

Gas exchange and production of sunflower (*Helianthus annuus* L.) irrigated with water of different salinity, cationic nature and nitrogen doses

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Abstract

This study aimed to evaluate the gas exchanges and production components of sunflower, cv. BRS 324, as a function of irrigation with water of different salinity levels and cationic nature associated with doses of nitrogen (N). The study was conducted in pots adapted as lysimeters, under field conditions, in an eutrophic Grey Argisol of sandy loam texture. The experimental design was randomized blocks, in 5 x 5 factorial scheme, with three replicates, corresponding to five combinations of water salinity and cationic nature - S (S₁- Control; S₂- NaCl; S₃- CaCl₂; S₄ - KCl and S₅ - NaCl+CaCl₂+MgCl₂) and five N doses (50; 75; 100; 125 and 150 mg of N kg⁻¹ of soil). Irrigation was applied using water with electrical conductivity - EC_w of 0.5 dS m⁻¹ for the control (S₁) and 5.0 dS m⁻¹ for the other treatments (S₂; S₃; S₄ and S₅). Gas exchange through stomatal conductance, transpiration, CO₂ assimilation rate, internal CO₂ concentration and intrinsic water use efficiency were evaluated and the production components were determined by the internal diameter of the capitulum, the phytomass of the capitulum with achenes and dry matter of the capitulum. The gas exchange of sunflower cv. BRS 324 were significantly influenced, being the biggest decrease due to the variation in the EC_w when compared with the cationic nature of irrigation water. Among the evaluated cations, potassium promoted the highest value of stomatal conductance and CO₂ assimilation rate. Irrigation with saline water negatively affected the production components of sunflower, regardless of the cation present in the irrigation water.

Keywords: *Helianthus annuus* L., salt stress, water quality, nitrogen.

Abbreviations: A_CO₂ assimilation rate; AW_available water; C_i internal CO₂ concentration; DAS_ days after sowing; E_transpiration; EC_w electrical conductivity of water; EICI_ instantaneous carboxylation efficiency; g_s stomatal conductance; ICD_internal capitulum diameter; PCA_Phytomass of capitulum with achenes;; DP_ phytomass of the capitulum; pH_{SP} - pH of the saturated paste; EC_{se} - electrical conductivity of the saturation extract.

Introduction

Sunflower (*Helianthus annuus* L.) is an annual dicotyledon plant from the Asteraceae family and the most important cultivated species from the commercial point of view in the genus *Helianthus*, which comprises 49 species and 19 subspecies, all native to the Americas (Souza, 2010).

Sunflower cultivation has called the interest of farmers, technicians and companies due to the possibility of using its oil as raw material for biodiesel production (Backes et al., 2008). Additionally, sunflower is an excellent alternative not only for biodiesel production, but also for a diversity of applications in different areas, such as production of fodder, silage, oil for human consumption, floriculture and animal feed (Pereira et al., 2008). The oil extracted from its seeds can also be used in the industry of cosmetics,

pharmaceuticals, manufacturing of soaps, among various other purposes.

Despite the importance of sunflower in the most varied agroindustrial sectors and its adaptation to the various types of soil and climate in Brazil, the success of its cultivation in semi-arid areas, like many other crops, is conditioned to the use of the technology of irrigation (Oliveira et al., 2010). Thus, the use of irrigation is the only alternative to make agricultural exploitation viable in this region, but most available waters contain relatively moderate contents of salts, which frequently reach electrical conductivity of 5.0 dS m⁻¹ (Cavalcanti et al., 2005). Thus, the use of these water sources with high concentration of salts (especially Na⁺) in agriculture compromises the quality of harvested product and of the soil. As a consequence of this process, there is a loss of

the productive capacity of the soils and large socioeconomic damages (Neves et al., 2009).

One of the main factors that limit plant growth and yield is salinity, and this limitation is due to the fact that, under saline conditions, there is a reduction in the availability of water to the plants, because of the decrease in the osmotic potential of the soil solution and, therefore, plants tend to spend more energy to absorb water and nutrients (Leonardo et al., 2003). In addition, salinity can cause nutritional imbalance due to the excess of sodium in the soil solution, leading to disorder in the absorption of nutrients, particularly affecting the contents of Ca, Mg and K in the plant (Wanderley et al., 2010).

In order to minimize the effects of salinity on sunflower growth and yield, various strategies have been studied, particularly the use of nitrogen (N) fertilizers (Biscaro et al., 2008; Nobre et al., 2010; Nobre et al., 2011). Since N is a macronutrient required in large amount by the agricultural crops, it is among the main management techniques (Miller & Cramer, 2004) because of its participation in the formation of protein, amino acids and other compounds important for plant metabolism (Barhoumi et al., 2010). Besides this N reduces the deleterious effects of the stress, which can lead to an increase in the tolerance of plant to salinity.

