

PHYSIOLOGICAL INDICES AND PRODUCTION OF SESAME UNDER SALT STRESS AND NITRATE/AMMONIUM PROPORTIONS

ÍNDICES FISIOLÓGICOS E PRODUÇÃO DO GERGELIM SOB ESTRESSE SALINO E PROPORÇÕES DE NITRATO E AMÔNIO

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ABSTRACT: In semi-arid regions, the occurrence of water with high concentration of salts is common, which compromises the growth and consequently the production of crops. Thus, this study aimed to evaluate the gas exchanges and production of sesame, cv. CNPA G3, irrigated with saline water and fertilized with different proportions of nitrate and ammonium, in an experiment conducted using lysimeters in a greenhouse in the municipality of Campina Grande-PB, Brazil. The treatments were arranged in randomized blocks and analyzed in a 5 x 5 factorial scheme, with three replicates, relative to five levels of electrical conductivity of the irrigation water – EC_w (0.6, 1.2, 1.8, 2.4 and 3.0 dS m⁻¹) and five proportions of nitrate/ammonium - NO₃⁻/NH₄⁺ (200/0, 150/50, 100/100, 50/150 and 0/200 mg of N kg⁻¹ of soil). Irrigation with water of salinity level higher than 0.6 dS m⁻¹ promoted negative effect on gas exchanges and production components of the sesame cv. CNPA G3. Fertilization with N exclusively in the form of NH₄⁺ promoted increment in CO₂ concentration and reduction in its assimilation rate and instantaneous carboxylation efficiency. The highest rate of CO₂ assimilation, transpiration and instantaneous carboxylation efficiency were obtained when the plants were irrigated with water of 0.6 dS m⁻¹ and fertilization with 200/0 of NO₃⁻/NH₄⁺. Increasing levels of water salinity promoted a decrease in the total seed mass, regardless of the proportion of NO₃⁻/NH₄⁺. The sesame cv. CNPA G3 is classified as sensitive to salt stress from the electrical conductivity of water of 0.6 dS m⁻¹.

KEYWORDS: *Sesamum indicum* L. CNPA G3. Water scarcity. Nitrogen.

INTRODUCTION

Sesame (*Sesamum indicum* L.) occupies the ninth position among the most cultivated oilseed crops in the world and is exploited in 69 countries, with global production estimated at 3.5 million tons of grains (SILVA et al., 2011). From the industrial point of view, its seeds can be used fresh or for the extraction of oil, commonly used in energetic and pharmaceutical products, acting as protein source, in both direct consumption and enrichment of products, and standing out as a good option of cultivation for the Northeastern semi-arid region (BEZERRA et al., 2010).

In this region, the occurrence of water with high concentration of salts is common, which constitutes one of the abiotic stress factors that most limit plant growth and development (FREIRE et al., 2014), because the excess of salts promotes reduction in the osmotic potential of the soil solution, decreasing the availability of water to plants and possibly causing stomatal closure, limiting stomatal conductance and transpiration,

which reduces the photosynthetic rate (SILVA et al., 2010) and consequently the production. However, the use of these types of water depend on the tolerance of the crops to salinity and management practices of irrigation and fertilization, especially nitrogen (N) fertilization. Hence, one way to minimize the scarcity of water resources is associated with the possibility of using lower-quality water as an alternative source of water for agriculture (SOUSA et al., 2011).

Nitrogen fertilization stands out as an important management practice, because besides promoting plant growth it can reduce the deleterious effects of salt stress (SILVA et al., 2008; LIMA et al., 2012). In the soil, this element is found in different forms, and nitrate and ammonium are the two main mineral forms of N found in the soil. However, these different ionic forms cause complex effects on plant growth and metabolism (GUO et al., 2012) and may lead to beneficial or harmful physiological responses of the plants (BARTELHEIMER; POSCHLOD, 2013).

Thus, when N is supplied to crops exclusively as NO_3^- -N, it may result in decrease of dry matter production in plants with low capacity to reduce nitrate (ALI et al., 2007), whereas the assimilation of N in the ammoniacal form requires lower consumption of energy, due to its direct incorporation in the carbon chain, without the need of reduction by the enzymatic action, with energy expenditure, as occurs for NO_3^- (BITTSÁNSZKY et al., 2015), which may increase its use efficiency. However, high levels of ammonium in cell tissues can be toxic and cause negative effects, leading to physiological and nutritional disorders in the plants (HOLZSCHUH et al., 2011).

Cruz et al. (2008) evaluating the influence of three proportions of $\text{NO}_3^-/\text{NH}_4^+$ (12/0; 6/6 and 0/12 mM) on the gas exchange and the concentration of nitrogen compounds in cassava found that the application of NH_4^+ resulted in a highly detrimental effect on stomatal conductance. Lima et al. (2016), studying the effects of the fertilization with different proportions of $\text{NO}_3^-/\text{NH}_4^+$ on the cotton crop cv. BRS Topazio, concluded that the supply of NO_3^- and NH_4^+ in the proportion of 25/75 mg of N kg^{-1} of soil, promoted an increase in the growth variables (plant height, stem diameter and leaf area) and in the mass of cotton (cv. BRS Topazio) seed. Thus, knowledge of the adequate proportion of nitrate and ammonium can be an important tool to optimize the physiological responses and consequently the production of the crops.

