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Cultivation of CNPA G3 sesame irrigated with saline water and fertilized with nitrate-N and ammonium-N

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Key words:
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A B S T R A C T

The study aimed to evaluate the effects of irrigation with saline water and fertilization with nitrate (NO_3^--N) and ammonium (NH_4^+-N) ratios on growth, flowering, water consumption and water use efficiency of the sesame cv. CNPA G3. The treatments were distributed in randomized blocks in a 5 x 5 factorial with three replicates, referring to five levels of electrical conductivity of the irrigation water - ECw (0.6, 1.2, 1.8, 2.4 and 3.0 dS m^{-1}) and nitrate (NO_3^--N) and ammonium (NH_4^+-N) (200/0, 150/50, 100/100, 50/150, 0/200 mg kg^{-1}) ratios. Irrigation with saline water above 0.6 dS m^{-1} inhibited the growth, delayed flowering and promoted early maturation of capsules of sesame, cv. CNPA G3. The proportion of 0/200 mg kg^{-1} of NO_3^--N/NH_4^+-N promoted the greatest increase relative to stem diameter and height of sesame plants. Water consumption decreases with increasing ECw and was significantly lower in plants fertilized with the proportion of 0/200 of NO_3^--N/NH_4^+-N. The interaction between ECw levels and ammonium/nitrate proportions significantly affect water use efficiency, and the highest value was obtained with ECw of 0.6 dS m^{-1} and fertilization with 150:50 mg kg^{-1} of NO_3^--N and NH_4^+-N.

Palavras-chave:
Sesamum indicum L.
estresse salino
proporções de NO_3^--N e NH_4^+-N

Cultivo do gergelim ‘CNPA G3’ irrigado com águas salinas e adubação com N-nitrato e N-amônio

R E S U M O

O trabalho objetivou avaliar os efeitos da irrigação com águas salinas e adubação com diferentes proporções de nitrato (NO_3^--N) e amônio (NH_4^+-N) sobre o crescimento, a floração, o consumo hídrico e a eficiência do uso da água pelo gergelim cv. CNPA G3. Os tratamentos foram distribuídos em blocos casualizados, em esquema fatorial 5 x 5, com três repetições, referentes 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 às proporções de nitrato (NO_3^--N) e de amônio (NH_4^+-N) (200/0, 150/50, 100/100, 50/150, 0/200 mg kg^{-1}). A irrigação com água salina acima de 0,6 dS m^{-1} inibiu o crescimento, retardou o florescimento e aumentou a precocidade para maturação das cápsulas do gergelim CNPA G3. A proporção de 0/200 mg kg^{-1} de NO_3^--N e NH_4^+-N promoveu o maior crescimento relativo para diâmetro do caule e altura de plantas de gergelim. O consumo hídrico diminuiu com o incremento da CEa e foi significativamente menor nas plantas adubadas com a proporção de 0/200 de NO_3^--N e NH_4^+-N. A interação entre os níveis de CEa e as proporções de nitrato e amônio exerceu efeitos significativos na eficiência no uso da água e o maior valor foi obtido nas plantas irrigadas com água de 0,6 dS m^{-1} e adubação com a proporção NO_3^--N e NH_4^+-N de 150/50 mg kg^{-1}.

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Introduction

Belonging to the *Pedaliaceae* family, sesame (*Sesamum indicum* L.) is an oilseed crop and the oil from its seeds has high content of unsaturated fatty acids (60%), especially oleic and linoleic and, from the industrial point of view, has a variety of uses, such as in energetic and pharmaceutical products and in bakery, production of biscuits, candies and in the manufacturing of margarine, production of cosmetics, perfumes, medicines, lubricants, soap, paints and insecticides (Lago et al., 2001).

The semi-arid region of Northeast Brazil, despite the adequate conditions in terms of soil and luminosity, does not meet the water requirements of the crops for the cultivation on a commercial scale. For this reason, the economically competitive production system depends on irrigation (Andrade et al., 2012). In this region, the waters, in most sources, have high contents of salts and electrical conductivity of up to 5.0 dS m^{-1}, or more. These high values potentiate the problem of soil salinization, causing serious damages to the crops (Lima et al., 2015).