Although there are studies on the sunflower crop irrigated with saline waters and nitrogen fertilization but studies on the use of waters of distinct cationic nature associated to fertilization with nitrogen are still incipient. Thus, it is imperative to develop new studies that explore the effects of the different types of cations present in the irrigation water in order to identify the cation and the dose of N that cause less damage to the physiological and productive aspects of the sunflower to make possible the cultivation of this oilseed crop in the northeast of Brazil.

In this context, this study aimed to evaluate the gas exchanges and production components of sunflower, cv. BRS 324, as a function of irrigation water salinity associated with cationic nature and N doses.

Results and Discussion

Effect of salinity and the cationic nature of irrigation water and nitrogen doses on physiology of sunflower

According to the summary of the analysis of variance shown in Table 1, there was significant influence of the factor salinity (S) on the variables stomatal conductance (g_s) and CO_2 assimilation rate (A). For the factor N doses (ND) and for the interaction between factors (S x ND), there was no significant ($p > 0.05$) effect on any of the studied variables, indicating that the plants exhibited similar behavior when subjected to the different N doses. Sousa et al. (2012a), evaluating the gas exchange in jatropha irrigated with saline water prepared with NaCl (ECw: 0.6 and 2.4 $dS\ m^{-1}$), also verified that there was no significant difference on transpiration and internal CO_2 concentration.

For the data of g_s at 56 DAS, based on the comparison of means (Fig 1A), there was significant difference between the treatments; plants irrigated with water S_1 (Control - ECw of 0.5 $dS\ m^{-1}$) were statistically superior to those in the other treatments irrigated using water with cationic nature of Na^+ , Ca^{2+} and $Na^+Ca^{2+}Mg^{2+}$ (S_2 ; S_3 and S_5 , respectively), except for plants irrigated with water containing K^+ (S_4) in its composition. However, comparing the means obtained in the different treatments, it is noted that plants subjected to irrigation using waters S_2 , S_3 and S_4 (Na^+ , Ca^{2+} and K^+ , respectively) did not differ statistically. The lowest value of

g_s occurred for irrigation water composed of $Na^+Ca^{2+}Mg^{2+}$ (S_5); however, it did not differ from the treatments S_2 and S_3 (Na^+ and Ca^{2+} , respectively). The results of this study corroborate those found by Lima (2014), who studied the effects of salinity and cationic nature of the irrigation water (Na^+ ; Ca^{2+} ; Na^+Ca^{2+} ; K^+ and $Na^+Ca^{2+}Mg^{2+}$) on castor bean morphophysiology and production, and observed that plants irrigated with water of low salinity and plants irrigated with water containing K^+ in its composition showed higher stomatal conductance. Graciano et al. (2011) studying the photosynthetic capacity of peanut plants cv. BR 1 submitted to salt stress with water prepared by the addition of NaCl (ECw: 1.0 to 8.5 $dS\ m^{-1}$), also verified a reduction in stomatal conductance values.

According to Table 1, the summary of the analysis of variance for the contrasts of means referring to the stomatal conductance, there was significant effect for the contrast \hat{y}_1 (S_1 vs S_2 ; S_3 ; S_4 and S_5) at 56 DAS. Based on the estimate of the mean (Table 2), it is noted that sunflower plants subjected to the treatment S_1 , with lowest level of water salinity (0.5 $dS\ m^{-1}$), showed increment in g_s of 0.41 $mol\ H_2O\ m^{-2}\ s^{-1}$, in comparison to the treatments irrigated with water of different cationic nature (S_2 , S_3 , S_4 and S_5) with ECw of 5.0 $dS\ m^{-1}$. The negative effect on the g_s of plants in the treatments S_2 , S_3 , S_4 and S_5 results from the saline nature of the irrigation water, because the excess of salts that are present in the soil solution causes alteration in the osmotic potential, directly affecting water absorption by plants (Lima, 2014).

The closure of stomata may also be a consequence of the lower leaf water potential that these plants may present due to the salinity of the irrigation water to which they were submitted, as well as the reduction of the hydraulic conductivity of the roots. This fact exerts a detrimental effect on the stomatal opening process of plants, by increasing the resistance to CO_2 diffusion in the intercellular spaces or in the substomatic chamber, providing a reduction in the normal CO_2 flow towards the carboxylation site (Britto & Kronzucker, 2002; Flexas et al., 2008; Kusvuran, 2012). According to the test of comparison of means (Figure 1B), the CO_2 assimilation rate (A) was significantly influenced by the treatments with water of different ionic composition; at 56 DAS, plants irrigated with water S_1 (Control) showed higher CO_2 assimilation rate, in comparison to those irrigated using water with cationic nature of Na^+ , Ca^{2+} and $Na^+Ca^{2+}Mg^{2+}$ (S_2 ; S_3 and S_5 respectively); in comparison to the treatments irrigated with water containing K^+ (S_4) in its composition, there was no significant difference. However, when plants irrigated with water containing K^+ (S_4) were compared with those of the other treatments irrigated using water with cationic nature of Na^+ , Ca^{2+} and $Na^+Ca^{2+}Mg^{2+}$ (S_2 ; S_3 and S_5 , respectively) regarding A, there was no significant difference, thus pointing to a possible action similar to that of these salts on the CO_2 assimilation rate of sunflower plants.