In this context, the aim of this study was to evaluate the gas exchange and sesame production cv. CNPA G3 as a function of irrigation with waters of different salinities and fertilization with different proportions of nitrate and ammonium.

MATERIAL AND METHODS

The experiment was conducted in plastic recipients adapted as lysimeters under greenhouse conditions, at the Center of Technology and Natural Resources of the Federal University of Campina Grande (CTRN/UFCEG), located in the municipality of Campina Grande-PB, Brazil, at the geographic coordinates of 7°15'18" S, 35°52'28" W and mean altitude of 550 m.

The adopted experimental design was completely randomized blocks in 5 x 5 factorial scheme, with three replicates, in a total of 75 experimental units, in which the treatments resulted from a combination of five levels of electrical conductivity of the irrigation water - ECw (0.6, 1.2, 1.8, 2.4 and 3.0 dS m^{-1}) associated with five proportions of nitrate and ammoniacal nitrogen - $\text{NO}_3^-/\text{NH}_4^+$ (200/0, 150/50, 100/100, 50/150 and 0/200 mg N kg^{-1} of soil).

The different ECw levels were obtained through the dissolution of salts of NaCl, $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ in the water from the public supply system of Campina Grande-PB, maintaining a proportion equivalent to 7:2:1 of $\text{Na}^+:\text{Ca}^{2+}:\text{Mg}^{2+}$, which is found in most water sources used for irrigation in Northeast Brazil (MEDEIROS et al., 2003).

The experiment used recipients with capacity for 20 L, with a hole at the bottom to allow drainage, connected to a transparent drain with diameter of 4 mm. A plastic container was placed below each drain to collect the drained water to estimate water consumed by the plant. The lysimeters were filled with a 0.5-kg layer of crushed stone, followed by 24.5 kg of a Eutrophic Regolithic Neosol of sandy loam texture, whose chemical and physical characteristics are shown in Table 1.

Table 1. Chemical and physical characteristics* of the Eutrophic Regolithic Neosol, used in the experiment.

Chemical characteristics									
pH(H_2O) (1:2,5)	OM dag kg^{-1}	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	$\text{H}^+ + \text{Al}^{3+}$	ESP (%)	ECse (dS m^{-1})
6.24	10.79	48.00	0.28	1.82	7.41	5.23	3,07	11.38	2.50
Physical characteristics									
Size fraction (g kg^{-1})			Textural class	Water contente (kPa)		AW	Total porosity $\text{m}^3 \text{m}^{-3}$	AD	PD
Sand	Silt	Clay		33.42	1519.5				
656.6	175.0	168.4	SL	28.84	10.42	18.42	0.53	1.27	2.74

*Determined according to methodologies proposed by Claessen (1997); OM – Organic matter; Walkley-Black wet digestion; Ca^{2+} and Mg^{2+} extracted with 1 mol L^{-1} KCl at pH 7.0; Na^+ and K^+ extracted with 1 mol L^{-1} NH_4OAc at pH 7.0; ESP - Exchangeable sodium percentage; ECse – Electrical conductivity of the saturation extract; SL – Sandy loam; AW – Available water; AD - Apparent density; PD - Particle density.

Before sowing, an irrigation sufficient for the soil to achieve field capacity was applied, using water according to the treatments. After sowing, irrigation was daily performed in each lysimeter by applying water according to the treatments, to maintain soil moisture close to field capacity.

Fifteen seeds of sesame, cv. CNPA G3, were planted in each lysimeter and thinning was later performed in two steps, when plants showed at least two and three pairs of true leaves, at 20 and 30 days after sowing (DAS), respectively.

Potassium and phosphate fertilizations (100 and 300 mg kg⁻¹ of P₂O₅ and K₂O, respectively) were performed according to the recommendation (NOVAIS et al., 1991); the former was applied as basal dose, using single superphosphate as source, and the latter was divided into four applications, ¼ as basal application and ¾ in three equal applications at 15, 30 and 45 DAS, using potassium chloride as source. Calcium nitrate and ammonium chloride were used as sources of NO₃⁻ and NH₄⁺ nitrogen, respectively.

The doses of N (200 mg kg⁻¹ of soil) in the form of NO₃⁻/NH₄⁺ proportions were split into five equal applications in intervals of ten days, and the first one was applied at 15 DAS. In order to inhibit the nitrification of the ammoniacal N applied to the soil, a nitrification inhibitor, dicyandiamide (DCD), was used in each application of ammonium chloride, at the dose of 10% in relation to the total NH₄⁺-N.

The gas exchanges were determined during the fruiting stage, at 70 DAS, based on stomatal conductance (*g_s* - mol H₂O m⁻² s⁻¹), CO₂ assimilation rate (*A*) (µmol m⁻² s⁻¹), transpiration (*E*) (mmol of H₂O m⁻² s⁻¹) and internal CO₂ concentration (*C_i*) (µmol mol⁻¹), instantaneous water use efficiency (WUE) (*A/E*) [(µmol m⁻² s⁻¹) (mmol H₂O m⁻² s⁻¹)⁻¹] and instantaneous carboxylation efficiency (EICI), obtained by the *A/C_i* ratio.

