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Scientific Article

Water and salt stress on gas exchange, chlorophyll and growth of sesame in brazilian semi-arid

Estresses hídrico e salino nas trocas gasosas, clorofila e crescimento do gergelim no semiárido brasileiro

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ABSTRACT - Semi-arid regions face problems such as water deficit and salt accumulation in the soil, which compromise the physiological performance and growth of crops. This study evaluated the effects of salinity and water deficit on gas exchange, chlorophyll, and growth in sesame. The experiment was conducted at the Piroás Experimental Farm, belonging to the Universidade da Integração Internacional da Lusofonia Afro-brasileira, Redenção, Ceará, Brazil. The experimental design used was randomized blocks in a split-plot scheme, with four replicates. The plots correspond to five electrical conductivities of irrigation water (ECw - 0.8, 1.6, 2.4, 3.2, and 4.0 dS m^{-1}), and the subplots correspond to two water regimes, 50% and 100% of crop evapotranspiration (ETc). Increase in the electrical conductivity of irrigation water above 1.6 dS m^{-1} reduces the CO_2 assimilation rate, stomatal conductance, transpiration, and water use efficiency, resulting in lower vegetative development of BRS Anahí sesame. A 50% reduction in ETc reduced all physiological parameters, chlorophyll, and consequently growth in the sesame crop.

Keywords: *Sesamum indicum* L. Salinity. Water deficit. Morphophysiological performance.

RESUMO - As regiões semiáridas apresentam problemas, como déficit hídrico e acúmulo de sais no solo, que comprometem o desempenho fisiológico e o crescimento das culturas. Este estudo avaliou os efeitos da salinidade e do déficit hídrico sobre as trocas gasosas, clorofila e crescimento do gergelim. O experimento foi conduzido na Fazenda Experimental Piroás, pertencente à Universidade da Integração Internacional da Lusofonia Afro-brasileira, Redenção, Ceará, Brasil. O delineamento experimental utilizado foi de blocos ao acaso em esquema de parcela subdividida, com quatro repetições. As parcelas correspondem a cinco condutividades elétricas da água de irrigação (CEa - 0,8; 1,6; 2,4; 3,2 e 4,0 dS m^{-1}), e as subparcelas a dois regimes hídricos, 50% e 100% da evapotranspiração da cultura (ETc). O aumento da condutividade elétrica da água de irrigação acima de 1,6 dS m^{-1} reduz a taxa de assimilação de CO_2, condutância estomática, a transpiração e a eficiência do uso da água, refletindo em menor desenvolvimento vegetativo do gergelim BRS Anahí. A redução de 50% da ETc reduziu a taxa de assimilação de CO_2, eficiência do uso da água, clorofila e consequentemente o crescimento na cultura do gergelim.

Palavras-chave: *Sesamum indicum* L. Salinidade. Déficit hídrico. Desempenho morfofisiológico.

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INTRODUCTION

Sesame (*Sesamum indicum* L.) is a plant belonging to the Pedaliaceae family, of the genus *Sesamum*, known for its high ability to adapt to different soil and climate conditions, especially in hot tropical regions (KOUIGHAT et al., 2024). This oilseed is cultivated globally in about 71 countries, especially those in Africa and Asia, which account for approximately 81.38% of world grain production (ARRIEL; BELTRÃO, 2023). In Brazil, the national average yield was 482 kg ha^{-1} in the 2022/2023 harvest, and increased to 547 kg ha^{-1} in the 2023/2024 harvest, in the first half of 2024 (CONAB 2024).

The Brazilian Northeast is a region with a semi-arid climate, which stands out for its irregular rainfall throughout the year (BARBOSA et al., 2022). In this context, it is necessary to use irrigation to meet the water needs of plants and ensure food security. However, in this region, salts are commonly present in irrigation water, making it brackish (ARRIEL; BELTRÃO 2023; SOUSA et al., 2022), leading to excessive absorption of Na^+ and Cl^-, due to the transpiration flow, affecting the physiological functions of the plant, including the closure of the stomata, reducing the availability of CO_2 and the concentration of essential pigments, such as chlorophyll and carotenoids (SOUSA et al., 2018; SOUSA et al., 2021) and negatively impacting agricultural production, from seed germination to final yield.

Water deficit is one of the main limiting factors for plant growth,

especially in semi-arid regions. However, this condition occurs when the soil does not have enough water to meet the water needs of plants, triggering responses such as the production of abscisic acid (ABA), stomatal closure, accumulation of osmolytes, and changes in the redox balance with a direct consequence of decreased yield (CAMPOS; SANTOS; NACARATH, 2021; SOUSA et al., 2023).

When combined, water stress and salt stress can increase ionic toxicity and lead to reduction in cell volume, nutritional imbalance, partial closure of stomata, increased leaf temperature, and reduced agronomic performance (SOUSA et al., 2022; CAMPOS; SANTOS; NACARATH, 2021). For example, Pereira et al. (2024) concluded that salt stress negatively impacted growth and biomass production in sesame crop cv. BRS Anahí. Lima et al. (2023), when evaluating BRS Anahí sesame under controlled water deficit, concluded that the genotype has a semi-tolerance characteristic with morphological and biochemical adjustments.