Additionally, sunflower plants studied at 56 DAS under irrigation with water of the treatments S_1 and S_4 (Figure 1B) stood out with the highest CO_2 assimilation rates (21.48 and 14.57 $\mu mol\ m^{-2}\ s^{-1}$, respectively). In relation to the other treatments (S_2 ; S_3 and S_5), the CO_2 assimilation rates followed the same trend of the stomatal conductance observed in Figure 1A. Although plants were subjected to the stress caused by the salts present in the irrigation water, according to Taiz & Zeiger (2013), the values of A obtained are satisfactory, because sunflower is a C_3 plant and the CO_2 assimilation rates of these plants vary between 10 and 20 $\mu mol\ m^{-2}\ s^{-1}$.

Table 1. Summary of the analysis of variance for stomatal conductance (g_s), internal CO₂ concentration (C_i), transpiration (E), CO₂ assimilation rate (A) and intrinsic water use efficiency (WUE) of sunflower, cv. BRS 324, at 56 days after emergence, cultivated under different types of salinity and nitrogen doses.

| Source of variation/Contrasts | DF | Mean square | | | | |
|-------------------------------------|----|----------------------|--------------------------|------------------------|------------------------|----------------------|
| | | g_s^1 | C_i^1 | E^1 | A^1 | WUE ¹ |
| Blocks | 2 | 0.1398 ^{ns} | 34228.9881* | 105.5749 ^{ns} | 800.6651** | 11.2901* |
| Cationic composition of water (CCW) | 4 | 0.7160** | 14544.6018 ^{ns} | 31.9594 ^{ns} | 286.8949* | 2.0092 ^{ns} |
| \hat{y}_1 | 1 | 2.0295** | 37862.6242 ^{ns} | 24.8601 ^{ns} | 993.3196* | 3.4397 ^{ns} |
| \hat{y}_2 | 1 | 0.0011 ^{ns} | 16661.6333 ^{ns} | 0.2707 ^{ns} | 10.0688 ^{ns} | 0.1370 ^{ns} |
| \hat{y}_3 | 1 | 0.4440 ^{ns} | 187.5000 ^{ns} | 3.8664 ^{ns} | 19.2800 ^{ns} | 0.0456 ^{ns} |
| \hat{y}_4 | 1 | 0.8046 ^{ns} | 3618.0500 ^{ns} | 0.7119 ^{ns} | 95.7031 ^{ns} | 0.5401 ^{ns} |
| Nitrogen doses (DN) | 4 | 0.1270 ^{ns} | 8025.1895 ^{ns} | 51.5535 ^{ns} | 113.8312 ^{ns} | 2.5606 ^{ns} |
| Interaction (CCW x DN) | 16 | 0.0883 ^{ns} | 6792.0260 ^{ns} | 48.6879 ^{ns} | 36.7252 ^{ns} | 1.9059 ^{ns} |
| Residual | 48 | 0.0851 | 6484.6236 | 39.9069 | 46.5103 | 1.2581 |
| CV. | | 16.57 | 18.42 | 18.34 | 14.88 | 19.93 |

¹= Control; S₂= NaCl; S₃= CaCl₂; S₄=KCl; S₅=NaCl+CaCl₂+MgCl₂; \hat{y}_1 (S₁ vs S₂; S₃; S₄; S₅); \hat{y}_2 (S₂ vs S₃); \hat{y}_3 (S₂ vs S₄); \hat{y}_4 (S₅ vs S₂; S₃; S₄); DF - Degrees of freedom; CV - Coefficient of variation; (*) and (**) Significant at 0.05 and 0.01 probability levels; (ns) Not significant; (¹) data transformed to \sqrt{x} .