Gas exchange variables were measured in intact leaves of the intermediate productive branches using a portable infrared CO₂ analyzer (IRGA), model LCPro+ Portable Photosynthesis System®.

The relative growth rates in plant height (RGRph) and stem diameter (RGRsd) were determined according to Eq. 1 and 2:

$$RGRph = \frac{(\ln PH_2 - \ln PH_1)}{(t_2 - t_1)} \quad (1)$$

$$RGRsd = \frac{(\ln SD_2 - \ln SD_1)}{(t_2 - t_1)} \quad (2)$$

where:

RGRph = relative growth rate in plant height (cm cm⁻¹ day⁻¹),

PH₁ = plant height (cm) at time t₁,

PH₂ = plant height (cm) at time t₂,

RGRsd = relative growth rate in stem diameter (mm mm⁻¹ day⁻¹),

SD₁ = stem diameter (mm) at time t₁,

SD₂ = stem diameter (mm) at time t₂.

The harvest index (HI) was calculated through the relationship between total mass of seeds and total dry phytomass of the plant. The total mass of seeds (TMS) was obtained after processing the capsules through weighing on a scale with precision of 0.01g.

The collected data were subjected to analysis of variance through F test and, when significant, orthogonal regression analysis was applied for the factor water salinity levels and test of comparison of means (Tukey at 0.05 probability level) for the proportions of nitrate and ammonium, using the statistical software SISVAR 4.2 (FERREIRA, 2011).

RESULTS AND DISCUSSION

Based on the summary of the analysis of variance presented in Table 2, the water salinity levels significantly (p<0.01) affected all studied variables, except the instantaneous water use efficiency (WUE). The proportions of nitrate and ammonium influenced (p<0.01) the internal CO₂ concentration and transpiration. Regarding the interaction between the studied factors (SL x NAP), there was significant effect (p<0.05) on transpiration, CO₂ assimilation rate and instantaneous carboxylation efficiency.

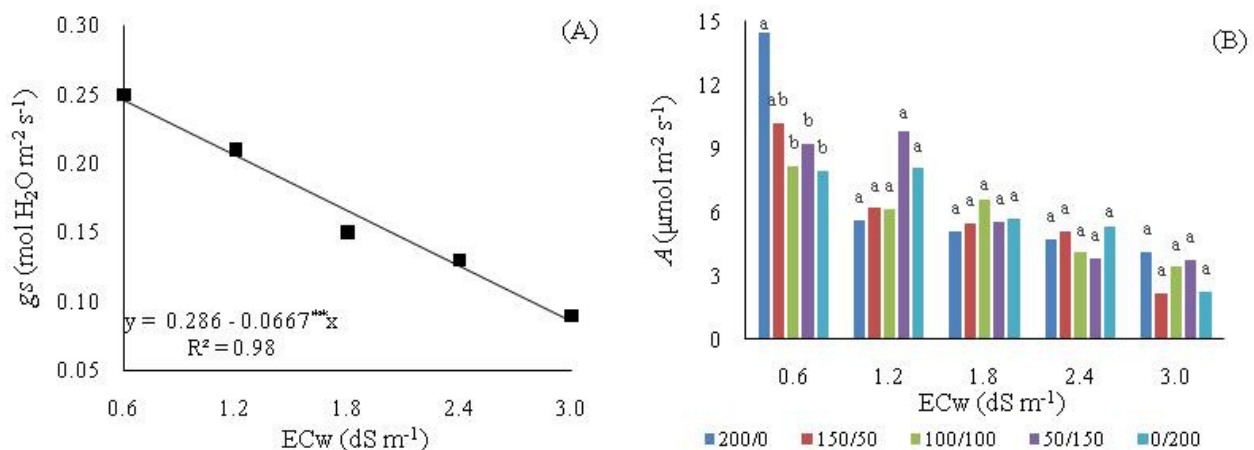
Irrigation water salinity negatively affected (p<0.01) the stomatal conductance of sesame plants and, according to the regression equation (Figure 1A), the increase in the electrical conductivity of the irrigation water caused reductions in *g_s* of 23.32% with per unit increase in EC_w and plants irrigated with water of highest salinity level (3.0 dS m⁻¹) showed reduction of 65.07% in relation to those subjected to irrigation with water of lowest salinity (0.6 dS m⁻¹). Suassuna (2013) evaluating the tolerance of sesame genotypes (BRS Seda, CNPA G2, CNPA G4, Branquinha e Pretinha) to salt stress, irrigated with salinized waters, concluded that the harmful effects of salinity are more evident in stomatal conductance and in the rate of liquid photosynthesis. Silva et al. (2011) explain that this reduction in *g_s* is due to stomatal closure caused by the osmotic effects promoted by salinity, as a

defense mechanism of the plant, as well as its ionic effects on the plant.

Table 2. Summary of the analysis of variance for stomatal conductance (g_s), CO_2 assimilation rate (A), transpiration (E), internal CO_2 concentration (C_i), instantaneous water use efficiency (WUE) and instantaneous carboxylation efficiency (EICI) of sesame plants irrigated with saline water and fertilized with different proportions of nitrate and ammonium at 70 days after sowing.