The main restrictions of saline waters to plants include the decrease in the osmotic potential, toxicity of specific ions and nutritional imbalance. These effects result in serious modifications in the metabolism of the plants, altering the physiological and biochemical processes (Neves et al., 2009). Thus, some authors point to the sesame crop as sensitive to salinity (Rhoades et al., 2000; Suassuna, 2013). However, other studies highlight it as moderately tolerant to salts (Azevedo et al., 2003; Abbasdokht et al., 2012; Bahrami & Razmjoo, 2012). Therefore, plant tolerance to salinity may vary among species and cultivars of the same species, besides depending on other factors such as type of salt, time of exposure and interaction between both (Garcia et al., 2010).

Considering that nutritionally balanced plants tolerate more the action of salts, nitrogen (N) emerges as an element that performs vital functions in the formation of organic compounds, such as nucleic acids, amino acids, proteins, vitamins and on the activity of chlorophyll and photosynthesis, among others (Chaves et al., 2011). In the soil solution, N can be found in the forms of nitrate and ammonium, and the preferential form of absorption and assimilation depends on the plant species (Duan et al., 2007). In addition, the absorption rates of NO_3^- and NH_4^+ by plants can be influenced by various factors, such as species, NO_3^-:NH_4^+ proportion in the solution, pH, temperature, luminosity intensity, concentration of carbohydrates in the roots, among others (Cruz et al., 2008).

Given the above, this study aimed to evaluate the growth, flowering, water consumption and water use efficiency of the sesame cultivar CNPA G3, as a function of irrigation with saline water and N fertilization with nitrate/ammonium proportions.

Material and Methods

The study was conducted in pots adapted as drainage lysimeters under greenhouse conditions, from November 2015 to February 2016, at the Center of Technology and Natural Resources of the Federal University of Campina Grande (CTRN/UFCG), located in the municipality of Campina Grande, PB, Brazil (7° 15' 18" S; 35° 52' 28" W; 550 m).

The experimental design was completely randomized blocks, with three replicates, using a 5 x 5 factorial scheme, and the treatments corresponded to five levels of electrical conductivity of the irrigation water - ECw (0.6; 1.2; 1.8; 2.4 and 3.0 dS m^{-1}) and five proportions of nitrate (NO_3^--N) and ammonium (NH_4^+-N) (200/0; 150/50; 100/100; 50/150 and 0/200 mg N kg^{-1} of soil).

The bottom of each lysimeter was connected to a drain, which consisted of a hose with diameter of 4 mm to drain the leachate in a container and evaluate the drained water, to determine the water consumption by the plants. The tip of the drain inside the pot was involved with a nonwoven geotextile (Bidim OP 30) to avoid obstruction by soil material.

The lysimeters were filled with a 0.5-kg layer of crushed stone (size 0), followed by 26 kg of Eutrophic Regolithic Neosol, of a sandy loam texture (0-20 cm), whose chemical and physico-hydraulic characteristics were determined according to the methodologies proposed by Claessen (1997): Ca^{2+} = 7.41 $cmol_c$ kg^{-1}; Mg^{2+} = 5.23 $cmol_c$ kg^{-1}; Na^+ = 1.82 $cmol_c$ kg^{-1}; K^+ = 0.28 $cmol_c$ kg^{-1}; $H^+ + Al^{3+}$ = 3.07 $cmol_c$ kg^{-1}; Al^{3+} = 0 $cmol_c$ kg^{-1}; CEC = 17,81 $cmol_c$ kg^{-1}; organic matter = 10.79 dag kg^{-1}; P = 48.0 mg kg^{-1}; pH in water (1:2.5) = 6.24; electrical conductivity of the saturation extract = 2.50 dS m^{-1}; SAR = 5,60 (mmol $L^{-1})^{0.5}$; exchangeable sodium percentage = 11.38%; sand = 656.6 g kg^{-1}; silt = 175.0 g kg^{-1}; clay= 168.4 g kg^{-1}; water content at 33.42 kPa = 28.84 dag kg^{-1}; water content at 1519.5 kPa = 10.42 dag kg^{-1}.