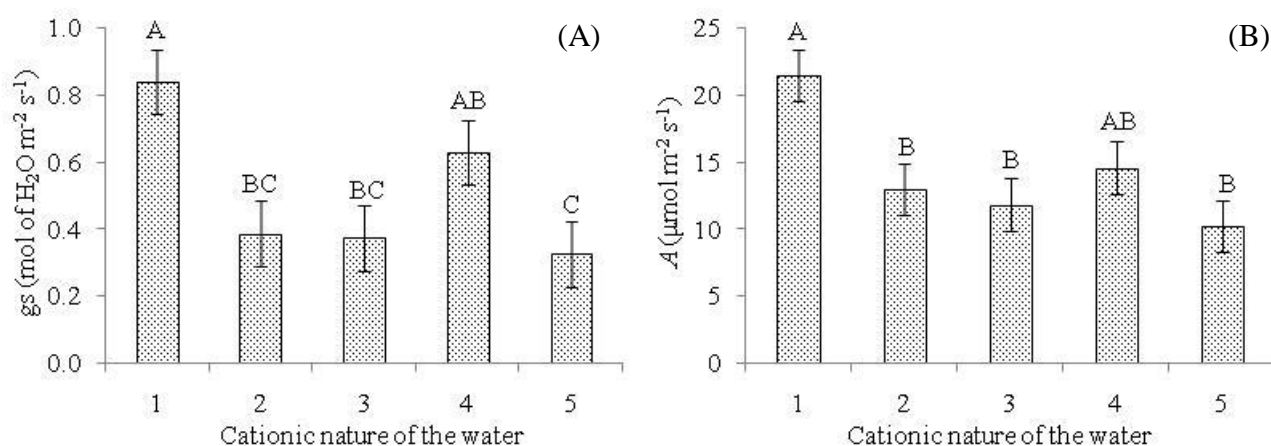


Fig 1. Stomatal conductance (g_s) (A) and CO₂assimilation rate (A) (B)of sunflower, cv. BRS 324, as a function of the salinity and cationic nature of the irrigation water at 56 DAS. 1= Control; 2= NaCl; 3= CaCl₂; 4=KCl; 5=NaCl+CaCl₂+MgCl₂; Means followed by different letters indicate that the treatments differ by Tukey test, $p < 0.05$. Bars represent the standard error of the mean ($n=3$).

Table 2. Estimate of mean for stomatal conductance (g_s), internal CO₂concentration (C_i), transpiration (E), CO₂assimilation rate (A) and intrinsic water use efficiency (WUE) at 56 days after emergence of sunflower, cv. BRS 324, cultivated under different types of salinity and nitrogen doses.

| Source of variation | Estimation of mean | | | | |
|---------------------|--------------------|-------|-----|------|-----|
| | g_s | C_i | E | A | WUE |
| \hat{y}_1 | 0.41 | ns | ns | 9.09 | ns |
| \hat{y}_2 | ns | ns | ns | ns | ns |
| \hat{y}_3 | ns | ns | ns | ns | ns |
| \hat{y}_4 | ns | ns | ns | ns | ns |

\hat{y}_1 (S₁ vs S₂; S₃; S₄; S₅); \hat{y}_2 (S₂ vs S₃); \hat{y}_3 (S₂ vs S₄); \hat{y}_4 (S₅ vs S₂; S₃; S₄); (ns) not significant; S₁= Control; S₂= NaCl; S₃= CaCl₂; S₄=KCl; S₅=NaCl+CaCl₂+MgCl₂.

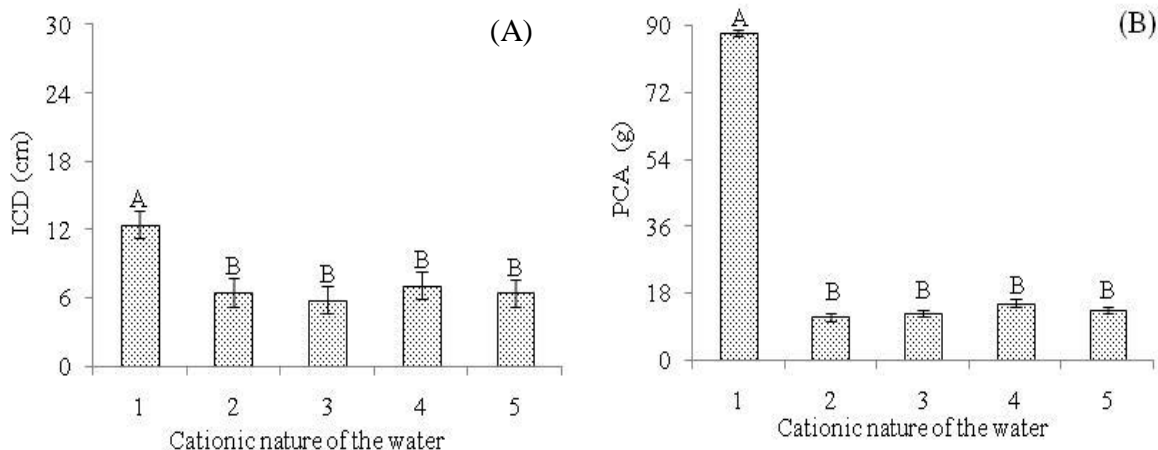


Fig 2. Internal capitulum diameter - ICD (A) and phytomass of the capitulum with achenes - PCA (B) of sunflower, cv. BRS 324, as a function of the salinity and cationic nature of the water. 1= Control; 2= NaCl; 3= CaCl₂; 4=KCl; 5=NaCl+CaCl₂+MgCl₂; Means followed by different letters indicate that the treatments differ by Tukey test, p<0.05. Bars represent the standard error of the mean (n=3).