Thus, the hypothesis of the present study is that salt and water stresses compromise gas exchange, chlorophyll and growth of BRS Anahí sesame. Therefore, the objective of this study was to evaluate the effects of water and salt stress on gas exchange, pigments and growth of the sesame crop cv. BRS Anahí.

MATERIAL AND METHODS

The experiment was conducted from August 24 to October 14, 2023, at the Piroás Experimental Farm belonging to the Universidade da Integração Internacional da Lusofonia Afro-brasileira (UNILAB), located in the Baturité Massif, in the city of Redenção, Ceará, Brazil, approximately 55 km away from the capital Fortaleza (04°14'53"S, 38°45'10" W, and average altitude of 240 m). The climate of the region is of the BSh' type (hot semi-arid climate) with predominant rainfall in the summer and autumn seasons (ALVARES et al., 2013).

Precipitation was monitored using a rain gauge installed in the experimental area. Relative humidity and maximum and minimum air temperature values were collected daily during the experiment (Figure 1) using a Data logger (HOBO® U12-012 Temp/RH/Light/Ext).

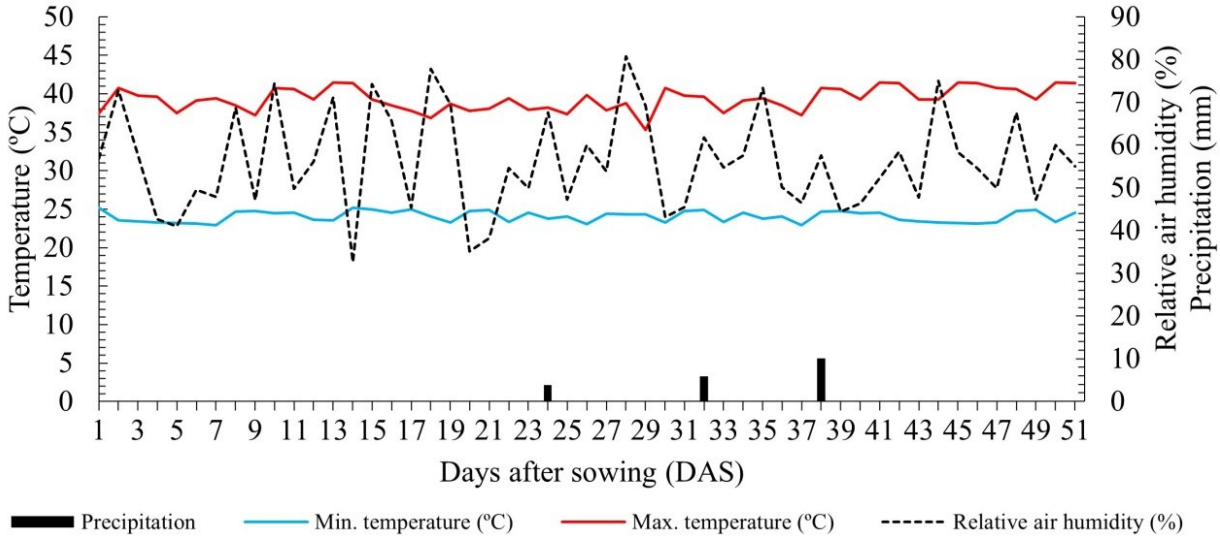


Figure 1. Average values of maximum temperature (Max), minimum temperature (Min), relative humidity and precipitation obtained during the experimental cycle.

The soil of the experimental area was classified as *Argissolo vermelho-amarelo* (Ultisol) (SANTOS et al., 2018). Soil samples were collected in the 0-20 cm layer and sent for analysis to the Soil and Water Laboratory of the Department of Soil Sciences of the Federal University of Ceará, to determine the chemical attributes (Table 1), according to the methodology of Teixeira et al. (2017).

Table 1. Soil chemical characteristics before the experiment.

OM	N	P	K	Mg	Ca	Na	pH H_2O	ESP (%)	ECse dS m^{-1}
------g kg^{-1}------		mg kg^{-1}	g kg^{-1}	----------$cmol_c$ dm^{-3}---------					
12.52	0.79	14	0.14	2.5	5.2	0.18	5.6	2	0.9

OM = organic matter; pH = hydrogen potential; ESP = exchangeable sodium percentage; ECse = electrical conductivity of soil saturation extract.

The experimental design was randomized blocks, in a split-plot scheme, with four replicates. Plots corresponded to five electrical conductivities of irrigation water - ECw: 0.8, 1.6, 2.4, 3.2 and 4.0 dS m^{-1}, and subplots corresponded to two water regimes - WR: 50 and 100% of crop evapotranspiration (ETc).

The brackish waters were prepared with the local-supply water of the Piroás farm (0.8 dS m^{-1}), using the sodium chloride (NaCl), calcium chloride ($CaCl_2.2H_2O$), and magnesium chloride ($MgCl_2.6H_2O$) salts, whose quantities were determined so as to obtain the desired ECw in the proportion of 7:2:1, following the relationship between the concentration of the salts in the water and its electrical conductivity ($mmol_c\ L^{-1}$ = EC × 10) (RHOADES; KANDIAH; MASHALI, 2000). Water electrical conductivity was measured periodically with a portable conductivity meter (AZ® 806505 pH/Cond./TDS/Salt).

Sesame (cultivar BRS Anahí) seeds were sown manually following the spacing of 1.0 m between rows and 0.3 m between plants, with distribution of eight seeds per hole, at a depth of 2 cm. At 14 days after sowing (DAS), right after seedling establishment, thinning was carried out, leaving two plants per hole.

