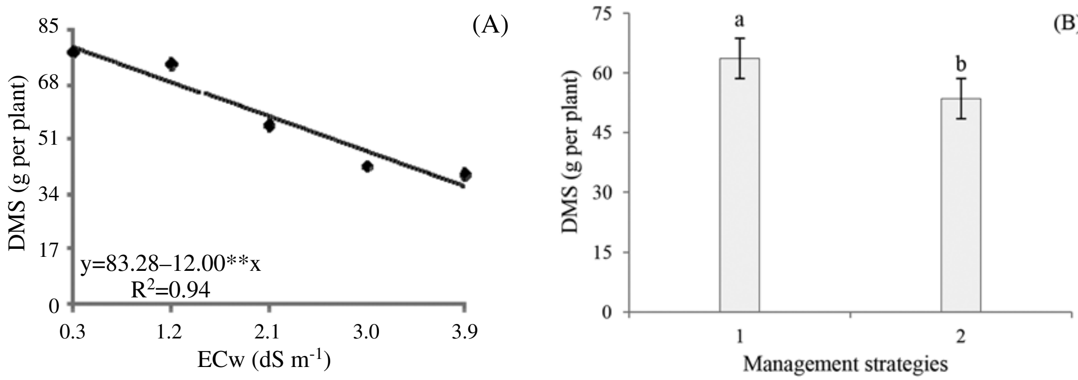


Figure 4. Dry biomass of stem (DMS) of castor bean as a function of electrical conductivity of irrigation water – ECw (A) and management strategies of use of saline water (B) 120 days after sowing.

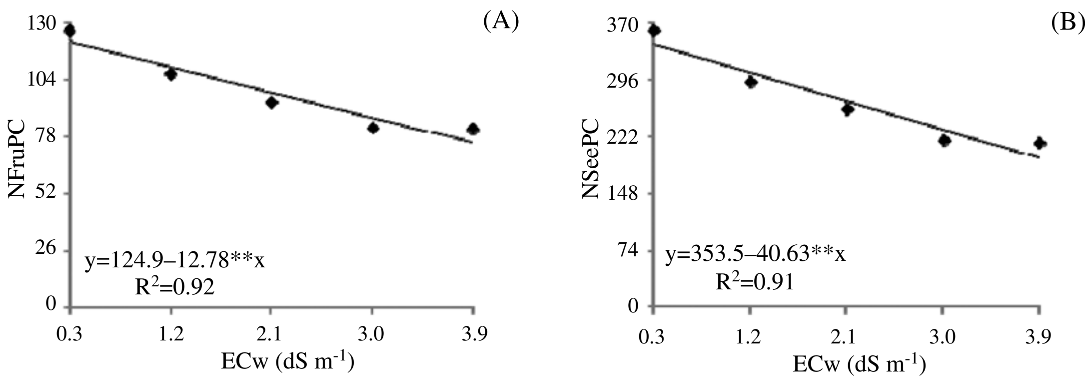


Figure 5. Number of fruits – NFruPC (A) and seeds - NSeePC (B) of primary cluster of castor bean as a function of electrical conductivity of irrigation water – ECw 120 days after sowing.

nitrogen fertilization doses on the physiology and biomass accumulation of the castor bean cv. BRS Energia, and reported a 56.16% reduction in dry weight of aerial parts of plants due to an increase in ECw from 0.3 to 3.9 dS m^{-1}.

The DMS of the castor bean (Figure 4B) was significantly greater in plants subjected to saline stress only in the formation phase, with a mean value of 62.63 g. However, plants irrigated with saline water during the vegetative and fruit formation stages accumulated a DMS of 53.51 g. In other words, when there was a change in the irrigation management strategy from 1 to 2 there was a decline of 14.57% in DMS, according to use of saline water in the crop's development stage. Decreased DMS suggests that an increase in salinity caused a decrease in the osmotic potential of the soil solution, with difficulties in water absorption by roots. The above effect was intensified in proportion to stress duration, affecting the plants' physiological processes due to toxic effects. Further, the plant spends part of its metabolic energy to adjust to the medium, with a consequent decrease in growth (Lazof & Bernstein, 1999).

Increase in ECw affected significantly the number of fruits of the castor bean plants. The regression equation (Figure 5A) showed a 10.23% decrease per unit increase in ECw, which is equivalent to a 36.83% reduction in NFruPC of plants irrigated with water of 3.9 dS m^{-1} compared to that of the lowest water salinity level (0.3 dS m^{-1}). The decrease in castor bean production due to an increase in ECw may be attributed to lower water uptake by plants mainly due to the reduction of the osmotic potential of soil solution caused by excess ions hindering the entry of water in the plant cells and decreasing CO_2 assimilation, stomatal conductance, transpiration and photosynthesis of plants (Gulzar *et al.*, 2003).