Table 3. Summary of the analysis of variance for internal capitulum diameter (ICD), phytomass of the capitulum with achenes (PCA) and dry phytomass of the capitulum (DPC) of sunflower plants, cv. BRS 324, cultivated under different types of salinity and nitrogen doses.

| Source of variation/Contrasts | DF | Mean square | | |
|-------------------------------------|----|------------------------|--------------------------|-------------------------|
| | | ICD | PCA ¹ | DPC ¹ |
| Blocks | 2 | 0.4139 ^{ns} | 131.3436 ^{ns} | 4.7315 ^{ns} |
| Cationic composition of water (CCW) | 4 | 111.0963 ^{**} | 16829.0241 ^{**} | 2329.8434 ^{**} |
| \hat{y}_1 | 1 | 432.0000 ^{**} | 67199.7346 ^{**} | 9291.8248 ^{**} |
| \hat{y}_2 | 1 | 3.4171 ^{ns} | 7.6507 ^{ns} | 1.0982 ^{ns} |
| \hat{y}_3 | 1 | 2.7755 ^{ns} | 107.1819 ^{ns} | 24.7611 ^{ns} |
| \hat{y}_4 | 1 | 8.2347 ^{ns} | 87.7246 ^{ns} | 23.0087 ^{ns} |
| Nitrogen doses (DN) | 4 | 1.2385 ^{ns} | 252.7004 ^{ns} | 51.2775 ^{ns} |
| Interaction (CCW x DN) | 16 | 2.5822 ^{ns} | 107.1088 ^{ns} | 45.4336 [*] |
| Residual | 48 | 1.6834 | 165.1254 | 21.7788 |
| CV. | | 16.94 | 25.54 | 21.09 |

S₁= Control; S₂= NaCl; S₃= CaCl₂; S₄=KCl; S₅=NaCl+CaCl₂+MgCl₂; \hat{y}_1 (S₁ vs S₂; S₃; S₄; S₅); \hat{y}_2 (S₂ vs S₃); \hat{y}_3 (S₂ vs S₄); \hat{y}_4 (S₃ vs S₂; S₃; S₄); DF - Degrees of freedom; CV - Coefficient of variation; Significant at 0.05 (*) and at 0.01(**) probability levels; (ns) Not significant; (1) data transformed to \sqrt{x} .

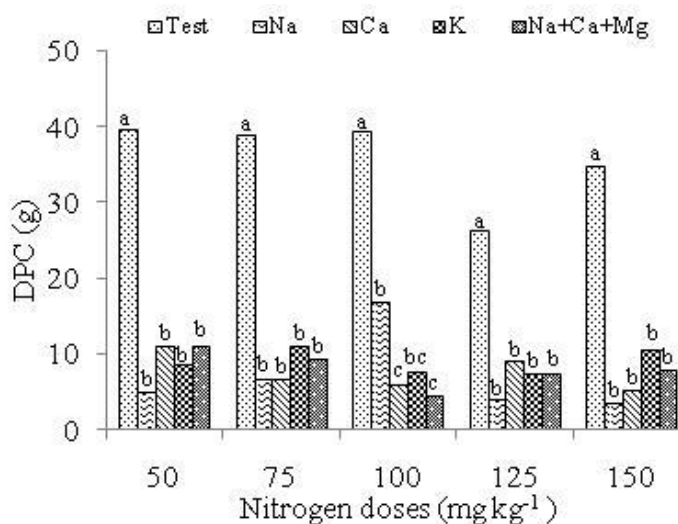


Fig 3. Dry phytomass of the capitulum - DPC of sunflower, cv. BRS 324, as a function of the salinity and cationic nature of the water and nitrogen doses. 1= Control; 2= NaCl; 3= CaCl₂; 4=KCl; 5=NaCl+CaCl₂+MgCl₂; Means followed by different letters indicate that the treatments differed by Tukey test, p<0.05.

Table 4. Estimate of mean for internal capitulum diameter (ICD), phytomass of the capitulum with achenes (PCA) and dry phytomass of the capitulum (DPC) of sunflower plants, cv. BRS 324, cultivated under different types of salinity and nitrogen doses.

| Source of variation | Estimation of mean | | |
|---------------------|--------------------|-------|-------|
| | DCI | FCA | FSCa |
| \hat{y}_1 | 6.00 | 74.83 | 27.82 |
| \hat{y}_2 | ns | ns | ns |
| \hat{y}_3 | ns | ns | ns |
| \hat{y}_4 | ns | ns | ns |

\hat{y}_1 (S₁ vs S₂; S₃; S₄; S₅); \hat{y}_2 (S₂ vs S₃); \hat{y}_3 (S₂ vs S₄); \hat{y}_4 (S₅ vs S₂; S₃; S₄); (ns) not significant; S₁= Control; S₂= NaCl; S₃= CaCl₂; S₄=KCl; S₅=NaCl+CaCl₂+MgCl₂

Table 5. Physical and chemical characteristics of the soil used in the experiment.

| 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) |
| 1.14 | 57.93 | 14.00 | 4.87 | 9.13 | 1.52 | 1.95 | 0.38 | 0.07 | 4.84 | 0.20 |

Ca²⁺ and Mg²⁺ extracted with 1 mol L⁻¹ KCl at pH 7.0; Na⁺ and K⁺ extracted with 1 mol L⁻¹ NH₄OAc at pH 7.0; pH_{sp} - pH of the saturation paste; EC_{se} - electrical conductivity of the saturation extract

