

CASTOR BEAN PRODUCTION AND CHEMICAL ATTRIBUTES OF SOIL IRRIGATED WITH WATER WITH VARIOUS CATIONIC COMPOSITIONS¹

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ABSTRACT – This study aimed to evaluate the production of castor beans, cv. ‘BRS Energia’, in terms of soil chemical composition as a function of the cationic nature, and salinity levels, of the irrigation water. The experiment was carried out using lysimeters in a controlled environment at the Center of Technology and Natural Resources of the Federal University of Campina Grande, from November 2013 to February 2014. The treatments consisted of six types of salinity (S₁ - Control; S₂ - Na⁺; S₃ - Ca²⁺; S₄ - Na⁺ + Ca²⁺; S₅ - K⁺, and S₆ - Na⁺ + Ca²⁺ + Mg²⁺), distributed in randomized blocks with four replicates; each plot consisted of five plants for evaluation, totaling 120 experimental plots. Plants in the control treatment (S₁) were irrigated with water with an electrical conductivity (ECw) of 0.6 dS m⁻¹, and the other treatments (S₂; S₃; S₄; S₅ and S₆) with ECw of 4.5 dS m⁻¹, but with (a) different cation(s). Water salinity of 4.5 dS m⁻¹ hampers castor bean production, regardless of the cationic nature of the water; castor bean ‘BRS Energia’ was more sensitive to salinity caused by the presence of potassium salts in the irrigation water; the mass of seeds in the primary raceme is the most sensitive variable to salinity and the cationic nature of the irrigation water; the adopted leaching fraction (0.10) was not sufficient to avoid salt accumulation in the soil; irrigation with low ECw promoted the lowest value of exchangeable sodium percentage.

Key words: *Ricinus communis* L.. Water quality. Salinity stress. Productivity.

PRODUÇÃO DA MAMONEIRA E ATRIBUTOS QUÍMICOS DO SOLO IRRIGADO COM ÁGUAS DE DIFERENTES NATUREZA CATIÔNICA

RESUMO - Objetivou-se, com o presente trabalho, avaliar a produção da mamoneira cv. BRS Energia e os atributos químicos do solo em função da natureza catiônica e nível salino das águas de irrigação. O experimento foi desenvolvido em lisímetros em ambiente telado no Centro de Tecnologia e Recursos Naturais da Universidade Federal de Campina Grande, entre novembro de 2013 e fevereiro de 2014. Estudaram-se seis tipos de salinidade da água (S₁-Testemunha; S₂- Na⁺; S₃- Ca²⁺; S₄- Na⁺+ Ca²⁺; S₅- K⁺ e S₆- Na⁺+Ca²⁺+Mg²⁺), distribuídos em delineamento de blocos ao acaso com quatro repetições, sendo a parcela constituída de cinco plantas úteis, totalizando 120 parcelas experimentais. Salienta-se que as plantas do tratamento testemunha (S₁) foram irrigadas com água de condutividade elétrica (CEa) de 0,6 dS m⁻¹, e os demais tratamentos (S₂; S₃; S₄; S₅ e S₆) com CEa de 4,5 dS m⁻¹, porém com diferente (s) cátion (s). A salinidade da água ao nível de 4,5 dS m⁻¹ prejudica a produção da mamoneira, independente da natureza catiônica das águas; a mamoneira BRS Energia foi mais sensível à salinidade provocada pela presença de sais de potássio na água de irrigação; a massa de sementes do racemo primário é a variável mais sensível à salinidade e a natureza catiônica da água; e a fração de lixiviação adotada (0,10) não foi suficiente para evitar o acúmulo de sais no solo; a irrigação com água de baixa condutividade elétrica proporcionou o menor valor para a percentagem de sódio trocável.

Palavras-chave: *Ricinus communis* L.. Qualidade de água. Estresse salino. Rendimento.

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INTRODUCTION

In Northeast Brazil, especially semiarid areas, the scarcity of water, due to climatic reasons, irregular rain distribution, or both (resulting in an imbalance between rainfall and evaporation), severely affects the human population. This results in large social and economic losses, which decreases the land's production capacity (ALVES et al., 2011). Thus, irrigation becomes essential to guarantee good agricultural production; further, it should be noted that the quality of the water for irrigation in this region varies greatly, both geographically and seasonally throughout the year (BEZERRA et al., 2010).

Although these regions have large potential areas for irrigated agriculture, their water resources, in general, have high salt contents. Especially in crystalline areas, irrigation water contains high chloride and sodium levels, low concentrations of sulfate, and variable concentrations of calcium, magnesium, carbonates, and bicarbonates (SILVA JÚNIOR et al., 1999). These limitations increase the risk of soil salinization, which compromises growth, development, and yield of most commercial glycophytic crops, including castor bean (PESSOA et al., 2012).

Use of this water for agriculture, because of the salinity level and cationic composition, can stress crops and negatively affect the physical and chemical properties of the soil (AQUINO et al., 2007). In this context, the salt concentrations in the soil solution that limit plant development vary among genotypes, with type of salt, time of exposure of plants to saline stress, and development stage of the plant (CAVALCANTE et al., 2010; DEUNER et al., 2011).

The main restrictions for saline water in crop production include decrease in osmotic potential, specific ion toxicity, and nutritional imbalance, resulting in direct and indirect losses in physical and chemical properties of soil. These effects result in stresses that harm plant metabolism, compromising vital physiological and biochemical processes (DIAS et al., 2011; DONG et al., 2012).

Castor bean (*Ricinus communis* L.) stands out among the important crops grown in semiarid regions owing to its xerophytic and heliophilous

characteristics, along with adequate adaptation to variations in soil and management. It is a rustic crop, with rapid growth, high yield, and many uses for the oil extracted from its seeds (MARINHO et al., 2010).

The oil is extracted by pressing, and it contains 90% ricinoleic acid, which imparts unique characteristics to the oil; it is used as raw material for industry in more than 700 commercial products (SALIMON et al., 2010). Its production generates a byproduct, the cake, which has excellent chemical properties for agriculture when used as a fertilizer (PAIXÃO et al., 2013); the castor bean fruit husk is an organic material rich in K (SILVA et al., 2012).

Given the socioeconomic importance of castor bean cultivation for the semiarid regions of Northeast Brazil, and the need for using saline water in agriculture, especially water differing in cationic composition, this study aimed to evaluate the production of castor bean, cv. 'BRS Energia', in relation to the soil chemical attributes, as a function of the cationic nature and salinity level of the irrigation water.