With regard to the number of seeds of the primary cluster (NSeePC), the regression equation (Figure 5B) showed that salinity levels of irrigation water affected linearly and negatively the NSeePC. There was a 10.23% decrease in NSeePC per unit increase in ECw. The regression equation (Figure 5B) also showed that castor bean plants irrigated with water of higher ECw (3.9 dS m^{-1}) had a decrease of 146.27 seeds (36.83%) compared to seeds produced by plants irrigated with water with ECw = 0.3 dS m^{-1}. According to Munns *et al*. (2006), plants cultivated under saline stress may accumulate salts in the transpiration pathways causing damage to the leaf tissues, leading to more pronounced inhibition in photosynthesis and consequently a negative effect on growth and production. Results obtaied in this study concur with Lima *et al*. (2012), who analysing the effects of irrigation with water of different salinity levels (ECw: 0.4 to 4.4 dS m^{-1}) and of nitrogen fertilization in castor bean cv. BRS Energia cultivation reported a 12.60% decrease in the number of seeds in the secondary cluster per unit increase in ECw.

Conclusions

Irrigation with water of electrical conductivity exceeding 0.3 dS m^{-1} affected dry leaf biomass negatively. Dry biomass of stems decreased with an increase in electrical conductivity of irrigation water; the greatest accumulation occurred in plants which were not irrigated with saline water during the initial development phase. Irrigation with saline water caused changes in the gas exchange of the castor bean plant with effects varying according to management strategies of use of saline water. Nitrogen supplementation with 160 mg kg^{-1} dose increased the dry mass of leaves of the castor bean plant. Increase in the electrical conductivity of irrigation water affected production negatively, regardless of the stage of development. No interactive effects were observed for the factors studied on the evaluated variables of the castor bean cv. BRS Energia.

Literature Cited

Azevedo, D.M.P. de; Lima, E.F.
2001. *O agronegócio da mamona no Brasil*. Campina Grande: EMBRAPA-Algodão, 350 p.

Azevedo Neto, A.D. de; Tabosa A.D. de
2000. Estresse salino em plântulas de milho. Parte I: análise do crescimento. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 4: 159-164.

Bezerra, A.K.P.; Lacerda, C.F. de; Hernández, F.F.F.; Silva, F.B. da; Gheyi, H.R.
2010. Rotação cultural feijão caupi/milho utilizando-se águas de salinidades diferentes. *Revista Ciência Rural,* 40: 1075-1082.

Cavalcanti, M.L.F.; Barros Júnior, G.; Carneiro, P.T.; Fernandes, P.D.; Gheyi, H.R.; Cavalcanti, R.S.
2004. Crescimento inicial da mamoneira submetido à salinidade da água de irrigação. *Revista de Biologia e Ciências da Terra,* 4: s.p.

Claessen, M.E.C. (Org.)
1997. *Manual de métodos de análise de solo*. 2.ed. rev. atual. Rio de Janeiro: Embrapa CNPS, 212 p. (Embrapa CNPS. Documentos, 1).

Fernandes Neto, S.; Abreu, B.S.; Baracuhy Neto, Moura, G.; Araújo, P.S. de.; Baracuhy, J.G.V.
2008. Impacto ambiental-agroindústria processadora de óleo de mamona/PB. *Revista Ciência e Natura* 30: 141-154.

Gulzar, S.; Khan, M.A.; Ungar, I.A.
2003. Salt tolerance of a coastal salt marsh grass. *Soil Science Plant Analysis,* 34: 2595-2605.

Kurban, H.; Saneoka, H.; Nehira, K.; Adilla, R.; Premachandra, G.S.; Fujita, K.
1999. Effect of salinity on growth, photosynthesis and mineral composition in leguminous plant *Alhagipseudo alhagi* (Bieb.). *Soil Science and Plant Nutrition,* 45: 851-862.

Lazof, D.B.; Bernstein, N.
1999. Effects of salinization on nutrient transport to lettuce leaves: consideration of leaf developmental stage. *The New Phytologist,* 144: 85-94.

Lima, G.S.; Nobre, R.G.; Gheyi, H.R.; Soares, L.A.A.; Lourenço, G.S.
2012. Resposta da mamoneira cv. BRS Energia a diferentes níveis de salinidade da água e doses de nitrogênio. *Revista Verde de Agroecologia e Desenvolvimento Sustentável,* 7: 79-87.

Machado, E.C.; Schmidt, P.T.; Medina, C.L.; Ribeiro, R.V.
2005. Respostas da fotossíntese de três espécies de citros a fatores ambientais. *Pesquisa Agropecuária Brasileira,* 40: 1161-1170.