Source of variation	DF	Mean squares					
		g_s	A	E	C_i	WUE	EICI
Saline levels (SL)	4	0.06**	103.02**	1.82**	11866.1**	4.98 ^{ns}	0.002**
Linear regression	1	0.25**	384.56**	6.94**	43908.3**	15.55*	0.006**
Quadratic regression	1	0.001 ^{ns}	9.67 ^{ns}	0.01 ^{ns}	306.1 ^{ns}	3.14 ^{ns}	0.0004*
Nitrate and ammonium (NAP)	4	0.14 ^{ns}	3.57 ^{ns}	0.58**	4599.8**	3.08 ^{ns}	0.0001 ^{ns}
Interaction (SL x NAP)	16	0.001 ^{ns}	8.40*	0.19*	1785.3 ^{ns}	3.33 ^{ns}	0.0001*
Blocks	2	0.003 ^{ns}	1.67 ^{ns}	0.46*	1091.4	1.99	0.00002 ^{ns}
Residual	48	0.005	3.62	0.10	1731.65	2.63	0.000075
CV (%)		10.70	11.19	20.43	12.91	20.02	22.44

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



Means followed by different letters indicate that the treatments differ by Tukey test ($p < 0.05$)

Figure 1. Stomatal conductance – g_s as a function of the electrical conductivity of the irrigation water - EC_w (A) and CO_2 assimilation rate - A as a function of the interaction between the factors EC_w levels and proportions of nitrate/ammonium nitrogen (B) at 70 days after sowing.

The interaction between irrigation water salinity and proportions of nitrate and ammonium (SL x PNA) affected the CO_2 assimilation rate of sesame plants (Table 2). As the EC_w increased, there was reduction in A (Figure 1B), due to the decrease in the stomatal conductance of these plants when subjected to irrigation with saline water (Figure 1A). However, Martinazzo et al. (2013) cite that, although the reduction in g_s helps to maintain a high water content in the leaves, this adjustment results in the reduction of the photosynthetic activity.

The proportions of $\text{NO}_3^-/\text{NH}_4^+$ significantly influenced the CO_2 assimilation rate only when plants were irrigated with water of low electrical

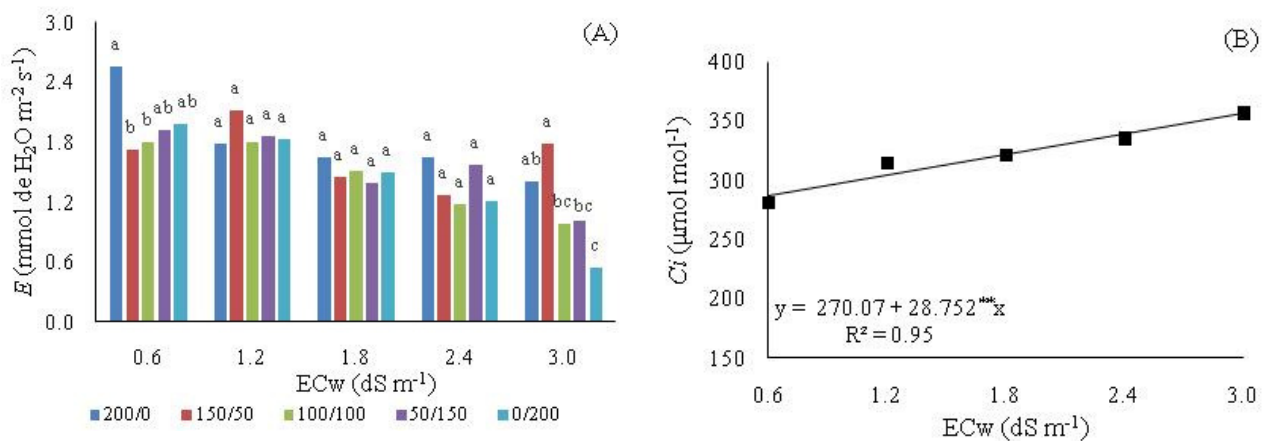
conductivity (0.6 dS m^{-1}) and, according to the test of comparison of means, there were significant differences between the treatments with $\text{NO}_3^-/\text{NH}_4^+$ proportions of 200/0 and 100/0, 50/150 and 0/200, while the other treatments did not differ. The highest value of A ($14.44 \mu\text{mol m}^{-2} \text{ s}^{-1}$) was obtained when plants were fertilized only with 200/0 of $\text{NO}_3^-/\text{NH}_4^+$ and the lowest value ($7.79 \mu\text{mol m}^{-2} \text{ s}^{-1}$) in plants fertilized with only ammonium-N (0/200 of $\text{NO}_3^-/\text{NH}_4^+$), which represents a reduction of 46.05% in A (Figure 1B) in sesame plants cultivated with only ammonium in relation to those exclusively under nitrate nitrogen. Guo et al. (2012) in studies with *Catharanthus roseus* also reported reduction in the CO_2 assimilation rate of these plants when

subjected to ammonium as the only N source and, according to these authors, this reduction is a result of the adverse effects of the excessive nutrition with ammonium.