MATERIAL AND METHODS

The experiment was carried out from November 2013 to February 2014 using drainage lysimeters in a greenhouse, at the Center of Technology and Natural Resources of the Federal University of Campina Grande (CTRN/UFCG), Campina Grande-PB, Brazil, located at 7°15'18" S, 35°52'28" W at an altitude of 550 m.

The treatments consisted of six types of water salinity, with respect to the cationic composition: S₁ - Control; S₂ - Na⁺; S₃ - Ca²⁺; S₄ - Na⁺ + Ca²⁺; S₅ - K⁺ and S₆ - Na⁺ + Ca²⁺ + Mg²⁺, distributed in randomized blocks with four replicates and five plants per plot for evaluation, totaling 120 experimental plots. Plants in the control treatment were irrigated with water having an electrical conductivity (EC_w) of 0.6 dS m⁻¹, according to the characteristics shown in Table 1, and the others with an EC_w of 4.5 dS m⁻¹, obtained by the addition of different salts, all in the form of chloride. Equivalent proportions of 1:1 and 7:2:1 were adopted for Na:Ca - S₄ and Na:Ca:Mg - S₆, respectively.

Table 1. Chemical characteristics of the water used in the control treatment

Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	CO ₃ ⁻	Cl ⁻	EC	pH	SAR
(mmol _c L ⁻¹)							dS m ⁻¹		(mmol L ⁻¹) ^{0.5}
1.19	1.58	2.83	0.10	1.45	0.00	4.22	0.60	7.23	2.41

EC – electrical conductivity. SAR – sodium adsorption ratio.

The castor bean cultivar 'BRS Energia' was used in the study. According to Silva et al. (2009), it has a growth cycle of 120 to 150 days, small size, semi-dehiscent fruits, mean seed oil content of 48%,

and mean yield of 1,800 kg ha⁻¹ under irrigated cultivation in non-saline soil.

The experiment was carried out in plastic pots with height of 50 cm, base diameter of 30 cm and

top diameter of 33 cm, with capacity of 100 L. The pots were adapted for drainage lysimeters, with a nonwoven geotextile (Bidim OP 30) and a 2-kg layer of crushed stone (n° zero) in order to reduce the risk of clogging of the drains. The pots were then filled with 130 kg soil, of which 54 kg was material from a eutrophic Gray Argisol, according to the classification criteria of Embrapa (2013). Soil was collected in São José da Mata, Campina Grande-PB,

and sieved through a 2.0-mm mesh. A volume of 76 kg of material from the same soil with earthworm humus was added to increase soil organic matter to 1%.

Before the experiment, the chemical and physical characteristics were determined (Table 2) at the Laboratory of Irrigation and Salinity of the CTRN/UFCG, according to the methodology proposed by Claessen (1997).

Table 2. Chemical and physical attributes of the soil used in the experiment, before cultivation.

Chemical characteristics									
pH (H ₂ O) (1:2,5)	OM dag kg ⁻¹	P (mg kg ⁻¹)	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	Al ³⁺	H ⁺	ECse (dS m ⁻¹)
.....(cmol _c kg ⁻¹).....									
5.13	0.34	20.09	0.07	0.05	0.40	1.30	0.04	1.74	0.16
Physical characteristics									
Size fraction (g kg ⁻¹)			Textural class	Water content (kPa)		AW	Total porosity m ³ m ⁻³	BD (kg dm ⁻³)	PD (kg dm ⁻³)
Sand	Silt	Clay		33.42	1519.5				
856.10	110.70	33.20	SL	6.72	1.62	5.10	0.49	1.54	2.72

OM. – Organic matter: Walkley–Black Wet Digestion; Ca²⁺ and Mg²⁺ extracted with KCl 1 mol L⁻¹ at pH 7.0; Na⁺ and K⁺ extracted with NH₄OAc 1 mol L⁻¹ at pH 7.0; ECse – electrical conductivity in the saturation extract; SL – Sandy Loam; AW – Available water; BD – Bulk density; DP – Particle density.

Because of the low calcium and pH levels, soil acidity was corrected using 49.25 g of dolomitic limestone [(CaO (45%), MgO (6%), RNV (85%)] in the soil material of each lysimeter (130 kg of soil), an amount necessary to neutralize Al³⁺ and increase the contents of Ca²⁺ and Mg²⁺ and soil CEC to 70% (Ribeiro et al., 1999). After correcting acidity, the soil showed the following chemical characteristics: Ca²⁺ = 1.14 cmol_c kg⁻¹; Mg²⁺ = 1.36 cmol_c kg⁻¹; Na⁺ = 0.30 cmol_c kg⁻¹; K⁺ = 0.14 cmol_c kg⁻¹; H⁺ = 0.11 cmol_c kg⁻¹; Al³⁺ = 0 cmol_c kg⁻¹; CEC = 3.05 cmol_c kg⁻¹; organic matter = 1.08 dag kg⁻¹; P = 47.80 mg kg⁻¹ and pH in water (1:2.5) = 6.42.

Irrigation water were prepared by dissolving sodium (NaCl), calcium (CaCl₂ · 2H₂O), magnesium (MgCl₂ · 6H₂O) and potassium (KCl) chlorides, with mean purity above 99% in water from the local supply system (Campina Grande-PB), with an ECw of 0.6 dS m⁻¹ using the equation described by Richards (1954): ECw = 10 x mmol_c L⁻¹. The water with 0.6 dS m⁻¹ was obtained by mixing water from the local supply system with rain water from the catchment system of the CTRN/UFCG.

Before sowing, the volume of water necessary to increase soil water content to field capacity was determined using the method of saturation through capillarity, followed by free drainage, and there after applying the solutions corresponding to the treatments in each lysimeter. Next, sowing was conducted by planting ten seeds of ‘BRS Energia’ castor bean in each lysimeter, at a depth of 2 cm. Ten days after sowing (DAS), thinning was performed, leaving only the most vigorous plant in each lysimeter.

After sowing, the soil was maintained at field capacity with daily irrigations by adding the solutions corresponding to the treatments to each lysimeter. The applied volume was determined according to plant water demand, as estimated through the water balance: applied water volume minus the water volume drained in the previous irrigation, plus a leaching fraction of 0.10, according to previous studies (NOBRE et al., 2013; LIMA et al., 2014b).