The sesame cultivar used in the experiment was CNPA G3, which is indicated for cultivation in the semi-arid region of Northeast Brazil. It is a cultivar with medium size (up to 1.60 m), cycle of 90 to 100 days, branched growth habit with uniform flowering and maturation. It has fruit per axil and a cream color. In addition, it is resistant to angular leaf spot and susceptible to Cercospora leaf spot and Macrophomina (Lima et al., 2013).

The irrigation waters with the respective values of electrical conductivity were prepared by dissolving the salts NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$, in the equivalent proportion of 7:2:1 of Na^+, Ca^{2+} and Mg^{2+}, respectively, in public-supply water (ECw = 1.40 dS m^{-1}) from the municipality of Campina Grande, PB, based on the relationship between the ECw and the concentration of salts (10*ECw dS m^{-1} = $mmol_c$ L^{-1}), according to Richards (1954). After preparation and ECw calibration of each water using a portable conductivity meter, each type of saline water was stored in 200-L plastic containers, properly protected to avoid losses through evaporation and increase in saline concentration.

Before sowing, the soil moisture content was increased to field capacity (33.42 kPa) using the respective water of each treatment. After sowing, irrigation was daily performed by applying in each lysimeter a water volume to maintain the soil moisture close to field capacity, and the volume to be applied was determined according to the water requirements of the plants, estimated through the water balance: applied volume minus volume drained in the previous irrigation, plus a leaching fraction of 0.10.

Fifteen seeds of the sesame cv. CNPA G3 were equidistantly sown in each lysimeter at a depth of 1.5 cm. At 20 and 30 days after sowing (DAS), thinnings were performed to leave only one plant per lysimeter. The fertilization with phosphorus and potassium was performed according to the recommendation of Novais et al. (1991), by applying the equivalent to 300 and 150 mg kg^{-1} of soil, respectively, of P_2O_5 and K_2O in the form of single superphosphate and potassium chloride. Calcium nitrate and ammonium chloride were used as sources of NO_3^- and NH_4^+, respectively. Phosphorus was totally applied as basal dose, while the fertilizations with potassium and the proportions of NO_3^--N and NH_4^+-N were split into three applications of 1/3 each, as basal, and the rest in three equal applications at intervals of 10 days, starting at 25 DAS. To reduce the nitrification of ammoniacal N, a nitrification inhibitor (Dicyandiamide) was applied along with each application of ammonium chloride, at a dose equivalent to 10% of the NH_4^+-N used.

The growth of CNPA G3 sesame was evaluated based on the relative growth rate of stem diameter (RGRsd) and plant height (RGRph). The production components were measured based on the number of days for flowering (NDF) and for capsule maturation (NDM). In addition, water consumption (WC) and water use efficiency (WUE) at the end of the crop cycle were evaluated.

The RGRsd and RGRph were obtained from the data of two evaluations, at 25 and 60 DAS, determined according to the methodology described by Benincasa (2003), calculated as in Eqs. 1 and 2:

$$RGRsd = \frac{(\ln SD_2 - \ln SD_1)}{(t_2 - t_1)} \quad (1)$$

$$RGRph = \frac{(\ln PH_2 - \ln PH_1)}{(t_2 - t_1)} \quad (2)$$

where:

RGRsd - relative growth rate in stem diameter, mm mm^{-1} d^{-1};
SD_1 - stem diameter (mm), at 25 DAS, at the time t_1;
SD_2 - stem diameter (mm), at 60 DAS, at the time t_2;
ln - natural logarithm;
RGRph - relative growth rate in plant height, cm cm^{-1} d^{-1};
PH_1 - plant height (cm), at 25 DAS, at the time t_1; and,
PH_2 - plant height (cm), at 60 DAS, at the time t_2.