Table 2 shows the contrasts of means for the CO₂ assimilation rate (A) at 56 DAS. There was significant effect only for the contrast \hat{y}_1 (S₁ vs S₂; S₃; S₄ and S₅) through the estimate of mean presented in Table 2. It is noted that plants subjected to the treatment S₁(control - EC_w of 0.5 dS m⁻¹) increased the rate of A by 9.09 μmol m⁻² s⁻¹ in relation to plants cultivated under irrigation with water of different ionic composition, S₂; S₃; S₄ and S₅ (Na⁺; Ca²⁺; K⁺ and Na⁺+Ca²⁺+Mg²⁺) and EC_w of 5.0 dS m⁻¹. The high saline concentration of the irrigation water causes reduction in the water potential of the soil and, as a consequence, the stomata close, thus reflecting in low CO₂ assimilation rate (Gurgel et al., 2003). This decline in the CO₂ assimilation rate of sunflower plants is also related to the damage in the photosynthetic apparatus and/or in the enzymatic system of CO₂ fixation (Kurban et al., 1999), due to the irrigation with water of different cationic nature and by the variation in EC_w levels. Similar results were also verified in cotton (Meloni et al., 2003) and jatropa (Sousa et al., 2012b).

Effect of salinity and the cationic nature of irrigation water and nitrogen doses on production components of sunflower

According to Table 3, which shows the results of the analysis of variance for the internal capitulum diameter (ICD), phytomass of the capitulum with achenes (PCA) and dry phytomass of the capitulum (DPC) of sunflower, there was significant effect of the types of water salinity (S) on all studied variables. For the factor N doses (ND), there was no significant influence for any of the studied variables, while the interaction (S x ND) showed to significance only for the dry phytomass of the capitulum (DPC). Nobre et al. (2011) evaluating the production of sunflower cv. Embrapa 122 / V-2000 cultivated under different irrigation water salinity levels (EC_w: 0.5 to 4.9 dS m⁻¹, prepared with addition of NaCl) and nitrogen fertilization rates, also observed no interaction between these factors for any production variable evaluated. Based on Fig2A, the internal capitulum diameter (ICD) differed statistically. According to the test of comparison of means, in plants irrigated with water S₁(Control), the ICD was significantly superior to that obtained by plants irrigated with waters of different cationic nature, S₂, S₃, S₄ and S₅, with reductions in the capitulum diameter of 47.89, 53.31, 43.01 and 48.42%, respectively.

According to the summary of the analysis of the contrasts of means for the variable ICD (Table 3), there was significant effect for the contrast \hat{y}_1 (S₁ vs S₂; S₃; S₄ and S₅) and, based on

the estimate of mean (Table 4), plants irrigated in the treatment S₁, with lowest level of water salinity (EC_w of 0.5 dS m⁻¹), showed superior ICD, with mean of 6.0 cm higher in relation to the plants that received water of different cationic nature, Na⁺; Ca²⁺; K⁺ and Na⁺+Ca²⁺+Mg²⁺ (S₂; S₃; S₄ and S₅, respectively) with EC_w of 5.0 dS m⁻¹. For ICD, in the other contrasts of mean, \hat{y}_2 (S₂ versus S₃), \hat{y}_3 (S₂ versus S₄) and \hat{y}_4 (S₅ versus S₂; S₃; S₄), there was no significant effect. Excess of salts in water, independently of their cationic nature, cause damage to various physiological and biochemical processes such as respiration, photosynthesis, protein synthesis and lipid metabolism, and may also lead the plant to a state of water stress with loss of water to the external environment and to suffer from toxicity, which will result in serious damage to the growth and production of plants (Esteves & Suzuki, 2008). Corroborating with the results obtained Nobre et al. (2011) found that the effect of irrigation with water of different saline levels and nitrogen rates on sunflower growth and flowering, decreased both internal and external diameter of capitulum. According to Figure 2B, the phytomass of the capitulum with achenes (PCA) of the plants differed significantly due to the use of water with different cationic nature, and the highest value (88.03 g) was obtained using water of the treatment S₁ (control). However, plants irrigated with water of the treatments S₂, S₃, S₄ and S₅ obtained PCA of 11.51, 12.52, 15.29 and 13.46 g, respectively, i.e., reductions of 86.92, 85.77, 82.62 and 84.70%, in comparison to the control (S₁). Based on the summary of the analysis of variance and the contrasts of means (Table 3) referring to the PCA, there was significant effect for the contrast \hat{y}_1 (S₁ vs S₂; S₃; S₄ and S₅). According to the estimate of mean referring to the PCA (Table 4), sunflower plants subjected to the treatment S₁, i.e. irrigated with water of lowest salinity level (0.5 dS m⁻¹), were superior to those under irrigation with waters of different types of cationic nature, Na⁺; Ca²⁺; K⁺ and Na⁺+Ca²⁺+Mg²⁺ (S₂; S₃; S₄ and S₅, respectively), and EC_w of 5.0 dS m⁻¹, showing a mean increment of 74.83 g in the PCA. According to Lima (2014), the effect caused by salt stress of the irrigation water is more associated with the irrigation water EC_w than with the cationic nature. The decline in sunflower PCA as a function of water salinity can also be attributed to the osmotic stress caused by the reduction of external water potential and the ionic effect caused by the accumulation of ions in plant tissues (Munns & Tester, 2008), causing a reduction in the photosynthetic rate and energy deviation destined for the activation and maintenance of plant metabolic activity (Munns et al., 2002). Marengo Centeno et