Fertilization with nitrogen, potassium, and phosphorus was performed according to Novais et al. (1991), by applying in each pot 40.62 g of potassium nitrate and 75 g of monoammonium phosphate, equivalent to 100, 150, and 300 mg of N, P₂O₅, and K₂O, respectively, per kg of soil. This was applied as a top-dressing, in four applications through fertigation, in intervals of ten days, with the first application at 15 DAS. Two foliar fertilizations were performed, containing 2.5 g L⁻¹ of Ubyfol [(N (15%); P₂O₅ (15%); K₂O (15%); Ca (1%); Mg (1.4%); S (2.7%); Zn (0.5%); B (0.05%); Fe (0.5%); Mn (0.05%); Cu (0.5%); Mo (0.02%)] at 30 and 60 DAS.

The cultivation practices during the experimental period consisted of weekly manual weeding, superficial soil chiseling before each irrigation, and plant staking at the flowering stage to avoid lodging. Additionally, insecticides from the neonicotinoid group, fungicide from the triazole group, and acaricide from the abamectin group were sprayed, at concentrations of 5.4, 7.0, and 3.5 g L⁻¹, respectively.

Racemes were collected when approximately 90% of the fruits reached physiological maturation

from 70 to 100 DAS. The following variables were analysed: total length (TLPR) and effective length (ELPR) of the primary raceme, number of fruits (NFPR), and number of seeds (NSPR); mass of seeds of the primary raceme (MSPR), total mass of seeds (TMS), mass of a hundred seeds (MHSPR), and density of seeds of the primary raceme (DSPR). TLPR was determined from the insertion point to the apex of the racemes and ELPR was the distance from the basal insertion of the fruits to the apex of the raceme. After drying, NFPR were counted; the husk was then removed and NSPR were counted. The values of MSPR, TMS, and MHSPR were obtained using an analytical scale. DSPR was determined based on the quotient between NSPR and ELPR.

The data were subjected to analysis of variance using F test, and the means were compared by Tukey's test at 0.05 probability level and orthogonal contrasts, using the program SISVAR-ESAL. The contrasts were defined as follows: \hat{y}_1 (S_1 vs S_2 ; S_3 ; S_4 ; S_5 ; S_6); \hat{y}_2 (S_2 vs S_3); \hat{y}_3 (S_2 vs S_6); \hat{y}_4 (S_2 vs S_5) and \hat{y}_5 (S_5 vs S_2 ; S_3 ; S_4 ; S_6). For the comparison between treatments, the standard error was calculated for each mean. Given the normality

of the residues obtained in the present study, evidenced by the high values of the coefficient of variation ($CV > 20\%$) (Tables 3 and 5), it was necessary to perform an exploratory analysis of the data, which were transformed to.

RESULTS AND DISCUSSION

According to the summaries of the analyses of variance, the environment and the cationic nature of the water had significant effects on the total length (TLPR), effective length (ELPR), number of fruits (NFPR), and number of seeds (NSPR) of the primary raceme of the castor beans (Table 3). The significant differences between blocks concerning the analysed variables were probably due to increased sunlight, and consequently, higher temperature, resulting in higher evapotranspiration (CAVALCANTE et al., 2010). As for the treatments, irrigation water with various chemical compositions shows different effects on the growth and production of the same genotype.

Table 3. Summary of the analysis of variance for total length (TLPR), effective length (ELPR), number of fruits (NFPR), and number of seeds (NSPR) of the primary racemes of castor beans irrigated with water of different cationic composition and saline levels.

VS/Contrasts	DF	Mean square			
		TLPR ¹	ELPR ¹	NFPR ¹	NSPR ¹
Blocks	3	776.29*	716.65*	9340.26**	80897.74**
Cationic composition of water	(5)	776.29*	716.65*	9340.26**	80897.74**
\hat{y}_1	1	3390.97**	3276.07**	46413.33**	3987,07**
\hat{y}_2	1	41.40 ^{ns}	17.70 ^{ns}	200.00 ^{ns}	1953.12 ^{ns}
\hat{y}_3	1	36.12 ^{ns}	15.40 ^{ns}	0.0001 ^{ns}	91.12 ^{ns}
\hat{y}_4	1	166.53 ^{ns}	114.00 ^{ns}	32.00 ^{ns}	968.00 ^{ns}
\hat{y}_5	1	125.04 ^{ns}	285.01 ^{ns}	5.00 ^{ns}	3484.80 ^{ns}
Residual	15	117.87	121.36	804.44	4871.16
CV (%)		13.68	16.66	15.81	13.71

\hat{y}_1 (S_1 vs S_2 ; S_3 ; S_4 ; S_5 ; S_6); \hat{y}_2 (S_2 vs S_3); \hat{y}_3 (S_2 vs S_6); \hat{y}_4 (S_2 vs S_5); \hat{y}_5 (S_5 vs S_2 ; S_3 ; S_4 ; S_6); VS – variation source; CV – coefficient of variation; DF – degrees of freedom; (*) and (**) significant at 0.05 and 0.01 probability, respectively; (ns) not significant.

When comparing means for TLPR (Figure 1A) it was found that plants irrigated with treatment S1 did not differ statistically from those irrigated with water containing only potassium (S_5). On the other hand, water prepared with Na^+ , Ca^{2+} , Na^+Ca^{2+} , and $Na^+Ca^{2+}Mg^{2+}$, inhibited raceme length. Based on the differences in TLPR between plants irrigated with low-salinity water (S_1) and those under each type of artificial water (S_2 ; S_3 ; S_4 ; S_5 and S_6 – 4.5 dS m^{-1}), linear decreases of 31.80, 36.35, 32.60, 22.68, and 36.05 cm, respectively were observed, which correspond to percent losses of 57.71, 65.97, 59.16, 41.16, and 65.42%, respectively, in comparison to plants in the control treatment (S_1).