NDF was determined through the daily monitoring of the appearance of flower buds in each plot. NDM was measured at the harvest of the capsules, which started at 85 and continued up to 100 DAS. The water consumption in each experimental plot along the crop cycle was obtained through the sum of the applied water volume minus the drained volume during the cycle. Water use efficiency was measured as the ratio between grain yield and the water volume effectively consumed by the plants of each treatment, according to the methodology of Sartori et al. (2013).

The data were subjected to analysis of variance by the F test and, when significant, regression analysis was applied to the factor irrigation water salinity and the test of comparison of means (Tukey at 0.05 probability level) was applied to the nitrate/ammonium proportions, using the statistical software Sisvar-ESAL (Ferreira, 2011). After analysis of normality of residue, an exploratory analysis was performed for the WUE data, transforming the values to log x.

Results and Discussion

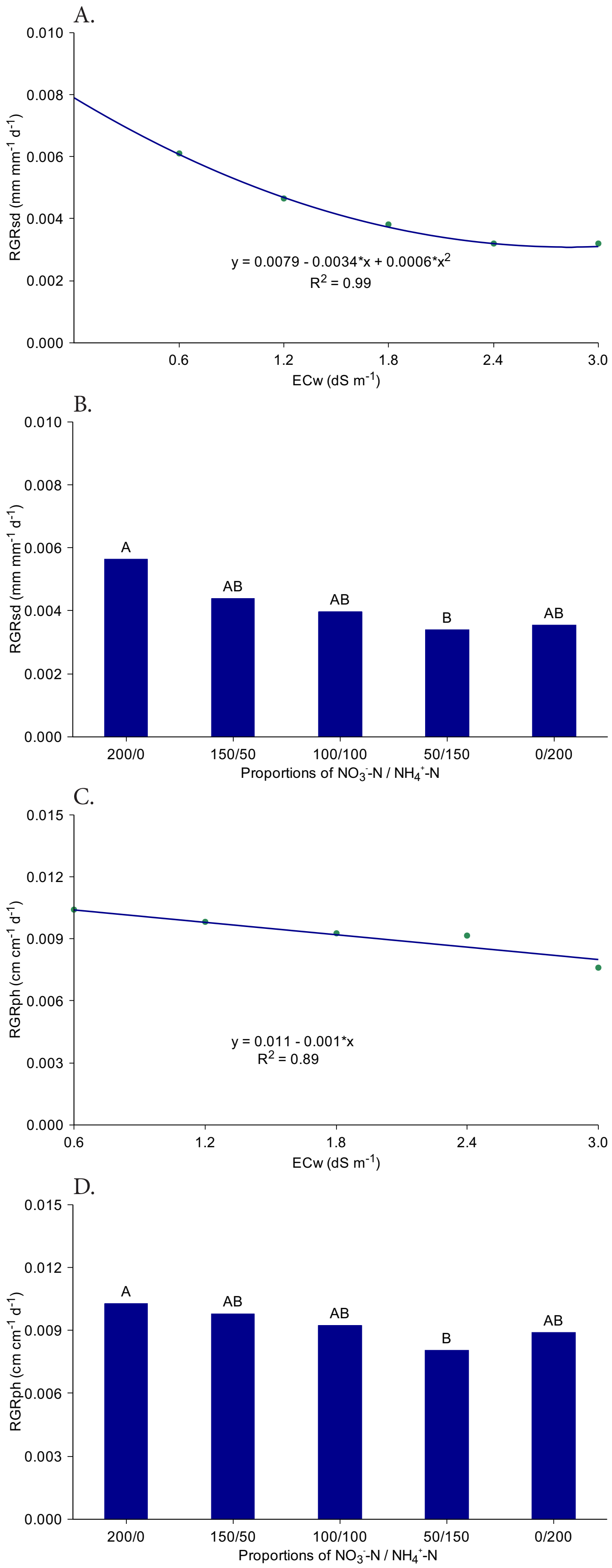
Based on the summary of the analysis of variance (Table 1), there was significant effect of the levels of irrigation water salinity on the relative growth rate of stem diameter and plant height, number of days for flowering and capsule maturation ($p < 0.05$), and for water consumption and water use efficiency of sesame, cv. CNPA G3 ($p < 0.01$). Regarding the proportions of nitrate-N and ammonium-N, there was significant effect ($p < 0.05$) on RGRsd, RGRph, NDM, WC and WUE. The interaction between factors (SL x NAP) promoted significant effect ($p < 0.05$) only on WUE.