A drip irrigation system was used in the experiment, with a spacing of 0.3 m between emitters, corresponding to one emitter per plant. Emitters with flow rates of 4 and 8 L h^{-1} were used in order to standardize the irrigation time, meeting the water regimes of 50 and 100% ETc, respectively. Uniformity tests were performed, obtaining a distribution uniformity coefficient (DUC) of approximately 92%.

Irrigation management was estimated daily by reference evapotranspiration, using data from a Class A evaporation pan. On the days when rainfall events were recorded, the values were considered in irrigation. Crop evapotranspiration in mm day^{-1} was calculated from the evaporation measured in the Class A pan, by Equation 1:

$$ETc = ECA \times Kp \times Kc \quad (1)$$

where:
ETc - Crop evapotranspiration, in mm day^{-1};
ECA - Evaporation measured in the class A pan, in mm day^{-1};
Kp - Class A pan coefficient, (1) dimensionless;
Kc - Crop coefficient, dimensionless

The following crop coefficients (Kc) were adopted: 0.6 (up to 45 DAS) and 0.8 (45 to 51 DAS), according to Amaral and Silva (2008). A leaching fraction of 15% was added to the applied irrigation depth (AYERS; WESTCOT, 1999), with a two-day interval. Irrigation time was obtained using Equation 2:

$$Ti = \frac{ETc \times Sp}{Ea \times q} \times 60 \quad (2)$$

where:
Ti - Irrigation time (min);
ETc - Crop evapotranspiration in the period (mm);
Sp - spacing between drippers;
Ea - application efficiency (0.92);
q - flow rate (L h^{-1}).

Crop fertilization management was carried out based on the initial chemical analysis of the soil (Table 1) from organic sources (cattle manure and goat biofertilizer). For this purpose, the maximum recommendation provided by Arriel and Beltrão (2023) was adopted, corresponding to: 125 kg ha^{-1} of N, 35 kg ha^{-1} of P_2O_5 and 150 kg ha^{-1} of K_2O.

At 51 days after sowing (51 DAS), gas exchange analyses were performed to determine CO_2 assimilation rate (A, µmol CO_2 m^{-2} s^{-1}), transpiration (E, mmol m^{-2} s^{-1}), stomatal conductance (gs, mol H_2O m^{-2} s^{-1}), internal carbon concentration (Ci, µmol CO_2 mol^{-1}), water use efficiency (WUE, [µmol m^{-2} s^{-1} (µmol m^{-2} s^{-1})$^{-1}$]) and leaf temperature (LT, ºC). The plants were evaluated in the third fully expanded leaf, counted from the apex, with an infrared gas analyzer (IRGA - LI-6400XT, LICOR, Lincoln, USA), in an open system, with air flow rate of 300 mL min^{-1}, CO_2 of 400 µmol mol^{-1}, and photosynthetically active radiation of 1300 µmol m^{-2} s^{-1}.

In addition, in the same period (51 DAS) on the same leaf where gas exchange was measured, the relative chlorophyll index (RCI, SPAD) was measured with a portable meter (SPAD-502 Plus, Minolta, Tokyo, Japan). Gas exchange and chlorophyll measurements were taken between 9:00 a.m. and 11:00 a.m.

At 51 DAS, the following growth variables were analyzed: stem diameter (SD, mm), using a digital caliper measuring two centimeters from the ground; number of leaves (NL), obtained by direct counting of the leaves in each plant; plant height (PH, cm), measured with a tape measure, from the base to the apex of the plant; and leaf area (LA, cm^2), using an area meter (Area meter, LI-3100, LICOR, Lincoln, USA).

The data obtained were subjected to the Kolmogorov-Smirnov normality test at 0.05 probability level. After normality was verified, the results were subjected to analysis of variance using the F test ($p \leq 0.05$). In cases of significance of the quantitative treatment (electrical conductivity of the water), polynomial regression analysis was applied, while in cases of interaction, the water regimes were analyzed at each level of ECw. Comparison of means by Tukey test was performed for qualitative treatments (water regimes), using the Assistat 7.7 Beta program (SILVA; AZEVEDO, 2016).

RESULTS AND DISCUSSION

The interaction between water electrical conductivity and water regimes significantly affected CO_2 assimilation rate and transpiration ($p \leq 0.01$), as well as leaf temperature, internal CO_2 concentration and water use efficiency ($p \leq 0.05$) (Table 2). On the other hand, stomatal conductance was influenced separately by the electrical conductivity of irrigation water ($p \leq 0.05$), while the relative chlorophyll index was affected only by the water regimes ($p \leq 0.05$).

The CO_2 assimilation rate in plants under the 100% ETc water regime showed a decreasing response, with an average reduction of 1.86 µmol CO_2 m^{-2} s^{-1} per unit increase in ECw. Under the 50% ETc water regime, the CO_2 assimilation rate showed a maximum value of 19.43 µmol CO_2 m^{-2} s^{-1} at ECw of 2.09 dS m^{-1} (Figure 2A).

Table 2. Summary of the analysis of variance for CO_2 assimilation rate (*A*), transpiration (*E*), stomatal conductance (*gs*), internal carbon concentration (*Ci*), leaf temperature (*LT*), water use efficiency (*WUE*) and relative chlorophyll index (*RCI*) of sesame plants grown under different levels of irrigation water electrical conductivity (ECw) and water regimes (WR).