For the different types of salinity, the highest reduction in TLPR was observed in plants irrigated using water containing sodium, calcium, sodium + calcium, and sodium + calcium + magnesium. These

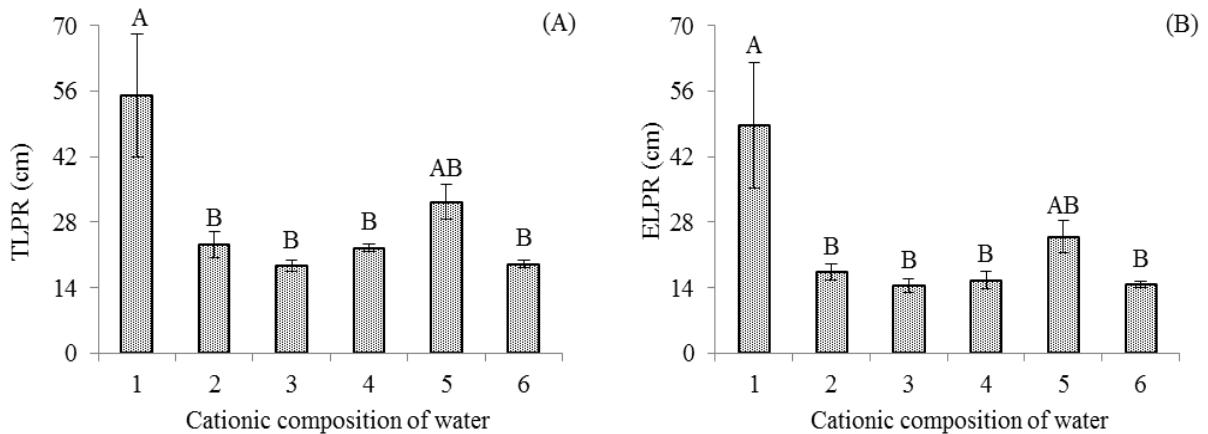
reductions in primary raceme growth can be attributed more to the high saline level than to the cationic nature of the respective water, since treatments with different cations did not differ (Figure 1A).

The decrease in castor bean production due to the variation in ECw can be attributed to a lower water absorption by the plants, which leads to saline stress. Additionally, increased salt concentration in the root zone has deleterious effects on crop production owing to a higher osmotic effect around the roots, restricting the flow of water from the soil to the plants (OLIVEIRA et al., 2012).

As for the effective length of the primary raceme (Figure 1B), the effects of the water treatments are similar to those on TLPR, without significant differences between the treatments with low-salinity water (S_1) and water containing

potassium (S₅), but with superior growth in plants irrigated with S₁ as compared to those receiving water containing sodium, calcium, and magnesium. Comparatively, there was a significant ($p < 0.01$) difference between the salinity levels; the highest value (48.77 cm) was observed in the treatment with low-salinity water (control), which was significantly different from the treatments S₂, S₃, S₄, and S₆. In contrast, the lowest values of ELPR (14.45 and 14.65

cm) were observed in the treatments with water containing calcium (S₃) and sodium + calcium + magnesium (S₆), respectively. Despite finding no difference ($p > 0.05$) between S₅ and the other types of salts (S₂, S₃, S₄, and S₆) on ELPR, irrigation with water containing potassium causes less damage to 'BRS Energia' castor bean plants as compared to the other types of water salinity.



1= Control; 2= Na⁺; 3= Ca²⁺; 4=Na⁺: Ca²⁺; 5=K⁺; 6=Na⁺:Ca²⁺:Mg²⁺.

Bars represent mean standard error (n = 4). Means followed by different letters indicate difference between treatments by Tukey's test, $p < 0.05$.

Figure 1. Total length – TLPR (A) and effective length – ELPR (B) of the primary raceme of castor bean as a function of irrigation with water of different cationic composition and saline level.

According to the summary of the analysis of variance for mean comparisons (Table 3), there were significant differences between the tested treatments for all the evaluated variables (TLPR, ELPR, NFPR, and NSPR). In the comparison of plants subjected to the lowest salinity level (0.6 dS m⁻¹) with plants irrigated with water of EC_w of 4.5 dSm⁻¹ (S₂; S₃; S₄; S₅; and S₆), based on the estimate of the mean (Table 4), there were increments in TLPR and ELPR of 31.89 and 31.35 cm, respectively.

For NFPR and NSPR, there were increases of about 118 and 345.85, respectively, when comparing plants in the EC_w of 0.6 dS m⁻¹ treatment with those under the EC_w of 4.5 dS m⁻¹ treatment. The observed

reduction in TLPR, ELPR, NFPR, and NSPR for plants under the high EC_w (4.5 dS m⁻¹) is probably due to the osmotic effects of the dissolved salts, which reduces the osmotic potential of the soil solution, and inhibits the movement of water to the cells, causing water stress in the plants (FLOWERS, 2004). Nobre et al. (2012), when studying the effects of different EC_w levels (0.4 to 4.4 dS m⁻¹) associated with doses of N fertilization on the production of 'BRS Energia' castor bean, also observed a reduction in primary raceme growth, number of racemes, fruit production per plant, and mass of a hundred seeds, in the primary raceme.

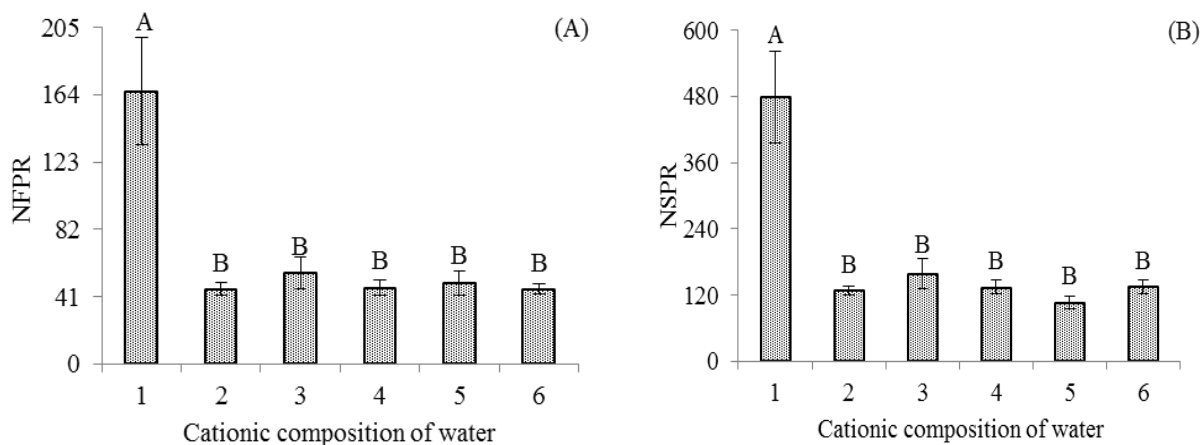
Table 4. Estimate of the mean for total length (TLPR), effective length (ELPR), number of fruits (NFPR), and number of seeds (NSPR) of the primary racemes of castor beans irrigated with water of different cationic composition and saline levels.