Based on Table 2, the interaction between the factors (SL x PNA) significantly interfered ($p < 0.05$) with the transpiration of sesame plants and there was difference (Figure 2A) between the means when plants were irrigated with water of lowest and highest ECw levels (0.6 and 3.0 dS m^{-1} , respectively). At these salinity levels, the highest values for this variable were obtained when plants received fertilization with 200/0 and 150/50 ($\text{NO}_3^-/\text{NH}_4^+$), indicating a possible preference of this crop for the absorption of N in the nitrate form, since, as observed for CO_2 assimilation rate (Figure 1B),

sesame plants show higher transpiration when fertilized with higher proportions of NO_3^- nitrogen. In addition, as irrigation water salinity increased (Figure 2A), there was a reduction in E so that its lowest values were observed in plants subjected to irrigation with water of 3.0 dS m^{-1} .

This reduction in transpiration due to the increase in ECw is caused by the stomatal limitation, which occurs as a defense strategy of the plant to minimize water loss, since E is closely related to the opening of the stomata, because they offer resistance to water diffusion from the leaf to the atmosphere. Hence, reductions in stomatal conductance to decrease the excessive water loss also reduce transpiration (BATISTA, 2011).



Means followed by different letters indicate that the treatments differ by Tukey test ($p < 0.05$)

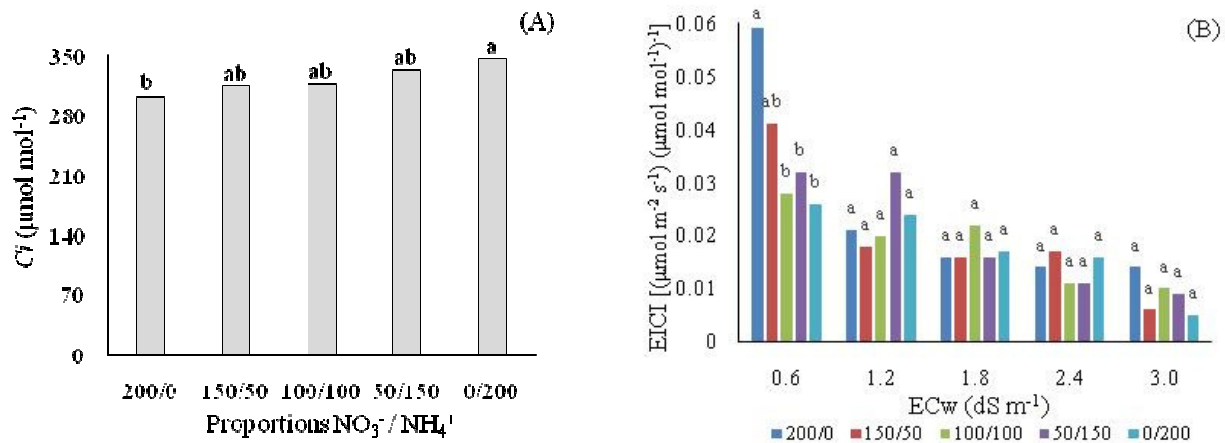
Figure 2. Transpiration (E) as a function of the interaction between irrigation water salinity - ECw and proportions of nitrate and ammonium (A) and internal CO_2 concentration (C_i) of sesame plants as a function of irrigation water salinity - ECw (B) at 70 days after sowing.

The internal CO_2 concentration was significantly ($p < 0.01$) affected by the increase in ECw (Table 2) and, according to the regression equation (Figure 2B), this variable increased by 10.64% with per unit increase in ECw. Comparing plants irrigated with water of 3.0 dS m^{-1} with those under irrigation with water of low salinity level (0.6 dS m^{-1}), there was an increase of 24.01% in C_i . This increase in C_i is due to the low values of water potential in the leaf, which occur because of the reduction in g_s caused by the salinity, as observed in Figure 1A, and can be related to the decrease in the activity of enzymes involved in the process of CO_2 fixation.

According to Freire et al. (2014) under salt stress conditions, the increase in CO_2 indicates that it is not being used for the synthesis of sugars during the photosynthesis, with consequent accumulation

of this gas, suggesting the interference of some non-stomatal factor in this process.

The different proportions of $\text{NO}_3^-/\text{NH}_4^+$ also significantly affected ($p < 0.01$) the internal CO_2 concentration and there were significant differences between the ammonium/nitrate proportions of 0/200 and 200/0, according to the test of comparison of means (Figure 3A), while the other proportions did not show significant differences. The internal CO_2 concentration increased as the amount of ammonium increased and the highest (364.2 $\mu\text{mol mol}^{-1}$) and lowest (301.06 $\mu\text{mol mol}^{-1}$) values of C_i were obtained when plants were subjected to the $\text{NO}_3^-/\text{NH}_4^+$ proportions of 0/200 and 200/0, respectively, i.e., plants fertilized exclusively with nitrate nitrogen showed reduction of 17.34% in the internal CO_2 concentration in relation to those fertilized with ammonical nitrogen as the only source.



Means followed by different letters indicate that the treatments differ by Tukey test ($p < 0.05$)

Figure 3. Internal CO_2 concentration (C_i) as a function of the different proportions of $\text{NO}_3^-/\text{NH}_4^+$ nitrogen (A) and instantaneous carboxylation efficiency (EICI) as a function of the interaction between irrigation water salinity - ECw and proportions of nitrate and ammonium nitrogen (B).

As observed in the C_i of plants exposed to increasing levels of ECw (Figure 2B), the increment of this variable when plants were exclusively under nutrition with ammonium also is due to the stomatal restriction, since Guo et al. (2012) claim that this cation causes stomatal closure, which results in inhibition of the photosynthetic rate, as observed in Figure 1B, because of the adverse effects of the excess of this cation in the plants.