For the relative growth rate of stem diameter (RGRsd) in the period of 25 to 60 DAS, as a function of the different salinity levels (Figure 1A), there was a quadratic response with minimum point of 0.0031 mm mm^{-1} d^{-1} obtained at the salinity level of 3.0 dS m^{-1}. For the relative growth rate of plant height (RGRph) (Figure 1C), as observed for RGRsd, the increment in the saline levels of the irrigation water promoted a decreasing linear effect, with reduction of 9.09% per unit increase in ECw, which corresponded to decreases of 49.01 and 21.81% in RGRsd and RGRph, respectively, in plants irrigated with 3.0 dS m^{-1} in relation to those under irrigation with water of lower ECw (0.6 dS m^{-1}). The reduction in the respective growth rates of stem diameter and height are a reflex of the excess of salts in the root zone, causing deleterious effect on the growth of the plants, which showed a sharp decrease in the growth of different

Table 1. Summary of the analysis of variance for the relative growth rate of stem diameter (RGRsd) and plant height (RGRph) in the period of 25 to 60 days after sowing, number of days for flowering (NDF) and maturation of capsules (NDM), water consumption (WC) and water use efficiency (WUE) of sesame plants, cv. CNPA G3, irrigated with saline waters and fertilized with different proportions of nitrate-N and ammonium-N

Source of variation	DF	Mean squares					
		RGRsd	RGRph	NDF	NDM	WC	WUE[1]
Saline levels (SL)	4	0.000079*	0.000017*	57.861*	102.292*	0.0052**	114738.204**
Linear regression	1	0.000255**	0.000059*	183.975*	350.910**	0.01910**	410779936**
Quadratic regression	1	0.000155*	0.000003ns	0.338ns	3.080ns	0.00001ns	2737.620ns
Nitrate-N and ammonium-N proportions (NAP)	4	0.000013*	0.000011*	13.586ns	23.720*	0.000016*	19711.449*
Interaction (SL x NAP)	15	0.000063ns	0.000005ns	24.114ns	36.215ns	0.000001ns	6633.122*
Blocks	2	0.000185ns	0.000007ns	14.040ns	17.320ns	0.000002ns	1146.115ns
Residual	49	0.000038	0.000004	18.899	10.884	0.000002	3828.760
CV (%)		10.40	12.64	9.50	3.50	2.58	22.94

ns, **, *Not significant and significant at $p < 0.01$ and $p < 0.05$, respectively; [1]Statistical analysis performed after transforming the data to log x



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

Figure 1. Relative growth rate for stem diameter - RGRsd (A and B) and plant height - RGRph (C and D) of sesame, cv. CNPA G3, in the period of 25 to 60 days after sowing, as a function of the electrical conductivity of the irrigation water - ECw and proportions of nitrate-N and ammonium-N

organs, because the excess of salts restricts the turgor of tissues in expansion (Boughalleb et al., 2012; Wang et al., 2012).