Sources of variation	DF	Mean squares						
		A	E	gs	Ci	LT	WUE	RCI
Blocks	3	2.10^{ns}	0.26^{ns}	7.66^{ns}	287.37*	0.55^{ns}	0.48*	16.71^{ns}
ECw	4	48.40**	2.68**	4.27*	1266.75**	33.97**	4.17**	97.05^{ns}
Residual (ECw)	12	4.32	0.47	2.54^{ns}	75.83	0.25	0.13	41.45
Plots	19							
Water Regime (WR)	1	23.36*	0.44^{ns}	0.11^{ns}	210.08^{ns}	1.49*	0.7^{ns}	402.2*
Residual (WR)	15	3.09	0.18	5.56	99.27	0.3	0.19	72.1
ECw × WR	4	24.96**	1.51**	10.99^{ns}	421.6*	1.28*	0.79*	98.99^{ns}
Total	39							
CV - ECw (%)	-	12.29	12.77	11.12	2.46	1.66	11.59	16.87
CV - WR (%)	-	10.39	8.06	15.59	2.82	1.83	13.74	12.25

DF: Degrees of freedom; (*) significant by the F test at 5% probability level; (**) Significant by the F test at 1% probability level; ns: not significant; CV: Coefficient of variation.

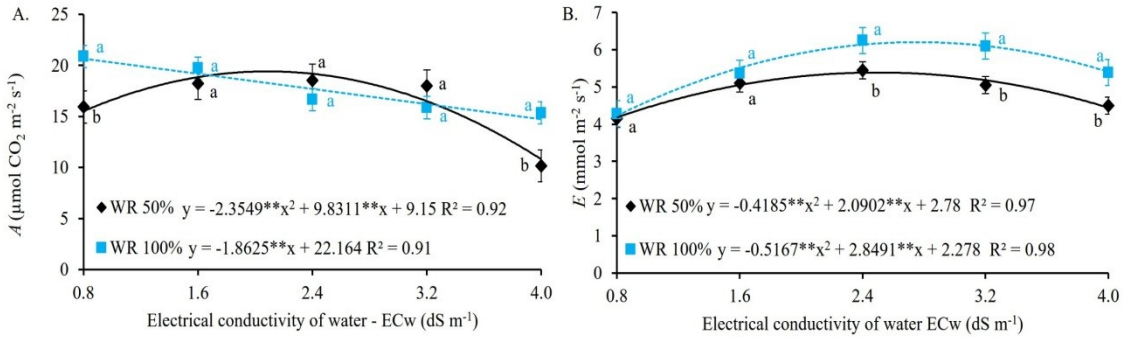


Figure 2. CO_2 assimilation rate – *A* (A) and transpiration – *E* (B) of sesame plants under different levels of electrical conductivity of irrigation water and water regimes of 100% (■) and 50% (♦) ETc. Different lowercase letters at the same ECw indicate significant difference by the F test ($p \leq 0.05$). Vertical bars represent the standard error (n = 4). ** - Significant at $p \leq 0.01$ by the F test.

The reduction in CO_2 assimilation rate is associated with the deposition of salts in the soil through irrigation water. Salts, in turn, can cause a reduction in the photosynthetic rate, due to the osmotic and toxic effects of the ions, as reported by Sousa et al. (2022). In addition, it can be observed that leaf gas exchange is usually controlled by stomatal opening to allow CO_2 to enter, resulting in water loss. Therefore, in situations of salt and/or water stress, there is a restriction in CO_2 assimilation (PEREIRA FILHO et al., 2019).

Similar responses with sesame crop were observed by Dias et al. (2022), when studying different levels of electrical conductivity of irrigation water (0.3, 1.1, 1.9, 2.7, and 3.5 dS m^{-1}) in a full irrigation regime. These authors observed that the increase in the electrical conductivity of irrigation water reduced the CO_2 assimilation rate, with average decreases of 0.842 μmol CO_2 m^{-2} s^{-1} per unit increase in the electrical conductivity of irrigation water. Pereira Filho et al. (2019), when studying the lima bean crop under different water regimes (50% and 100% ETc) and salt stress, also observed a reduction in CO_2 assimilation rate, with a decrease of approximately 3.57 and 1.99 μmol CO_2 m^{-2} s^{-1} per unit increase in ECw, for the water regimes of 50% and 100% ETc, respectively.

The increase in the electrical conductivity of the water had a negative impact on transpiration (*E*), with a greater intensity in the 50% ETc water regime. The data obtained showed maximum transpiration of 5.39 and 6.2 mmol m^{-2} s^{-1} at an ECw of 2.5 and 2.76 dS m^{-1}, for the water regimes of 50% and 100% ETc, respectively (Figure 2B).

This result was reflected in the closure of the stomata, which is a consequence of abiotic stresses, such as water and/or salt stress, which result in a reduction in water availability, leading to a decrease in transpiration (BARBOSA et al., 2022). This defense mechanism is employed by the plant to

avoid excessive water loss and the risk of dehydration, because under conditions of salt stress, water absorption is limited due to the increase in the osmotic potential of the soil (KOUIGHAT et al., 2024). On the other hand, under conditions of water stress, there is a signaling between the root and the shoot as a defense mechanism, mediated by abscisic acid, which in turn induces partial closure of the stomata (SOUSA et al., 2023).