The interaction between the factors (SL x PNA) significantly affected the instantaneous carboxylation efficiency, which represents the relationship between the CO_2 assimilation rate and internal CO_2 concentration (A/C_i), so that this variable exhibited a behavior similar to that of A (Figure 1B). According to the results (Figure 3B), the EICI decreased as the levels of irrigation water salinity increased. Additionally, based on the test of comparison of means (Figure 3B), only plants irrigated with water of 0.6 dS m^{-1} showed significant differences between the different proportions of nitrate/ammonium nitrogen, as observed for A (Figure 1B).

The highest and lowest EICI values (Figure 3B) were obtained when plants were fertilized exclusively with nitrate and ammonical nitrogen and irrigated with ECw levels of 0.6 and 3.0 dS m^{-1} , respectively, and this difference represents a reduction of 55.94% in the EICI of plants fertilized only with ammonical nitrogen in relation to those that received only nitrate nitrogen and were under irrigation with ECw of 0.6 dS m^{-1} . This deleterious effect on the EICI, regardless of the proportion of N

studied is a consequence of decrease in water absorption due to the reduction in the osmotic potential of the soil solution..

Silva et al. (2015) explained that these reductions in EICI are related to decreases in both stomatal conductance and CO_2 assimilation rate, as a consequence of the salt stress, as observed in the present study. Moreover, there is an increase in internal CO_2 concentration (Figure 3A) in response to the adverse effects of ammonium on plants, according to the previously presented explanation (GUO et al., 2012), since the increase in C_i in detriment of CO_2 assimilation rate promotes reductions in this variable.

Based on the results of the analysis of variance (Table 3), there was significant effect ($p < 0.01$) of the factor irrigation water salinity (ECw) on the variables relative growth rate in plant height (RGRph) and stem diameter (RGRsd), total mass of seeds (TMS) and harvest index (HI). As to the factor proportions of nitrate/ammonical nitrogen, there was significant effect on the total mass of seeds (TMS), while the interaction between ECw and proportions of nitrate/ammonical nitrogen significantly influenced only TMS.

The factor irrigation water salinity significantly affected ($p < 0.01$) the relative growth rate in height of sesame plants and, according to the regression equation (Figure 4A), there was a linear behavior, with decrease in RGRph of 4.64% per unit increase in ECw, i.e., reduction of 11.45% in plants irrigated with water of 3.0 dS m^{-1} in relation to the control (0.6 dS m^{-1}).

Table 3. Summary of the analysis of variance for the relative growth rate in plant height (RGRph) and stem diameter (RGRsd), total mass of seeds (TMS) and harvest index (HI) of sesame plants irrigated with saline water and fertilized with different proportions of nitrate and ammonical nitrogen at 70 days after sowing.

Source of variation	Mean squares				
	DF	RGRph	RGRsd	TMS	HI
Saline levels (SL)	4	0.00005**	0.00006**	3492.61**	0.2307**
Linear regression	1	0.0002**	0.0002**	12470.62*	0.8268**
Quadratic regression	1	0.000001 ⁿ _s	0.00005*	815.002**	0.0018 ^{ns}
Nitrate and ammonium (NAP)	4	0.00002 ^{ns}	0.00002 ^{ns}	174.23*	0.0224 ^{ns}
Interaction (SL x NAP)	16	0.00001 ^{ns}	0.00001 ^{ns}	101.13*	0.0285 ^{ns}
Blocks	2	0.00006	0.00003 ^{ns}	10.20	0.0015 ^{ns}
Residual	48	0.000008	0.000009	49.08	0.0153
CV (%)		7.99	15.0	17.64	12.66

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

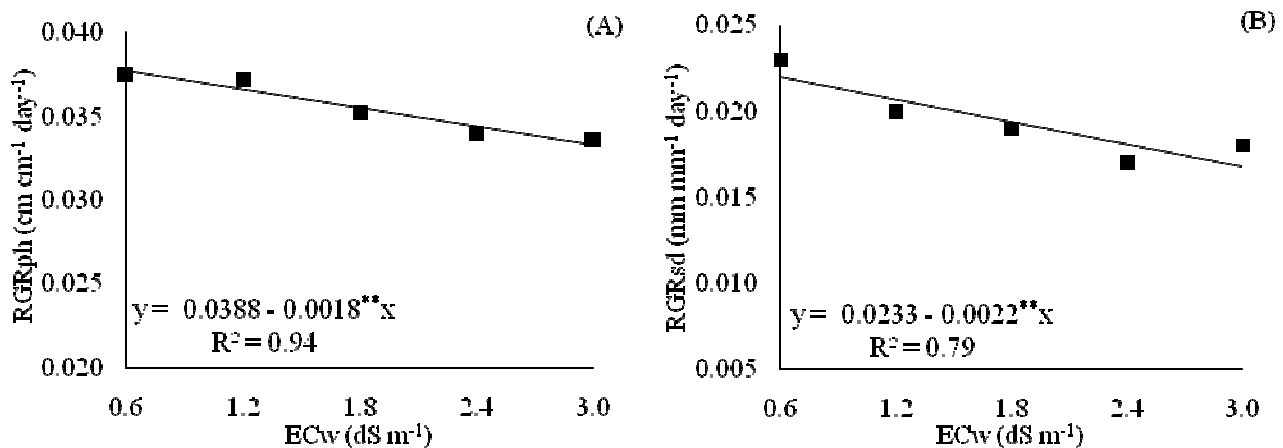


Figure 4. Relative growth rate in plant height - RGRph (A) and stem diameter - RGRsd (B) as a function of irrigation water salinity (ECw) during the period of 25 and 100 days after sowing.