al. (2014), studying the effect of irrigation water salinity and nitrogen fertilization on the production of sunflower, cv. Embrapa 122-V2000, and evaluating the influence of irrigation with saline water with ECw from 0.7 to 4.7 dS m⁻¹, observed the highest phytomass of the capitulum (130.24 g) in plants under ECw of 0.7 dS m⁻¹, while the lowest value (51.28 g) occurred in plants subjected to ECw of 4.7 dS m⁻¹, indicating a reduction of 60.63%. For dry phytomass of the capitulum - DPC (Figure 3) and based on the interaction between the cationic nature of the water and N doses, the highest values of PCA were obtained in plants irrigated by the treatment S₁ (Control) at all N doses, significantly differing from the other plants irrigated with water of different cationic nature, Na⁺, Ca²⁺, K⁺ and Na⁺+Ca²⁺+Mg²⁺ (S₂; S₃; S₄ and S₅, respectively). Also based on Figure 3, there was a significant effect between the waters of different cationic nature, in the treatments receiving 100 mg of N kg⁻¹ of soil, in which plants irrigated with waters containing Na⁺ (S₂) differed statistically from those that received waters containing Ca²⁺ and Na⁺+Ca²⁺+Mg²⁺ (S₃ and S₅, respectively). For the treatment S₄, which had K⁺ in the composition, there was no difference. Comparatively, according to the data in Figure 3, there was an expressive reduction in the dry phytomass of the capitulum in sunflower plants when subjected to irrigation using water containing NaCl; CaCl₂; KCl; NaCl+CaCl₂+MgCl₂, in relation to the result of the control treatment (S₁). Based on the results for dry phytomass of the capitulum, it is inferred that the effect of salinity on sunflower plants, cv. BRS 324, is more related to the variation of ECw than to the cationic nature of the irrigation water. The decrease in DPC (Figure 3), observed in the present study, reflects the negative effect of both the osmotic and ionic components in the salt stress.

Based on the summary of the analysis of variance for the contrasts of means for DPC (Table 3), there was significant effect for the contrast $\hat{y}_1(S_1 \text{ vs } S_2; S_3; S_4 \text{ and } S_5)$. According to Table 4, referring to the estimate of the mean for DPC, there was a greater increment (27.82 g) in DPC in the plants subjected to treatment S₁, lowest level of water salinity (0.5 dS m⁻¹), in comparison to plants irrigated by the treatments S₂, S₃, S₄ and S₅, using water with ECw of 5.0 dS m⁻¹. Such decrease in DPC is attributed to the osmotic effect of the dissolved salts, which reduce the osmotic potential of the soil solution and inhibit the movement of water to the cells, characterizing the water stress, besides the possibility of occurrence of ionic toxicity, nutritional imbalance, or both, due to the excessive accumulation of certain ions in the plant tissues (Flowers, 2004). In an experiment conducted in greenhouse with the sunflower cultivar Embrapa 122/V-2000 irrigated with waters of different salinity levels (0.5 to 4.9 dS m⁻¹), Nobre et al. (2011) observed that the production of achenes was negatively affected by the increase in the electrical conductivity of the irrigation water.

Materials and Methods

Localization, experimental procedure, treatments and plant material

The experiment was carried out from November 2014 to January 2015, in pots adapted as lysimeters under field conditions in the experimental area of the Center of Technology and Natural Resources of the Federal University of Campina Grande (CTRN/UFCG), in the municipality of Campina Grande-PB, Brazil, situated at the local geographic coordinates of 07°15'18" S, 35°52'28" W and mean altitude of 532 m.

The experimental design consisted of randomized blocks, arranged in a 5 x 5 factorial scheme, with three replicates, corresponding to five combinations of water salinity and cationic nature - S (S₁- Control; S₂ - NaCl; S₃ - CaCl₂; S₄ - KCl and S₅ - NaCl+CaCl₂+MgCl₂), in which the ECw used in irrigation was 0.5 dS m⁻¹ for the control treatment, and 5.0 dS m⁻¹, for the other treatments, prepared with different sources of salts according to treatment, in the form of chloride, and five N doses - N [50; 75; 100; 125 and 150 mg of N kg⁻¹ of soil, based on the recommendation of Novais et al. (1991)], thus totaling 75 experimental plots, each composed of 1 (one) plant. The ECw level of 5.0 dS m⁻¹ was used to maintain the sunflower plants in an iso-osmotic condition with respect to different cations in the irrigation water. While the lowest level of ECw (0.5 dS m⁻¹) was used as an absolute control in order to verify the effects of saline stress under low and high water salinity conditions.