Marinho, A.B.; Moreira, L.G.; Viana, T.V.A.; Albuquerque, A.H.P.; Oliveira, C.W.; Azevedo, B.M. de
2010. Influência da fertirrigação nitrogenada na produtividade da cultura da mamoneira. *Revista Brasileira de Agricultura Irrigada,* 4: 31-42.

Marschner, H.
1995. *Mineral nutrition of higher plants*. 2. ed. London: Academic Press, 889 p.

Mattos Junior, D.; Negri, J.D. de; Pio, R.S.; Pompeu Junior, J.
2005. Citros. Campinas: InstitutoAgronômico e Fundag, 929 p.

Munns, R.; James, R.A.; Läuchli, A.
2006. Approaches to increasing the salt tolerance of wheat and other cereals. *Journal of Experimental Botany,* 57: 1025-1043.

Neves, A.L.R.; Lacerda, C.F. de; Guimarães, F.V.A.; Gomes Filho, E.; Feitosa, D.R.C.
2009. Trocas gasosas e teores de minerais no feijão de corda irrigado com água salina em diferentes estádios. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 13: 873-881.

Nobre, R.G.; Lima, G.S. de; Gheyi, H.R.; Lourenço, G.S.; Soares, L.A.A.
2013. Emergência, crescimento e produção da mamoneira sob estresse salino e adubação nitrogenada. *Revista Ciência Agronômica,* 44: 76-85.

Novais, R.F.; Neves, J.C.L.; Barros, N.F.
1991.Ensaio em ambiente controlado. In: Oliveira, A.J. (ed). *Métodos de pesquisa em fertilidade do solo*. Brasília: Embrapa-SEA. pp. 189-253.

Oliveira, F.A. de; Oliveira, F.R.A. de; Campos, M. de S.; Oliveira, M.K.T. de; Medeiros, J.F. de; Silva, O.M. dos P.
2010. Interação entre salinidade e fontes de nitrogênio no desenvolvimento inicial da cultura do girassol. *Revista Brasileira de Ciências Agrárias,* 5: 479-484.

Rhoades, J.D.; Kandiah, A.; Mashali, A.M.
2000. *Uso de águas salinas para produção agrícola*. Campina Grande: UFPB, 117 p. Estudos da FAO, Irrigação e Drenagem, 48.

Silva, E.C.; Nogueira, R.J.M.C.; Araújo, F.P.; Melo, N.F.; Azevedo Neto, A.D.
2008. Physiological responses to salt stress in young umbu plants. *Environmental and Experimental Botany,* 63: 147-157.

Silva, J.V.; Lacerda, C.F. de; Costa, P.H.A. da; Enéas Filho, J.; Gomes Filho, E.; Prisco, J.T.
2003. Physiological responses of NaCl stressed cowpea plants grown in nutrient solution supplemented with $CaCl_2$. *Brazilian Journal of Plant Physiology,* 15: 99-105.

Silva, S.M.S.; Gheyi, H.R.; Beltrão, N.E. de M.; Santos, J.W. dos; Soares, F.A.L.
2009. Dotações hídricas em densidades de plantas na cultura da mamoneira cv. BRS Energia. *Revista Brasileira de Ciências Agrárias,* 4: 338-348.

Soares, L.A. dos A.; Lima, G.S. de; Nobre, R.G.; Gheyi, H.R.; Pereira, F.H.F.
2013. Fisiologia e acúmulo de fitomassa pela mamoneira submetida a estresse salino e adubação nitrogenada. *Revista Verde de Agroecologia e Desenvolvimento Sustentável,* 8: 247-256.

Sousa, A.E.C.; Lacerda, C.F. de; Gheyi, H.R.; Soares, F.A.L.; Uyeda, C.A.
2012. Teores de nutrientes foliares e respostas fisiológicas em pinhão manso submetido a estresse salino e adubação fosfatada. *Revista Caatinga,* 25: 144-152.

Willadino, L.; Camara, T.R.
2004. Origen y naturaleza de los ambientes salinos. In: Reigosa, M.J.; Pedrol, N.; Sánchez, A. (ed.). *La ecofisiología vegetal-Uma ciencia de síntesis*. Madrid: Thompson, pp. 303-330.

Wilson, C.; Liu, S.; Lesch, S.M.; Suarez, D.L.
2006. Growth response of major USA cowpea cultivars II. Effect of salinity on leaf gas exchange. *Plant Science,* 170: 1095-1101.

Xu, H.L.; Gauthier, L.; Gosselin, A.
1994. Photosynthetic responses of greenhouse tomato plants to high solution electrical conductivity and low soil water content. *Journal of Horticultural Science,* 69: 821-832.