When studying sesame crop irrigated with brackish water with different levels of electrical conductivity (0.3 and 2.7 dS m^{-1}), Silva et al. (2021) found that salt stress did not negatively affect transpiration. Barbosa et al. (2022), when conducting a study with peanut crop subjected to water stress (50% and 100% ETc) and different electrical conductivities of irrigation water (1.0, 2.0, 3.0, 4.0, and 5 dS m^{-1}), found a reduction of 25.94% under the 50% ETc water regime and a reduction of 14.88% under the 100% ETc water regime.

The increase in the electrical conductivity of irrigation water resulted in a reduction in stomatal conductance, with a maximum value of 3.77 mol $H_2O\,m^{-2}\,s^{-1}$ for an ECw of 2.14 dS m^{-1}. (Figure 3). The partial closure of the stomata, caused by the reduction in the osmotic potential of the plant and by the disparity between the absorption of water by the roots and the losses by transpiration, resulting from salt stress, is considered a strategy to avoid excessive water loss, reducing transpiration (DIAS et al., 2022; CAMPOS; SANTOS; NACARATH, 2021).

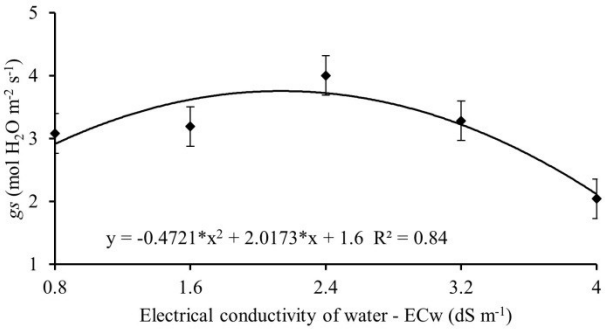


Figure 3. Stomatal conductance – *gs* of sesame plants under different levels of electrical conductivity of irrigation water. Vertical bars represent the standard error (n = 4). * - Significant at $p \leq 0.05$ by the F test.

Unlike the results found in this study, Silva et al. (2021) concluded that stomatal conductance was not impaired, when studying the sesame crop (BRS Seda and BRS Anahí) with an electrical conductivity of 2.7 dS m^{-1}. On the other hand, Dias et al. (2022) recorded a reduction in the stomatal conductance of the sesame crop cv. BRS Seda irrigated with brackish water.

Internal CO_2 concentration was negatively affected by the increase in the electrical conductivity of irrigation water. It is worth pointing out that the responses of plants cultivated under the water regimes of 50% and 100% ETc showed average decreases of 12.52 µmol CO_2 mol^{-1} and 9.73 µmol CO_2 mol^{-1} per unit increase in ECw under the water regimes of 50% and 100% ETc, respectively (Figure 4A).

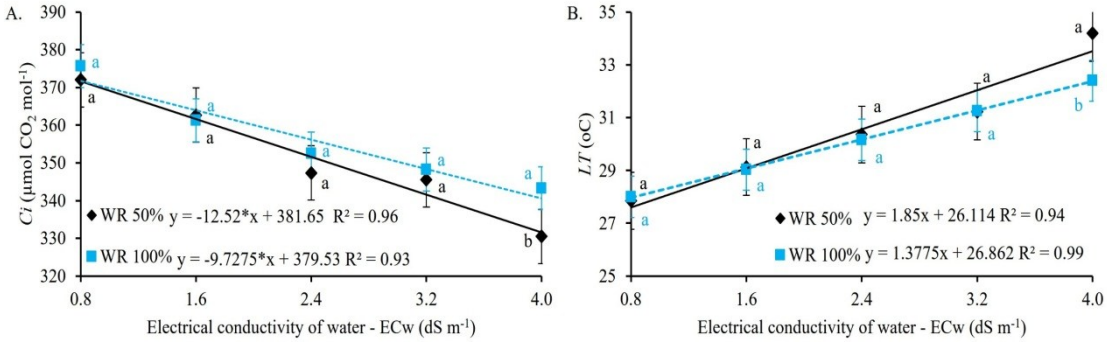


Figure 4. Internal carbon concentration – *Ci* (A) and leaf temperature – *LT* (B) of sesame plants under different levels of electrical conductivity of irrigation water and water regimes of 100% (■) and 50% (♦) ETc. Different lowercase letters at the same ECw indicate significant difference by the F test ($p \leq 0.05$). Vertical bars represent the standard error (n = 4). * - Significant at $p \leq 0.05$ by the F test.

Water stress combined with water salinity can lead to a situation of reduced internal CO_2 concentration. This is because salt stress intensifies the osmotic potential of the soil, thus decreasing water absorption and, consequently, CO_2 assimilation due to the lower input. In addition, the stomatal closure observed in Figure 3 with the increase in salinity causes less CO_2 diffusion for the production of sugars (BARBOSA et al., 2022; SOUSA et al., 2022).