The different waters used in irrigation were obtained by dissolving different salts, in the water from the local supply, sodium chloride (NaCl), calcium chloride (CaCl₂.2H₂O), potassium chloride (KCl) and magnesium chloride (MgCl₂.6H₂O) according to the pre-established treatments, whose amount was determined based on the empirical relationship between the concentration of salts and the electrical conductivity of the water (Richards, 1954). After the waters were prepared, a portable conductivity meter was used to calibrate the ECw; the respective waters were stored in plastic barrels.

This study used seeds of the sunflower cultivar BRS 324, precocious variety with cycle of approximately 100 days, oil content in the seeds varying from 45 to 49% and mean yield of 1,500 kg ha⁻¹ (EMBRAPA, 2013).

Establishment and management of the experiment

Plants were cultivated in pots adapted as lysimeters with capacity for 100 L, filled with a 2.0-kg layer of crushed stone (<1 cm), followed by 100 kg of soil material (sandy clay loam), properly pounded to break up clods, classified as eutrophic Grey Argisol, from the district of São José da Mata (Campina Grande-PB), whose physico-chemical characteristics (Table 5) were determined using the methodology of Claessen (1997).

At the bottom of the lysimeters, there was a 4-mm-diameter drain to allow drainage; the upper tip of the drain was involved in a nonwoven geotextile (Bidim OP 30) to avoid obstruction by the soil material and, below the drain, a plastic bottle was placed to collect the drained water, in order to estimate crop water consumption.

Sowing was performed on November 2, 2014, by planting 10 seeds equidistantly, at the depth 0.04 m. At 18 days after sowing (DAS), the first thinning was performed, leaving only three plants per plot, i.e., those with best vigor and, at 34 DAS, a new thinning was performed to leave only one plant per pot.

Phosphate, potassium and nitrogen fertilization was based on the recommendation of Novais et al. (1991). Phosphorus was applied in three intervals, 2/3 as basal dose, corresponding to 125 g of single superphosphate, and 1/3 divided into 2 equal applications via fertigation, corresponding to 9.62 g of monoammonium phosphate, at 10 and 20 days after emergence (DAE). Potassium fertilization, along with the nitrogen, was applied as top-dressing via fertigation divided into 3 applications in intervals of 10 days, from 10 DAE on. Each application used 8.62 g of potassium chloride and the treatment N₃ (100 mg of N kg⁻¹ of soil) used 4.85 g of urea. It should be highlighted that the first 2

applications aimed to complement the N supplied by the MAP and 7.41 g of urea in the last application, following the pre-established treatments.

The soil was maintained at field capacity through daily irrigations, the volume to be applied was based on the water consumption obtained through difference between the volume applied and drained in the previous irrigation, plus a leaching fraction of 0.10 (Lima, 2014).

Traits measured

At 56 DAS, the physiological parameters of the sunflower were evaluated through the determination of stomatal conductance (g_s) ($\text{mol of H}_2\text{O m}^{-2} \text{ s}^{-1}$), transpiration (E) ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$), CO_2 assimilation rate (A) ($\mu\text{mol m}^{-2} \text{ s}^{-1}$) and internal CO_2 concentration (C_i) ($\mu\text{mol m}^{-2} \text{ s}^{-1}$) in the third leaf counted from the apex, using a portable device for analyses of gas exchanges through infrared (IRGA), ("LCPro+", ADC BioScientific Ltda.). These data were used to quantify the water use efficiency (WUE) (A/E) [$(\mu\text{mol m}^{-2} \text{ s}^{-1}) / (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$] (Konrad et al., 2005; Melo et al., 2009).

The internal capitulum diameter (ICD) was evaluated by measuring, with a millimetric ruler, the horizontal and vertical diameters to obtain the arithmetic mean. For the variables phytomass of the capitulum with achenes (PCA) and dry phytomass of the capitulum (DPC), the material was stored in paper bags and dried in a forced-air oven maintained at 65 °C until constant weight. The material was weighed on a precision scale (0.01 g).

Statistical analysis

The obtained data were subjected to analysis of variance through the F test; when significant, orthogonal contrasts and test of comparison of means (Tukey at 0.05 probability level) was used for the factor "cationic nature of the water" and for the contrasts between the means of the treatments, regression analysis for the "N doses", the statistical software SISVAR-ESAL (Ferreira, 2011) was used. The contrasts were defined as follows: \hat{y}_1 (S_1 vs S_2 ; S_3 ; S_4 ; S_5); \hat{y}_2 (S_2 vs S_3); \hat{y}_3 (S_2 vs S_4); \hat{y}_4 (S_5 vs S_2 ; S_3 ; S_4).

Conclusion

The cationic nature of the irrigation water causes negative effects on gas exchanges, especially on stomatal conductance and CO_2 assimilation rate, of the sunflower cv. BRS 324, at 56 DAS; Among the evaluated cations, potassium promotes the highest values of stomatal conductance and CO_2 assimilation rate of the sunflower cv. BRS 324, at 56 DAS; Irrigation water salinity negatively affects the production components of the sunflower cv. BRS 324, regardless of the cation present in the irrigation water.

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