Contrasts	Mean estimate			
	TLPR (cm)	ELPR (cm)	NFPR	NSPR
\hat{y}_1	31.89	31.35	118	345.85
\hat{y}_2	ns	ns	ns	ns
\hat{y}_3	ns	ns	ns	ns
\hat{y}_4	ns	ns	ns	ns
\hat{y}_5	ns	ns	ns	ns

\hat{y}_1 (S₁ vs S₂; S₃; S₄; S₅; S₆); \hat{y}_2 (S₂ vs S₃); \hat{y}_3 (S₂ vs S₆); \hat{y}_4 (S₂ vs S₅); \hat{y}_5 (S₅ vs S₂; S₃; S₄; S₆); (ns) not significant.

When comparing the means for the treatments S_2 vs S_3 , S_2 vs S_6 , S_5 vs S_2 , and S_5 vs S_2 , S_3 , S_4 , S_6 (Table 3), there was no significant ($p > 0.05$) difference found for any of the analysed variables. Therefore, based on the obtained results, it can be inferred that these treatments affect plant growth in a similar way in terms of the analysed variables (TLPR, ELPR, NFPR, and NSPR). Thus, the highest effect on growth is attributed to the variation in the osmotic potential of the soil solution, promoted by the different levels of water electrical conductivity (ECw of 0.6 and 4.5 dS m^{-1}).

NFPR was significantly ($p < 0.01$) inhibited (Figure 2A) by the different salts (S_2 ; S_3 ; S_4 ; S_5 ; and S_6) in relation to the control (S_1), but did not differ between treatments. The salinity treatments with sodium (S_2), calcium (S_3), sodium + calcium (S_4), potassium (S_5), and sodium + calcium + magnesium (S_6) resulted in relative decreases of 72.67, 66.66, 72.07, 70.27, and 72.67%, respectively, in comparison to S_1 water (control). These results show that the number of fruits of the primary raceme (Figure 2A) in ‘BRS Energia’ castor bean is more severely affected by the total concentration of salts (ECw) than by the types of salts.



1= Control; 2= Na^+ ; 3= Ca^{2+} ; 4= $\text{Na}^+ : \text{Ca}^{2+}$; 5= K^+ ; 6= $\text{Na}^+ : \text{Ca}^{2+} : \text{Mg}^{2+}$. Bars represent mean standard error ($n = 4$). Means followed by different letters indicate difference between treatments by Tukey’s test, $p < 0.05$.

Figure 2. Number of fruits – NFPR (A) and number of seeds – NSPR (B) of the castor bean primary raceme, as a function of irrigation with water of different cationic composition and saline level.

The number of seeds in the primary raceme (Figure 2B), similar to NFPR, was statistically different between the treatments, and based on the comparison of means, it was significantly ($p < 0.01$) superior for plants under ECw of 0.6 dS m^{-1} (control), as compared to plants under the treatments S_2 , S_3 , S_4 , S_5 , and S_6 (4.5 dS m^{-1}). When comparing the values for each type of water with the control, decreases of 73.18, 66.66, 71.92, 77.79, and 71.78% were found in NSPR, for the treatments S_2 , S_3 , S_4 , S_5 , and S_6 , respectively.

The decreases in NFPR and NSPR reflect the negative effect of both the osmotic and the ionic components in saline stress. Additionally, the increase in the concentration of soluble salts reduces the water potential of the soil solution, thus inhibiting water absorption by plants, along with the photosynthetic capacity, owing to the dehydration of cell membranes, toxicity by salts, reduction in CO_2 supply, and consequently, reduction in plant production (WILLADINO; CÂMARA, 2004; AMBEDE et al., 2012).

Despite the lack of significant difference between the data, castor bean plants irrigated with water containing potassium showed the highest

numerical value for total length (Figure 1A) and effective length (Figure 1B) of the primary raceme, compared with those irrigated with water containing the other cations (S_2 ; S_3 ; S_4 ; and S_6), and the lowest numerical values for NFPR and NSPR. This can be attributed to the fact that potassium is frequently absorbed by many crops in amounts higher than required, reflecting “luxury consumption.” Under these conditions, the excess K^+ can negatively interfere with the absorption of other elements, especially when they compete for the same absorption sites in root tissues (MEURER, 2006), thereby inhibiting the absorption of Ca^{2+} and Mg^{2+} (MARSCHNER, 2012).

Ca^{2+} deficiency hampers the flowering stage by causing a deformity in the pollen tube. Additionally, pollen grain germination depends on the presence of Ca^{2+} in the substrate, and the direction of its growth is chemotropically controlled by the gradient of extracellular calcium (BEYOUNG, 1965). On this topic, Tisdale et al. (1993) comment that the optimal K^+ concentration for the soil solution is between 10 and 60 mg L^{-1} , depending on the crop, soil structure, fertility, and water supply, i.e., an amount 280.707 mg L^{-1} lower

than that applied in the present study.

According to the summary of the analysis of variance (Table 5), the variables MSPR, TMS,

MHSPR, and DSPR were significantly influenced by the cationic composition of the irrigation water.

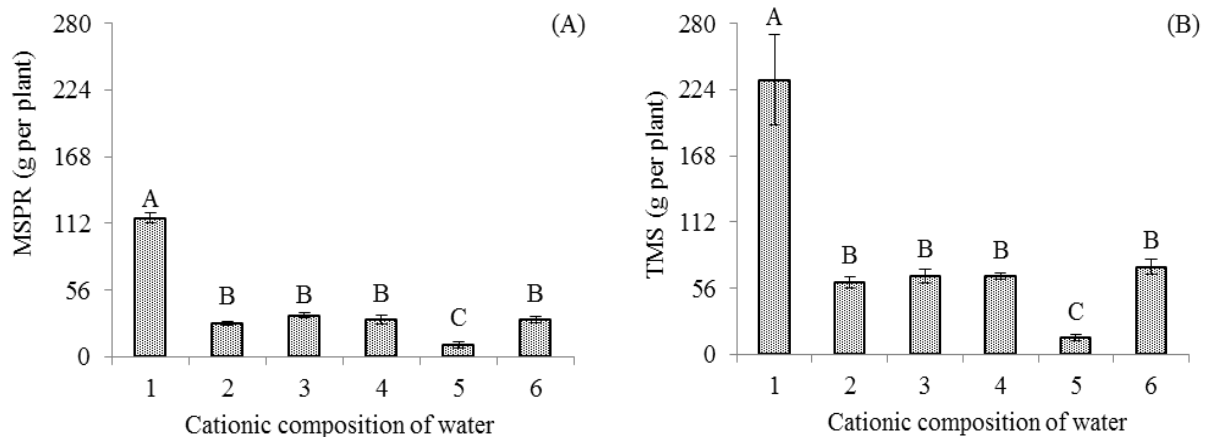
Table 5. Summary of the analysis of variance for the mass of seeds (MSPR), total mass of seeds (TMS), mass of a hundred seeds (MHSPR), and density of seeds (DSPR) of the castor bean primary raceme irrigated with water of different cationic composition and saline levels.