When evaluating the sesame crop under different electrical conductivities (0.6, 1.2, 1.8, 2.4 and 3.0 dS m^{-1}) in a full irrigation water regime, Dias et al. (2019) found that the increase in the electrical conductivity of the water promoted

an average increase of 31.433 µmol CO_2 mol^{-1} in the internal carbon concentration per unit increase in ECw. Similar results were reported by Barbosa et al. (2022), who evaluated gas exchange in peanut crop as a function of different levels of electrical conductivity of the water (1.0, 2.0, 3.0, 4.0 and 5.0 dS m^{-1}) and water regimes (50% and 100% ETc), and observed reduction in internal CO_2 concentration.

Leaf temperature data (Figure 4B) increased by 1.85 ºC and 1.37 ºC per unit increase in the electrical conductivity of the water, under the water regimes of 50% and 100% ETc, respectively. In the regime of 50% ETc, leaf temperature varied from 27.59 °C at the minimum electrical conductivity (0.8 dS m^{-1}) to 33.52 °C at the maximum electrical conductivity (4.0 dS m^{-1}). Under full irrigation, the variation was from 27.96 °C to 32.37 °C at the same salinity levels, showing that the increase in ECw raises leaf temperature regardless of the water regime.

This behavior results from the reduction in transpiration values observed in the sesame crop in the present study (Figure 2B), especially under the highest salinity levels, as water acts as a thermal regulator of plants. Therefore, when there is a decrease in its absorption due to water and/or salt stress, this can lead to an increase in the internal temperature of the plant (SOUSA et al., 2021). On the other hand, the partial closure of the stomata and the reduced passage of water through them decreases latent heat exchange, causing an increase in leaf temperature (SOUSA et al., 2023).

Similar results were found by Barbosa et al. (2022) in the peanut crop, when they observed an increase in leaf temperature under salt stress. Unlike the results found in this study, Freitas et al. (2021) evaluated the effects of salt stress on peanut crop under different electrical conductivities of irrigation water (0, 1.0, 2.0, 3.0, 4.0, and 5.0 dS m^{-1}), under full irrigation (100% ETc), and observed decreases in leaf temperature with the increase in water electrical conductivity.

Instantaneous water use efficiency was negatively affected by the increase in electrical conductivity, regardless of the water regime, but more intensely under 50% ETc, showing a maximum value of 3.58 [µmol m^{-2} s^{-1} (µmol m^{-2} s^{-1})$^{-1}$] at the electrical conductivity of water of 1.76 dS m^{-1}. The 100% ETc water regime, in turn, was better represented by the average reduction of 0.7238 [µmol m^{-2} s^{-1} (µmol m^{-2} s^{-1})$^{-1}$] per unit increase in the electrical conductivity of irrigation water (Figure 5).

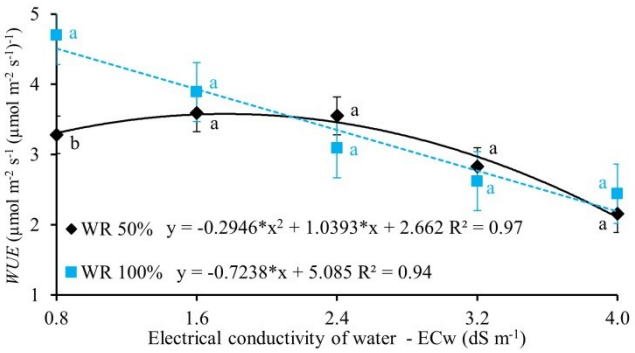


Figure 5. Instantaneous water use efficiency – *WUE* in sesame plants under different levels of electrical conductivity of irrigation water and water regimes of 100% (■) and 50% (♦) ETc. Different lowercase letters at the same ECw indicate significant difference by the F test ($p \leq 0.05$). Vertical bars represent the standard error (n = 4). * - Significant at $p \leq 0.05$ by the F test.

The combined effect of the absorption of specific ions and the reduction in water absorption may be directly related to the decrease in water use efficiency (LIMA et al., 2018). However, plants under combined stresses tend to adopt strategies for a more conservative use of water, through partial closure of stomata, regulation of transpiration losses, and reduction in the number of leaves and leaf area, as a survival mechanism (SOUSA et al., 2022).

Ebrahimian, Fujimaki and Toderich (2023), evaluating the Lebap-55 sesame cultivar under water and salt stress conditions, describe that the water use efficiency increased with the salinity level, from 2.24 to 3.99 kg m^{-3}, when compared to the control treatment. On the other hand, Dias et al. (2018), when studying sesame crop under different electrical conductivities (0.6, 1.2, 1.8, 2.4 and 3.0 dS m^{-1}) in a full irrigation water regime, found that salt stress negatively affected water use efficiency, causing an average decrease of 0.063 µmol CO_2 m^{-2} s^{-1} (µmol H_2O m^{-2} s^{-1})$^{-1}$ per unit increase in ECw.

Reducing the water regime from 100% to 50% ETc resulted in a decrease of 84.66% in the relative chlorophyll index (Figure 6). Under conditions of low water availability, the enzymatic activity of chlorophyllase can be activated, resulting in the degradation of chlorophyll molecules and inducing the destruction of chloroplasts, or there can also be a reduction in the enzymatic activity of protochlorophyll reductase, making it difficult for the precursor molecule of chlorophyll (protochlorophyll) to convert to this pigment, resulting in a lower chlorophyll level (DIAS et al., 2018).