The relative growth rates of stem diameter (Figure 1B) and plant height (Figure1D) varied significantly between the proportions of nitrate-N and ammonium-N. According to the comparison of means, plants cultivated with only nitrate-N (200/0) showed higher RGR, with mean values of 0.0056 mm mm^{-1} d^{-1} and 0.0102 cm cm^{-1} d^{-1}, respectively, thus 37.2 and 13.60% higher in comparison to the use of only ammonium-N as source of N (0/200). However, the lowest means of RGRsd and RGRph occurred for the NO_3^--N/NH_4^+-N proportion of 150/50, significantly differing only from plants fertilized with 200/0. The reason for which the NH_4^+ ion contributed to the lower RGRsd and RGRph of sesame plants is possibly related to alterations in the pH of the medium (acidification of the rhizosphere) and to the cytotoxic effects at high concentrations of NH_4^+ (Ivanova & Staden, 2009).

The number of days for flowering of CNPA G3 sesame linearly increased with the increasing saline levels and, according to the regression equation (Figure 2A), there were increases in NDF on the order of 4.52% per unit increase in ECw, i.e., plants irrigated with water of highest saline level (ECw of 3.0 dS m^{-1}) showed increment of 10.87% in NDF, compared with those irrigated with water of lower saline level (0.6 dS m^{-1}). According to Santos et al. (2012), the increase in NDF can be related to the genetics of the plant, which osmotically adjusts in the initial development stage, allocating larger amount of reserves in the form of energy for

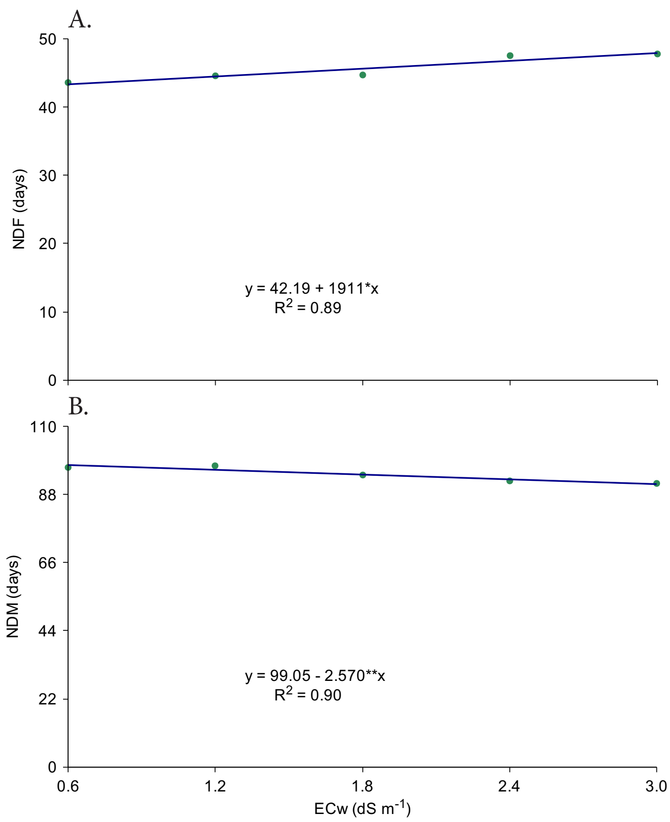


Figure 2. Number of days for flowering - NDF (A) and maturation of capsules - NDM (B) of sesame, cv. CNPA G3, cultivated with different proportions of nitrate-N and ammonium-N, as a function of the electrical conductivity of the irrigation water