VS/Contrasts	DF	Mean square			
		MSPR	TMS ¹	MHSPR	DSPR ¹
Blocks	3	43.11 ^{ns}	731.12 ^{ns}	4.48 ^{ns}	3.00 ^{ns}
Cationic composition of water	(5)	5649.24 ^{**}	22490.34 ^{**}	182.29 ^{**}	20.78 [*]
\hat{y}_1	1	26761.13 ^{**}	103154.79 ^{**}	490.58 ^{**}	16.17 [*]
\hat{y}_2	1	77.87 ^{ns}	55.44 ^{ns}	4.38 ^{ns}	19.86 [*]
\hat{y}_3	1	15.07 ^{ns}	341.32 ^{ns}	11.35 ^{ns}	5.60 ^{ns}
\hat{y}_4	1	645.84 [*]	4426.69 [*]	299.91 [*]	19.20 [*]
\hat{y}_5	1	1406.83 ^{**}	8947.61 [*]	405.14 ^{**}	67.09 [*]
Residual	15	30.18	1126.56	9.68	3.86
CV (%)		13.03	14.03	14.00	12.23

\hat{y}_1 (S₁ vs S₂; S₃; S₄; S₅; S₆); \hat{y}_2 (S₂ vs S₃); \hat{y}_3 (S₂ vs S₆); \hat{y}_4 (S₂ vs S₅); \hat{y}_5 (S₅ vs S₂; S₃; S₄; S₆); VS – variation source; CV – coefficient of variation; DF – degrees of freedom; (*) and (**) significant at 0.05 and 0.01 probability, respectively; (ns) not significant.

According to Figure 3A, the mass of seeds of the primary raceme (MSPR) of castor bean plants differed significantly ($p < 0.01$) between treatments with different types of cations. The highest value (116.82 g) was obtained in plants under the lowest water salinity (0.6 dS m⁻¹). On the other hand, plants irrigated with the treatments S₂, S₃, S₄, S₅, and S₆

produced 28.41, 34.65, 31.42, 10.44 and 31.16 g of MSPR, expressing reductions of 75.68, 70.33, 73.10, 91.06, and 73.32%, compared with the control treatment (S₁). When comparing these losses with the other studied variables, MSPR was reduced more by the saline stress due to the EC_w than by the cationic composition of the water.



1= Control; 2= Na⁺; 3= Ca²⁺; 4=Na⁺: Ca²⁺; 5=K⁺; 6=Na⁺:Ca²⁺:Mg²⁺.

Bars represent mean standard error (n = 4). Means followed by different letters indicate difference between treatments by Tukey's test, $p < 0.05$.

Figure 3. Mass of seeds of the primary raceme – MSPR (A) and total mass of seeds – TMS (B) of castor bean, as a function of irrigation with water of different cationic composition and saline level.

According to Figure 3B, plants irrigated with low-salinity water (control) surpassed the TMS of all the plants irrigated with water treatments of different cationic composition (S₂, S₃, S₄, S₅, and S₆) and with EC_w of 4.5 dS m⁻¹. Despite the inferiority in relation to the control, and although the cationic composition had congruent effects between plants, there was a numerical decrease of 60.11 g plant⁻¹, and a decrease of 80.78% between plants irrigated with the treatment S₆ (sodium + calcium + magnesium) and S₅ (potassium).

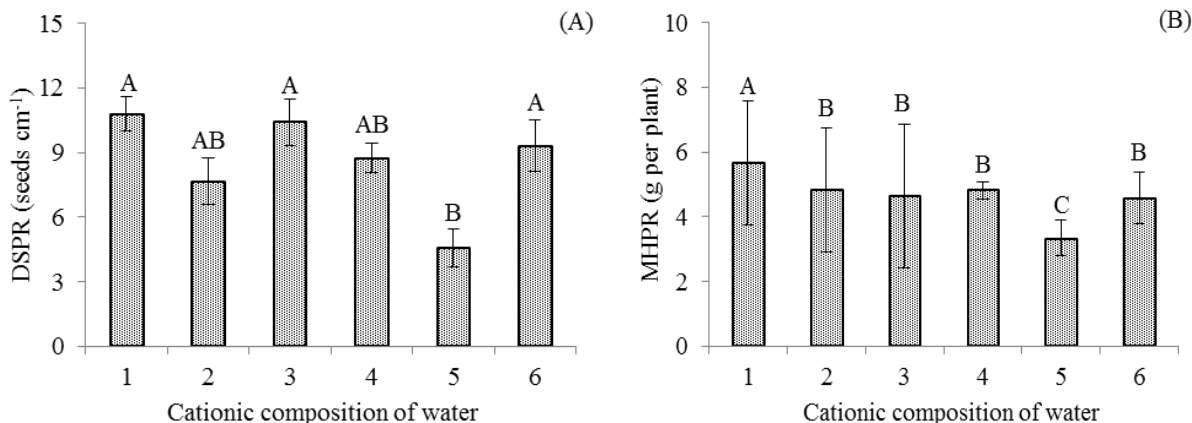
The decrease in the mass of seeds of the primary raceme (Figure 3A) and total mass of seeds (Figure 3B), as a function of the cationic composition of the water treatments, was a response to the excess of salts in each type of water, causing a reduction in the external osmotic potential and specific toxicity of each type of ion (MUNNS; TESTER, 2008). This stress leads to physiological and biochemical alterations, such as the reduction in chlorophyll efficiency, respiration, and photosynthesis (ESTEVES; SUZUK, 2008), which

can severely compromise the growth and production of 'BRS Energia' castor bean.

A similar result was reported by Lima et al. (2014), who studied the effects of NaCl salinity ranging from 0.4 to 4.4 dS m⁻¹, with intervals of 1.0 dS m⁻¹, and observed a reduction in the total mass of seeds from 64.57 to 13.93 g plant⁻¹, with a loss of 78.43% between plants irrigated with water of higher and lower salinity. Under the same conditions, there was a decrease from 115.80 to 32.94 g plant⁻¹, with a

reduction of 71.55%, in the mass of a hundred seeds of the raceme (MHSPR).