Similar results were reported by Kouighat et al. (2024) when assessing the tolerance of the sesame crop to water stress, subjecting it to three different levels of field capacity (100%, 75% and 50%). The results showed a decrease of 67.64% in the relative chlorophyll index, caused by the reduction of field capacity from 100% to 50%. Pereira Filho et al. (2019) observed that the reduction of the water regime from 100% to 50% ETc had a negative impact on this variable.

The analysis of variance presented in Table 3 showed that plant height, stem diameter, and leaf area were significantly influenced by the interaction between the factors water electrical conductivity and water regimes ($p \leq 0.01$), as well as the number of leaves ($p \leq 0.05$).

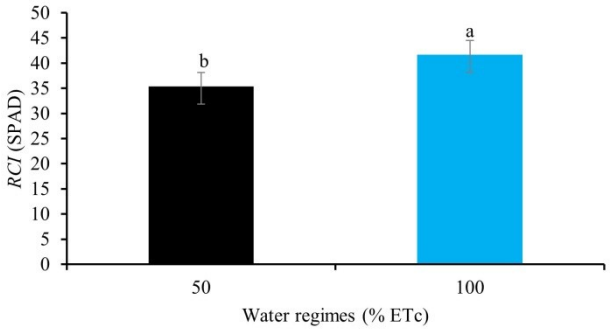


Figure 6. Relative chlorophyll index – *RCI* of sesame plants under water regimes of 100% and 50% ETc. Lowercase letters differentiate the means by Tukey test ($p \leq 0.05$). Vertical bars represent the standard error (n = 4).

Table 3. Summary of the analysis of variance for plant height (PH), number of leaves (NL), stem diameter (SD), and leaf area (LA) of sesame plants grown under different levels of irrigation water electrical conductivity (ECw) and water regimes (WR).

Sources of variation	DF	Mean squares			
		PH	NL	SD	LA
Blocks	3	183.53^{ns}	13.15^{ns}	0.29^{ns}	332.03^{ns}
ECw	4	1999.14**	190.06**	9.18**	4269.03**
Residual (ECw)	12	316.19	19.73	1.68	485.62
Plots	19				
Water regime (WR)	1	4050.35**	120.2**	30.38**	16397.71**
Residual (WR)	15	67.46	9.13	0.68	185.89
ECw × WR	4	1002.57**	38.63*	4.82**	3120.74**
Total	39				
CV - ECw (%)	-	16.67	15.45	16.06	19.64
CV - WR (%)	-	11.56	14.11	17.28	18.53

DF: Degrees of freedom; (*) significant by the F test at 5% probability level; (**) Significant by the F test at 1% probability level; ns: not significant; CV.: Coefficient of variation.

Plant height, under the 100% ETc water regime, showed a decrease of 17.69 cm per unit increase in ECw. Under the 50% ETc water regime, plant height had a maximum value of 36.92 cm at ECw of 2.13 dS m^{-1} (Figure 7A).

Excess salts in the soil increase its osmotic potential, causing a reduction in water absorption by plants, consequently inhibiting the absorption of some nutrients. This explains the reduction in plant height with the increase in the electrical conductivity of water. These effects can be intensified when there is association with water stress, as water reduction, in turn, drastically affects some vital processes (PEREIRA FILHO et al., 2020). Cell division and expansion are among the first processes impacted when there is a moderate water reduction, mainly associated with the reduction of cell turgidity, limiting these processes (SOUSA et al., 2022).

When working with sesame crop (CNPA G3 cultivar) subjected to salt stress, Dias et al. (2017) reported reduction in plant height with the increase of salts in irrigation water. Similar results were found by Pereira Filho et al. (2020) in the lima bean crop irrigated with brackish water under water regimes of 50% and 100% ETc.

Number of leaves was reduced by the increase in water salinity under both water regimes used (50% and 100% ETc), with an average decrease of 4.95 per unit increase in ECw under the full irrigation regime. Under the 50% ETc water regime, its approximate value was 14 leaves, at ECw of 0.53 dS m^{-1} (Figure 7B).

The impairment of water absorption by the plant, especially when combined with other stresses, such as salt stress, can lead to significant biometric and physiological changes, resulting in plants with lower leaf production. This behavior includes a decrease in shoot growth and a reduction in photosynthetic efficiency (Figure 2), while a smaller assimilatory area reduces production capacity, as a strategy to minimize the negative impact caused by the decrease in water absorption (CAMPOS; SANTOS; NACARATH, 2021).

Similar results were obtained by Barbosa et al. (2022) when evaluating the initial growth of the peanut crop under conditions of combined water and salt stress. These same authors found that the number of leaves was reduced in response to the increase in the electrical conductivity of water (1.0, 2.0, 3.0, 4.0 and 5.0 dS m^{-1}). Similarly, Dias et al. (2019) when studying sesame crop under salt stress, found a negative effect on the number of leaves.

Stem diameter was reduced with the increase in ECw under both water regimes used. The response of plants

cultivated under the 100% ETc water regime shows an average reduction of 1.22 mm per unit increase in water salinity. For the 50% ETc water regime, a maximum diameter of 4.90 mm was obtained, at a conductivity of 2.27 dS m^{-1} (Figure 7C). Water stress causes a reduction in cell division, resulting in a decrease in plant development. At the same time, the low absorption of water and nutrients resulting from salt stress contributes to maximizing the reduction of stem diameter (BARBOSA et al., 2022).