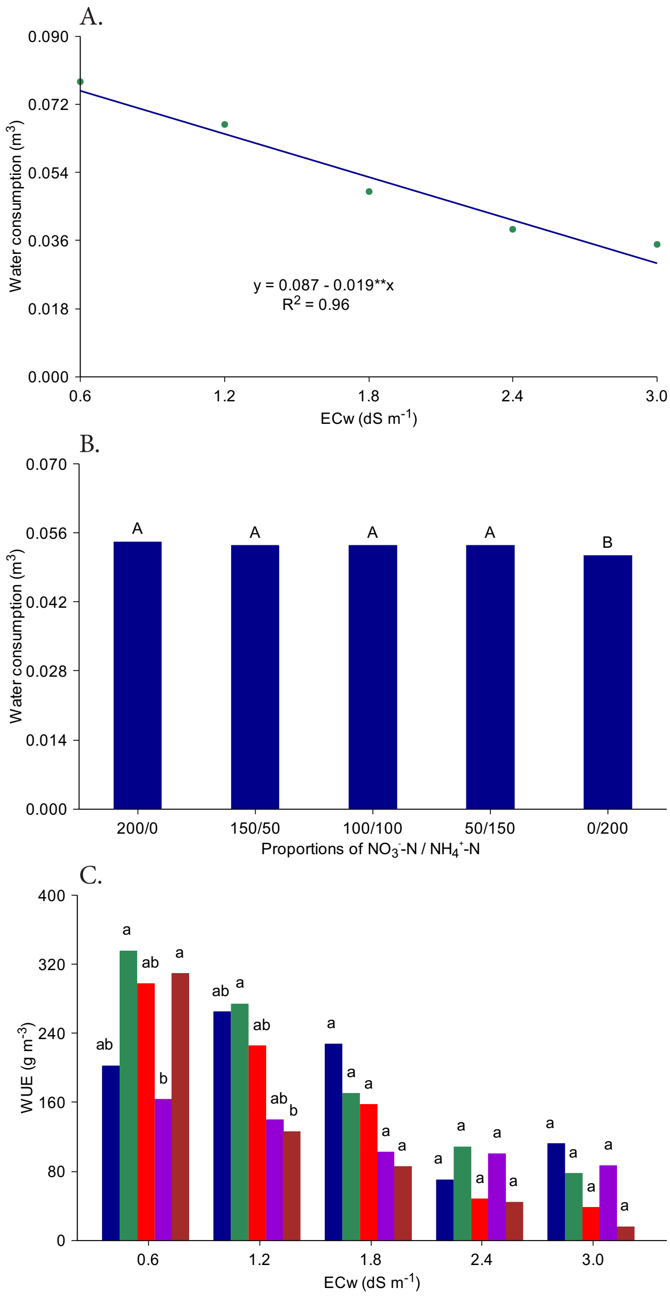
accumulation of sugars, organic acids and ions in the vacuole. This energy, under non-stress conditions, would be used for growth and flowering, resulting in a shorter period.

As to the number of days for maturation of sesame capsules, there was an opposite behavior in relation to that of flowering and, based on the regression equation (Figure 2B), there was a decreasing linear effect with reduction on the order of 2.59% in NDM per unit increase in irrigation water salinity between plants subjected to ECw of 0.6 and 3.0 dS m^{-1}, with decrease of 6.22% (6.17 days) in NDM, in comparison to plants irrigated with water of 0.60 dS m^{-1}. It should be pointed out that the decrease in the number of days for maturation of sesame capsules was possibly due to the osmotic stress caused by the increase in the saline concentration of the soil solution, which promoted early senescence and symptoms of ionic toxicity (burning on the leaves). On the other hand, the precocity in the cultivation cycle is an important characteristic, because the Brazilian programs of genetic improvement aim to select increasingly precocious sesame genotypes to obtain maximum yield.

The water consumption (WC) of sesame plants linearly decreased with the increase in irrigation water salinity and, based on the regression equation (Figure 3A), there was a decrease of the order of 21.83% per unit increase in ECw, i.e., reduction of 60.31% in WC in plants irrigated with water of higher saline level (3.0 dS m^{-1}) in relation to those under lower saline level (0.6 dS m^{-1}). The decrease of water consumption in plants under saline conditions may be related to the fact that the presence of salts in the rhizosphere restricts the water flow and reduces its absorption, due to the osmotic effect, inducing a water stress (Munns & Tester, 2008). Similar results were also found by Nobre et al. (2014), who evaluated water consumption of castor bean cv. 'BRS Energia', subjected to irrigation with saline water, and observed linear reduction on the order of 11.31% per unit increase in water electrical conductivity.