The density of seeds in the primary raceme (DSPR) (Figure 4A) decreased from 10.81 seeds cm⁻¹ in plants irrigated with low salinity water (S₁) to values of 7.66, 10.43, 8.76, 4.56, and 9.30 seeds cm⁻¹, with reductions of 29.13, 3.51, 18.96, 57.81, and 13.69% in plants irrigated with the treatments S₂, S₃, S₄, S₅, and S₆ (EC_w = 4.5 dS m⁻¹), respectively.



1= Control; 2= Na⁺; 3= Ca²⁺; 4=Na⁺: Ca²⁺; 5=K⁺; 6=Na⁺:Ca²⁺:Mg²⁺.

Bars represent mean standard error (n = 4). Means followed by different letters indicate difference between treatments by Tukey's test, p < 0.05.

Figure 4. Density of seeds – DSPR (A) and mass of a hundred seeds – MHSPR (B) of the castor bean primary raceme, as a function of irrigation with water treatments of different cationic composition and saline level.

The mass of a hundred seeds in the primary raceme (MHSPR) of plants in the control treatment (Figure 4B) was statistically higher than that of plants irrigated with water of the other treatments (S₂; S₃; S₄; S₅; and S₆). However, castor bean plants, when irrigated with water containing sodium, calcium, sodium + calcium, and sodium + calcium + magnesium, were statistically different (p < 0.01) from those receiving water containing potassium, and there were increases in MHSPR of 1.49, 1.32, 1.49, and 1.24 g in the treatments S₂, S₃, S₄, and S₆, respectively, compared with S₅.

According to the summary of the analysis of variance for the contrasts of means of MSPR, TMS, MHSPR, and DSPR (Table 5), there was a significant effect of the different treatments on all the evaluated variables. Based on the mean estimation data (Table 6), plants under low-salinity water (0.6 dS m⁻¹) showed increments of 89.60, 175.91, and 12.13 g, respectively, in MSPR, TMS, and MHSPR, and 2.20 seeds cm⁻¹ in DSPR, compared with the mean of plants cultivated under an EC_w of 4.5 dS m⁻¹ (S₂; S₃; S₄; S₅; S₆). Similar behavior was reported by Silva et al. (2008), who observed decreases in the mass of seeds in castor bean cultivars ('BRS Paraguaçu' and 'BRS Energia'), irrigated with water of different EC_w

levels, ranging from 0.7 to 6.7 dS m⁻¹.

Comparing plants in S₂ and S₃ treatments, there was significant (p < 0.05) effect only for the variable DSPR, which was reduced by 3.15 seeds cm⁻¹ in plants receiving water containing sodium (S₂), in relation to those receiving water containing calcium (S₃). However, according to the data obtained in the treatment S₂ versus S₆ (Na⁺ + Ca²⁺ + Mg²⁺), there was no substantial effect on any of the studied variables.

As for the treatments S₂ versus S₅ and S₅ versus S₂, S₃, S₄, and S₆, we observed a significant (p < 0.05) influence on all the analysed variables. However, according to the mean estimation (Table 6), plants irrigated with water containing sodium (S₂) showed increases of 17.97, 47.04, and 12.24 g in MSPR, TMS, and MHSPR, respectively, and 3.09 seeds cm⁻¹ in DSPR, as compared to plants under S₅.

For the differences in S₅ versus S₂, S₃, S₄ and S₆ (Table 6), decreases of 20.96, 52.87, 11.25 g and 4.57 seeds cm⁻¹ were found for MSPR, TMS, MHSPR, and DSPR, respectively. These results are consistent with obtained for the other variables (Table 3). 'BRS Energia' castor bean is more sensitive to the variation in EC_w (0.6 and 4.5 dS m⁻¹) than to cationic variation in irrigation water and, among the studied cations, the excess of potassium

in the irrigation water was more harmful. These results corroborate those obtained by Rodrigues et al. (2012), who studied the influence of the management of potassium fertilization at the levels of 0, 20, 40,

60, and 80 kg ha⁻¹ of K₂O on the cultivation of bean (*Phaseolus vulgaris* L.); this study observed a reduction in yield with doses above 60 kg ha⁻¹.

Table 6. Estimate of the mean for mass of seeds of the primary raceme (MSPR), total mass of seeds (TMS), mass of a hundred seeds (MHSPR), and density of seeds of the primary raceme (DSPR) of castor bean irrigated with water treatments of different cationic nature and saline level.

Contrasts	Mean estimate			
	MSPR (g)	TMS (g)	MHSPR (g)	DSPR (seeds cm ⁻¹)
\hat{y}_1	89.60	175.91	12.13	2.20
\hat{y}_2	ns	ns	ns	-3.15
\hat{y}_3	ns	ns	ns	ns
\hat{y}_4	17.97	47.04	12.24	3.09
\hat{y}_5	-20.96	-52.87	-11.25	-4.57

\hat{y}_1 (S₁ vs S₂; S₃; S₄; S₅; S₆); \hat{y}_2 (S₂ vs S₃); \hat{y}_3 (S₂ vs S₆); \hat{y}_4 (S₂ vs S₅); \hat{y}_5 (S₅ vs S₂; S₃; S₄; S₆); (ns) not significant.

In general, the highest reduction in NFPR, NSPR, MSPR, TMS, MHSPR, and DSPR was observed in the treatment containing potassium. This decrease in castor bean production components can be attributed to the antagonism between potassium, calcium, and magnesium ions, as previously mentioned (MARSCHNER, 2012). Thus, with the competition between K⁺ and Ca²⁺, a resulting calcium deficiency can promote undesirable alterations in the membranes. Since calcium acts as a stabilizing ion, it can induce higher crop sensitivity to saline stress due to the selectivity of the membranes in ionic absorption and compartmentation (AZEVEDO NETO; TABOSA, 2000). This can directly affect plant growth and, consequently, the crop yield. Prado et al. (2004), studying the effects of potassium (0; 75; 150; 225 and 300 mg of K⁺ dm⁻³), reported reductions in dry phytomass and mineral composition (N, P, Ca, Mg, Mn, Cu, Zn, and S) of seedlings of yellow passion fruit (*Passiflora edulis*) for K⁺ doses above 225 mg.