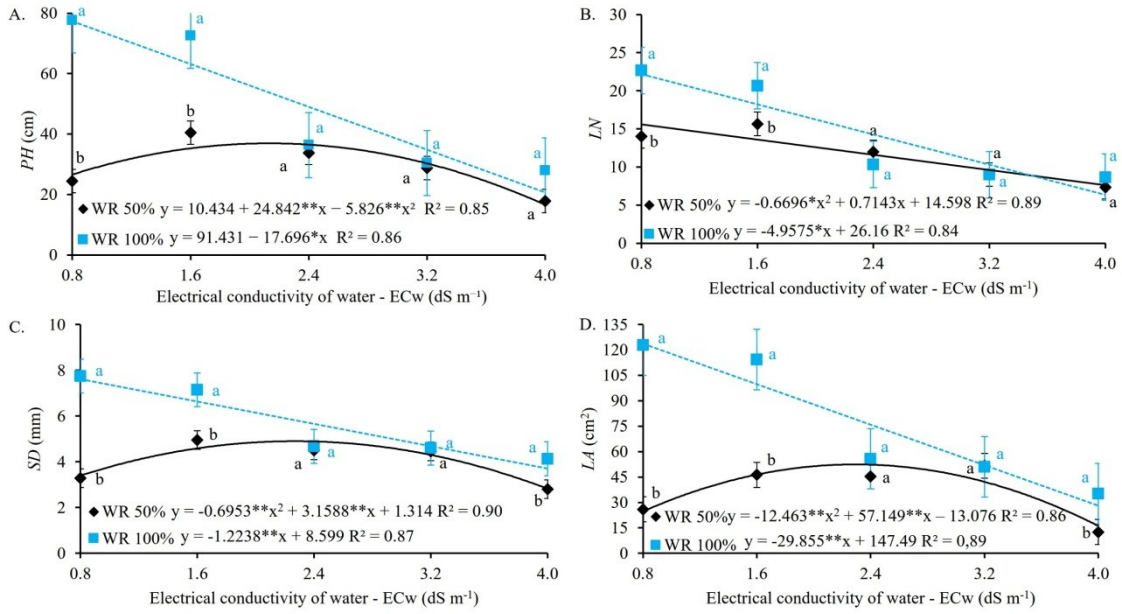


Figure 7. Plant height – *PH* (A), number of leaves – *NL* (B), stem diameter – *SD* (C) and leaf area – *LA* (D) of sesame plants under different levels of electrical conductivity of irrigation water and water regimes of 100% (■) and 50% (♦) ETc. Different lowercase letters at the same ECw indicate significant difference by the F test ($p \leq 0.05$). Vertical bars represent the standard error (n = 4). *, ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by the F test, respectively.

It should be noted that stem diameter directly reflects the water status of the plant, linked to the capacity to transport sap, being an important indicator of stress (KOUIGHAT et al., 2024). Pereira Filho et al. (2020), when evaluating the initial growth of the lima bean crop under water and salt stress, recorded a reduction in stem diameter as the electrical conductivity of irrigation water increased (1.1, 2.1, 3.1, 4.1 and 5.1 dS m^{-1}), with decreases of 0.35 and 0.29 mm for the water regimes of 100% and 50% ETc, respectively. The results of the present study are also in line with those reported by Lessa et al. (2022), who found a reduction in the stem diameter of the peanut crop caused by salt stress.

Sesame leaf area decreased under the 100% ETc water regime, with the increase in water salinity, showing an average reduction of 29.85 cm^2 per unit increase in ECw. On the other hand, plants cultivated under the 50% ETc water regime, according to the equation, had a maximum leaf area of 52.44 cm^2 at an electrical conductivity of 2.29 dS m^{-1} (Figure 7D).

In glycophyte plants subject to salinity conditions, the decrease in leaf area is one of the first responses observed, due to the efforts of the plants to adapt and acclimatize to the osmotic effects and toxicity of salts (SOUSA et al., 2022). In addition, partial closure of the stomata to minimize transpiration is an important mechanism employed by plants under water and/or salt stress conditions. Thus, under stress conditions, plants use this adaptation mechanism, but face metabolic and energy expenditures that minimize the development of new organs as well as leaf expansion (SOUSA et al., 2022; DAMASCENO et al., 2022).

Dias et al. (2019), when evaluating the sesame crop in response to different electrical conductivities of irrigation water (0.6, 1.2, 1.8, 2.4 and 3.0 dS m^{-1}) under a full irrigation water regime, concluded that salt stress reduced leaf area by about 14.88 cm^2 per unit increase in the electrical conductivity of the water.

CONCLUSIONS

Increase in the electrical conductivity of irrigation water above 1.6 dS m^{-1} reduces CO_2 assimilation rate, stomatal conductance, transpiration and water use efficiency, resulting in lower vegetative development of BRS Anahí sesame.

The 50% reduction of ETc reduced CO_2 assimilation rate, water use efficiency, chlorophyll and growth variables such as plant height, number of leaves, stem diameter and leaf area in the sesame crop. In addition, the water deficit caused increase in the leaf temperature of the plants.

The combination of salt stress and water deficit intensifies the physiological and morphophysiological limitations of the sesame crop, leading to reductions in gas exchange, water use efficiency and plant growth, highlighting the sensitivity of the BRS Anahí cultivar to the simultaneous occurrence of these stresses.

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