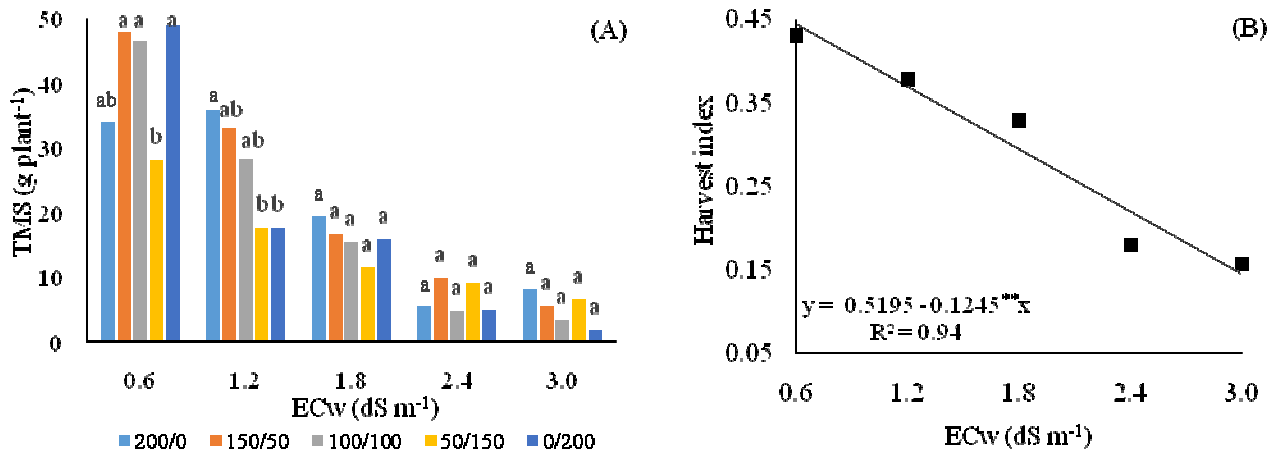
According to Lima et al. (2012), the reduction in the relative growth rate of plants under salt stress can be explained by the decrease in the osmotic potential of the soil solution, as well as the possibility of ionic toxicity and/or nutritional imbalance, due to the excessive accumulation of certain ions in plant tissues. In contrast, in study with castor bean under saline water irrigation, Nobre et al. (2014) observed that this crop showed increment in RGRph of 1.63% with per unit increase in ECw. These authors claim that this result reflects the tolerance of the crop to salt stress, which differs from the result observed in the present study with sesame.

As observed for RGRph, the RGRsd was also significantly affected ($p < 0.01$) by irrigation water salinity (Table 3) so that it was linearly inhibited by the ECw and, according to the

regression equation (Figure 4B), sesame plants cv. CNPA G3 irrigated with water of 3.0 dS m⁻¹ showed reduction in RGRsd of 24.02%, i.e., a decrease of 0.005 mm mm⁻¹ day⁻¹ in relation to plants subjected to the lowest ECw level (0.6 dS m⁻¹). For Dias et al. (2013), as soil salinity increases due to the addition of salts in the irrigation water, the availability of water to the crop decreases, causing the necessity of greater metabolic expenditure of energy in the attempt to maximize the absorption of water from the soil, thus inhibiting the vegetative growth of the crops. It should be pointed out that, because of the inability of sesame plants to produce new plant material per unit of pre-existing material under stress, due to the reductions in RGRph (Figure 4A) and RGRsd (Figure 4B), it can be inferred that this crop is sensitive to irrigation water electrical conductivity above 0.6 dS m⁻¹.

The interaction between the studied factors (irrigation water salinity and proportions of nitrate/ammonium) had significant influence ($p < 0.01$) on the total mass of seeds, confirming the fact that the studied factors do not act only individually on these variables. Based on Figure 5A, when sesame plants were subjected to the different proportions of nitrate/ammonical nitrogen, according to the test of comparison of means, there was significant difference ($p < 0.05$) only when

plants were irrigated with water of low salinity levels (0.6 and 1.2 dS m^{-1}); however, when they were subjected to irrigation with ECw of 1.8 , 2.4 and 3.0 dS m^{-1} , regardless of the applied proportion of $\text{NO}_3^-/\text{NH}_4^+$, there was no significant effect of these treatments ($p < 0.05$) on the TMS. This means that, above the salinity level of 1.2 dS m^{-1} , the different proportions of $\text{NO}_3^-/\text{NH}_4^+$ had similar negative effects under salt stress.



Means followed by different letters indicate that the treatments differ by Tukey test ($p < 0.05$)

Figure 5. Total mass of seeds -TMS of sesame as a function of the interaction between ECw and proportions of nitrate and ammonical nitrogen (A) and harvest index as a function of irrigation water salinity - ECw (B) at 100 days after sowing.