According to the data in Table 7, referring to the characteristics for the diagnosis of salinity problems, use of water with an EC_w of 4.5 dS m⁻¹ promoted an increase in the electrical conductivity of the saturation extract of soil (EC_{se}) in all the studied treatments (S₂; S₃; S₄; S₅ and S₆). These are, according to Richards (1954), the characteristics of a saline soil (EC_{se} > 4.0 dS m⁻¹). It should be pointed out that the highest EC_{se} observed in the treatment S₅ in relation to the others (S₂; S₃; S₄; and S₆) is consistent with the saline index of potassium chloride (116), which has a higher value compared with the other studied salts.

The increase in EC_{se} was also observed in the control treatment, in which the value of EC_w was

<1.0 dS m⁻¹. Additionally, both in the control and in the other treatments (Table 7), EC_{se} was on average 1.5 times the EC_w used in irrigation, consistent with Ayers & Westcot (1991), considering a leaching fraction of 0.10. The pH_{sp} was different, compared with EC_{se}, and lower values were found in the treatments with the high values of EC_{se}, i.e., in the treatments using water with the highest electrical conductivity (4.5 dS m⁻¹). This behavior can be related to the periodic application of the leaching fraction (on average at interval of 20 days) and to the removal of bases constituting the exchange complex, which probably contributed to this reduction in pH_{sp}.

Exchangeable sodium percentage (ESP) indicates the saturation of the soil exchange complex by the sodium ion, obtained from the ratio between the content of exchangeable sodium and the effective cation exchange capacity (CEC_e) of the soil (MEURER, 2010). Thus, in the treatments subjected to an EC_w of 4.5 dS m⁻¹, the highest ESP value (55.04%), as expected, was observed with the use of water salinized by sodium (S₂), followed by water with 70 and 50% of sodium in the composition (Na + Ca + Mg - S₆ and Na + Ca - S₄), respectively, with means of 44.97 and 42.23%.

The values obtained for exchangeable and soluble cations (Table 7) showed the same trend, according to the composition of the water. Thus, waters rich in potassium and calcium showed a higher proportion of the respective cation in the exchange complex and in the saturation extract. These data confirm the previously suggested antagonistic effect on the production components, i.e., when a certain cation prevails in excess in the soil solution, the availability of the others is reduced.

Table 7. Mean values of chemical attributes of the soil cultivated with castor bean, irrigated with water of different cationic composition and saline level.

Characteristics	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆
Exchange complex (cmol _c kg ⁻¹)						
Calcium (Ca ²⁺)	0.70	0.68	1.51	1.22	0.63	0.95
Magnesium (Mg ²⁺)	1.14	1.16	0.89	0.79	1.21	1.07
Sodium (Na ⁺)	0.48	2.62	0.46	1.64	0.84	1.86
Potassium (K ⁺)	1.62	0.34	0.35	0.30	3.08	1.20
Aluminium (Al ³⁺)	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen (H ⁺)	0.35	0.31	0.21	0.24	0.24	0.25
ESP - %	10.39	55.04	13.62	42.23	11.31	44.97
Saturation extract						
pH _{sp}	5.47	5.13	4.83	4.87	4.97	4.49
EC _{se} - dS m ⁻¹	0.87	7.03	7.47	8.06	8.17	7.35
Chloride (Cl ⁻ mmol _c L ⁻¹)	24.50	70.75	75.94	83.06	73.19	74.81
Carbonate (CO ₃ ²⁻ mmol _c L ⁻¹)	0.00	0.00	0.00	0.00	0.00	0.00
Bicarbonate (HCO ₃ ⁻ mmol _c L ⁻¹)	0.88	1.15	1.35	0.83	33.55	0.90
Sulfate (SO ₄ ²⁻ mmol _c L ⁻¹)	P	P	P	P	P	P
Calcium (Ca ²⁺ mmol _c L ⁻¹)	1.81	1.56	17.37	16.12	2.34	5.28
Magnesium (Mg ²⁺ mmol _c L ⁻¹)	5.44	4.48	9.57	9.82	8.25	11.00
Sodium (Na ⁺ mmol _c L ⁻¹)	15.18	48.17	15.62	44.37	19.99	49.66
Potassium (K ⁺ mmol _c L ⁻¹)	10.53	2.19	2.60	2.91	35.96	3.39
SAR (mmol L ⁻¹)	8.09	27.92	3.84	12.90	8.76	17.41

S₁= Control; S₂= Na⁺; S₃= Ca²⁺; S₄=Na⁺+Ca²⁺; S₅=K⁺; S₆=Na⁺+Ca²⁺+Mg²⁺; ESP = Exchangeable sodium percentage; pH_{sp} = pH in the saturation paste; EC_{se} = Electrical conductivity in the saturation extract; SAR = Sodium adsorption ratio.

Considering the anionic composition of the soil solution, there is a predominance of chloride in the water treatments of different cationic composition, because all of them, except for the control, were prepared using chloride salts. As for the sodium adsorption ratio (SAR; Table 7), the highest values were estimated in the soil under the treatment with only sodium, followed by sodium + calcium + magnesium, and sodium + calcium. For Dikinya et al. (2007), the increase in SAR promotes an increase in ESP because of the relationship between the exchangeable and soluble contents in the soil, as demonstrated by Richards (1954). Additionally, the increase in SAR results in an increase in the proportion of soluble sodium in the soil solution, along with a decrease in the other cations, which can promote a nutritional imbalance through reduced absorption of calcium, magnesium, and potassium by plants (PESSOA et al., 2010). In this context, Na⁺ can promote dispersion of soil colloids and cause movement of clay along the profile, which accumulates and clogs the porous space, hampering the availability of air, water, and nutrients to plants (FREIRE et al., 2003).

CONCLUSIONS

The salinity of the water used for irrigation, regardless of its cationic composition, negatively affects the 'BRS Energia' castor bean yield.

In the reproductive stage, 'BRS Energia' castor bean is more sensitive to the salinity of water containing potassium than to that of water containing

other cations.

The mass of seeds in the primary raceme of 'BRS Energia' castor bean is the most sensitive variable to water salinity and cationic composition.

The adopted leaching fraction (0.10) is not sufficient to avoid the accumulation of salts and exchangeable sodium in the soil caused by irrigation with water of an electrical conductivity of 4.5 dSm⁻¹.

Irrigation using water with the lowest salinity level (0.6 dSm⁻¹), despite the water containing a saline mixture, does not increase salinity (electrical conductivity of saturation extract) or the exchangeable sodium percentage to levels harmful to the soil and plants.

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