For the factor proportions of nitrate-N and ammonium-N, based on the comparison of means (Figure 3B), the variable WC of sesame plants fertilized with 0/200 mg significantly differed ($p < 0.05$) from the values of other proportions of NO_3^--N and NH_4^+-N. In the comparison between the data obtained with the different proportions of NO_3^--N and NH_4^+-N, the lowest water consumption (0.051 m^3) occurred in plants subjected to the proportion of 0/200 mg kg^{-1} of NO_3^--N/NH_4^+-N and, therefore, significantly lower than those of other treatments. Thus, the lower WC of sesame plants cultivated exclusively with ammonium has been related to the negative alteration caused in the intracellular water potential due to the greater resistance to water flow in the roots, resulting from the reduction in the osmotic potential and hormonal production of the plants (Cruz et al., 2008).

The water use efficiency (WUE) as a function of the proportions of nitrate-N and ammonium-N at each level of electrical conductivity of the irrigation water (Figure 3C), varied only between plants irrigated with waters of 0.6 and 1.2 dS m^{-1}, and the NO_3^--N/NH_4^+-N proportion of 150/50 led to the highest values of WUE, 335.39 and 273.94 g m^{-3}, respectively, significantly differing only from the proportion of 0/200. Frequently, at low ammonium concentrations, there



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

Figure 3. Water consumption - WC of sesame, cv. CNPA G3, as a function of the electrical conductivity of the irrigation water (A) and proportions of nitrate-N and ammonium-N (B), and water use efficiency - WUE (C), as a function of the interaction between the factors electrical conductivity of the irrigation water and proportions of nitrate-N and ammonium-N

is an increase in the absorption of nitrate, which results in greater plant growth; however, on the other hand, higher concentrations normally inhibit the growth, reflecting in production losses in the crops (Cárdenas-Navarro et al., 2006). When the proportions of nitrate-N and ammonium-N were associated with the highest saline level (ECw of 3.0 dS m^{-1}), there were the lowest values of WUE, with relative reductions of 44.71, 76.99, 87.18, 46.84 and 94.83% for proportion of NO_3^--N and NH_4^+-N of 200/0, 150/50, 100/100, 50/150, 0/200 mg kg^{-1}, respectively, compared with the lowest saline level of the irrigation water (0.6 dS m^{-1}).

In the follow-up analysis of the factor saline levels inside the proportions of NO_3^--N and NH_4^+-N, there was significant effect on sesame WUE only in plants irrigated with ECw levels of 1.2 dS m^{-1} ($y = 288.11-5.85^{**}x-5.8771^{*}x^2$ $R^2 = 0.91$) and 1.8 dS m^{-1} ($y = 288.4- 67.941^{**}x + 6.2633^{*}x^2$ $R^2 = 0.95$). In these equations, the x varies from 1 to 5, representing the proportions of NO_3^--N and NH_4^+-N of 200/0, 150/50, 100/100, 50/150 and 0/200 mg kg^{-1}, respectively. On the other hand, although the irrigation with ECw levels of 0.6, 2.4 and 3.0 dS m^{-1} did not interfere significantly with the WUE of sesame, when associated with the different proportions of N, it led to mean values of 261.46, 74.23 and 65.95 g m^{-3}.

Conclusions

1. Irrigation with saline water above 0.6 dS m^{-1} inhibits growth, retards flowering and accelerates maturation of capsules in CNPA G3 sesame.

2. The proportion of 200/0 mg kg^{-1} of NO_3^--N and NH_4^+-N promotes the highest relative growth rate of stem diameter and plant height in sesame in the period of 25 to 60 days after sowing.

3. The water consumption decreases with the increase in ECw and was significantly lower at the proportion of 0/200 of NO_3^--N and NH_4^+-N.

4. The interaction between the factors (water salinity levels and proportions of nitrate and ammonium) significantly affects the water use efficiency, and the highest value was obtained with ECw of 0.6 dS m^{-1} and fertilization with 150/50 mg kg^{-1} of NO_3^--N and NH_4^+-N.

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