When sesame plants were irrigated with water of low salinity level (0.6 dS m^{-1}) (Figure 5A), the highest mass of seeds was obtained when plants were fertilized exclusively with ammonical nitrogen ($0/200$) and this mean did not differ ($p > 0.05$) from those of the proportions of $200/0$, $150/50$ and $100/100$. On the other hand, when plants were irrigated with water of 1.2 dS m^{-1} , the fertilization with higher proportions of ammonical nitrogen ($50/150$ and $0/200$) promoted the lowest TMS (17.61 g). Such reduction in the mass of seeds is due to the increase in the proportion of ammonical nitrogen resulting from the restrictions in the absorption of water by the plant caused by the effect of salinity due to the ammonium ion (RIBEIRO et al., 2012), potentiating the effect of irrigation water salinity. These authors also claim that the effects of NH_4^+ toxicity have been attributed to the reduction or inhibition of the absorption of cations, especially potassium, as a consequence of the imbalance of ions, which may have negatively influenced the TMS in sesame plants, since Lima et al. (2016) observed that the $\text{NO}_3^-/\text{NH}_4^+$ proportion of $0/100$ mg promoted higher mass of seed cotton (27.94 g plant⁻¹).

Based on the analysis of the data (Table 3), there were significant effects ($p < 0.01$) only of the factor irrigation water salinity on the harvest index (HI) of sesame plants. According to the regression equation (Figure 5B), the linear model indicated decrease in HI of 23.96% per unit increase in the electrical conductivity of the irrigation water, i.e., a reduction of 67.17% in the HI of plants irrigated with water of 3.0 dS m^{-1} , in relation to the control ($\text{ECw} = 0.6$ dS m^{-1}). This reduction in HI occurs because of the stress caused by the excess of salts, to which sesame plants were subjected in this experiment. According to Lima et al. (2012), the excess of salts decreases CO_2 assimilation rate, stomatal conductance, transpiration and photosynthesis of the plants, as observed in the present study, and consequently damages crop production and yield.

The results are in agreement with the study of Nobre et al. (2011) evaluating the effects of irrigation water salinity on sunflower, they also observed reductions in the HI of this crop, with decreases of 3.9% per unit increase in ECw . Further, according to these authors, there was no effect of N

doses on the HI or even of their interaction with irrigation water salinity in their study.

CONCLUSIONS

Irrigation with water of salinity level higher than 0.6 dS m⁻¹ causes negative effect on gas exchanges and production components of sesame, cv. CNPA G3.

Fertilization with N exclusively in the form of NH₄⁺ promotes increment in CO₂ concentration and reduction in CO₂ assimilation rate and instantaneous carboxylation efficiency.

The use of water with electrical conductivity of 0.6 dS m⁻¹ associated with fertilization with 200/0 mg of N-NO₃⁻/N-NH₄⁺ provides a higher rate of CO₂ assimilation, transpiration and instantaneous carboxylation efficiency in sesame cv. CNPA G3.

Increasing levels of water salinity caused reduction in the total mass of seeds, regardless of the applied proportion of NO₃⁻/NH₄⁺ of nitrogen.

The sesame cv. CNPA G3 is classified as sensitive to salt stress from the electrical conductivity of water of 0.6 dS m⁻¹.

RESUMO: Nas regiões semiáridas é comum a ocorrência de águas com elevada concentração de sais que comprometem o crescimento e consequentemente a produção das culturas. Deste modo, objetivou-se avaliar as trocas gasosas e a produção do gergelim cv. CNPA G3 irrigado com águas salinas e adubado com diferentes proporções de nitrato e amônio em um ensaio conduzido em lisímetros dispostos em casa de vegetação no município de Campina Grande, PB. Os tratamentos foram distribuídos em blocos ao acaso e analisados em esquema fatorial 5 x 5, com três repetições, relativos a cinco níveis de condutividade elétrica da água de irrigação – CEa (0,6; 1,2; 1,8; 2,4 e 3,0 dS m⁻¹) e cinco proporções de nitrato e amônio - NO₃⁻/NH₄⁺ (200/0; 150/50; 100/100; 50/150 e 0/200 mg de N kg⁻¹ de solo). A irrigação com água de salinidade superior a 0,6 dS m⁻¹ promoveu efeito negativo sobre as trocas gasosas e os componentes de produção do gergelim cv CNPA G3. A adubação com N exclusivamente na forma de NH₄⁺ proporcionou incremento na concentração de CO₂ e redução na taxa de assimilação de CO₂, eficiência instantânea de carboxilação. A maior taxa de assimilação de CO₂, transpiração e eficiência instantânea de carboxilação foram obtidas quando as plantas foram irrigadas com água de 0,6 dS m⁻¹ e adubação com 200/0 de NO₃⁻/ NH₄⁺. Níveis crescentes de salinidade da água promoveram diminuição na massa total de sementes, independente da proporção de NO₃⁻ e NH₄⁺. O gergelim cv. CNPA G3 foi classificado como sensível ao estresse salino, a partir da condutividade elétrica da água de 0,6 dS m⁻¹.

PALAVRAS-CHAVE: *Sesamum indicum* L. CNPA G3. Escassez de água. Nitrogênio.

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