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Gas exchange and growth of peanut crop subjected to saline and water stress[1]

Trocas gasosas e crescimento do amendoim submetido ao estresse salino e hídrico

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HIGHLIGHTS:
Peanut crops was not affected by the interactive effects of water and salt stress.
Water stress reduced plant height and stem diameter of peanut crop.
Increased irrigation water salinity negatively affected transpiration and leaf temperature.

ABSTRACT: Peanut crops are of great economic interest because their seeds are used as an important source of vegetable protein and edible oil. The objective of this study was to evaluate the physiological indices and growth of peanut crops subjected to saline and water stress. The experiment was conducted in Auroras, Redenção, Ceará, Brazil using a completely randomized split plot statistical design. The plots were composed of irrigation water treatments with varying levels of electrical conductivity - ECw (1.0, 2.0, 3.0, 4.0 and 5.0 dS m^{-1}), while the subplots were formed by the water regimes of 50% and 100% crop evapotranspiration. Plant height, leaf number, shoot dry matter, relative chlorophyll level, transpiration, and leaf temperature were affected by salt stress. The water regime of 100% ETc provided better performance for the variables stem diameter, leaf number, and shoot dry mass of peanuts.

Key words: *Arachis hypogaea* L., water quality, water restriction

RESUMO: A cultura do amendoim apresenta grande interesse econômico, em decorrência de suas sementes, constituírem importante fonte de proteína vegetal e de óleo comestível. O objetivo do presente trabalho foi avaliar a fisiologia e crescimento da cultura do amendoim submetido a estresse salino e hídrico. O experimento foi conduzido em Auroras, Redenção, Ceará, Brasil. O delineamento experimental foi inteiramente casualizado em parcelas subdivididas, cujas parcelas referem-se aos níveis de condutividade elétrica da água de irrigação - CEa (1,0; 2,0; 3,0; 4,0 e 5,0 dS m^{-1}) e as subparcelas aos regimes hídricos de 50 e 100% da evapotranspiração da cultura. O estresse salino afeta negativamente a altura de planta, número de folhas e massa seca da parte aérea, índices relativos de clorofila, transpiração e a temperatura foliar da cultura do amendoim. O regime hídrico de 100% da ETc proporcionou maiores desempenhos para as variáveis diâmetro do caule, número de folhas e massa seca da parte aérea da cultura do amendoim.

Palavras-chave: *Arachis hypogaea* L., qualidade da água, restrição hídrica

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Introduction

Peanut (*Arachis hypogaea* L.), which belongs to the Fabaceae family, is the fourth most sown oilseed crop in the world and is cultivated on a large scale in the Americas, Africa, and Asia. It is considered one of the foremost industrial and food crops worldwide, and is beneficial for human nutrition, both in raw and processed form, or used for oil production (Arruda et al., 2015; Goes et al., 2021; Guilherme et al., 2021).

Peanut crops is subject to multiple abiotic stresses, such as water stress that is a frequent condition in the northeastern semiarid region of Brazil due to low rainfall levels, and results in reduced crop growth as well as physiological and nutritional disorders (Freitas et al., 2021; Sousa et al., 2021a).

Water quality in semiarid regions may also influence water stress, as the presence of salts reduces the osmotic potential of the soil solution. Plants exhibit complex reactions in saline environments, including changes to their growth rate, from seed germination to plant growth and productivity (Sousa et al., 2018; Pereira Filho et al., 2019; Rodrigues et al., 2021). Peanuts are considered moderately salt-tolerant, and can tolerate saline water irrigation with an electrical conductivity of up to 3.2 dS m^{-1} with no reduction in productivity (Ayers & Westcot, 1999).

Saline stress also impairs physiological functions, causing stomatal closure, which is one of the first stress responses to prevent excessive water loss under conditions of water restriction (Pereira Filho et al., 2019; Silva et al., 2020; Magalhães et al., 2021). Based on these factors, the present study hypothesized that saline stress associated with water negatively affects the agronomic performance of peanut crops.

The objective of the present study was to evaluate the physiological indices and growth of peanut crop subjected to saline and water stress.

Material and Methods

The experiment was conducted from August to September 2019 in full sun at the Aurora Seedling Production Unit (Portuguese acronym, UPMA), University of International Integration of Afro-Brazilian Lusophony (UNILAB), Redenção, Ceará, Brazil (4° 13' 33" S, 38° 43' 39" W, altitude 88 m). The climate of the region is of the Aw type, characterized as rainy tropical, very warm, with predominant rains in the summer and autumn.

The meteorological data collected during the survey is presented in Figure 1.

The statistical design was completely randomized into split plots. The plots were separated by the electrical conductivity of the irrigation water received (ECw) (1.0, 2.0, 3.0, 4.0 and 5.0 dS m^{-1}), and the subplots by water regimes (50% and 100% of the crop evapotranspiration; ETc, mm), and five replications were performed.

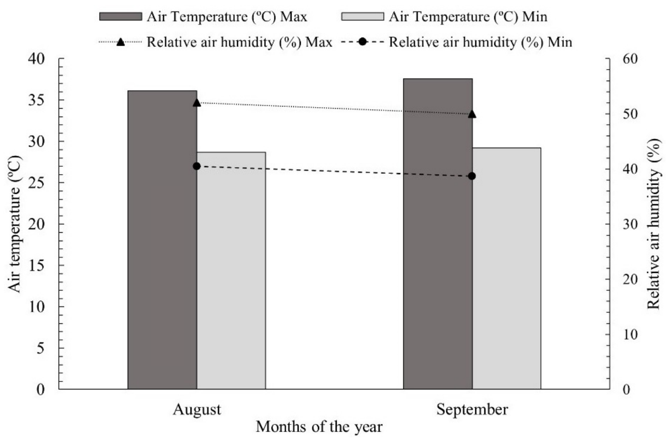


Figure 1. Mean values of temperature and relative air humidity during the experimental period

The peanut seeds Access 26 were used, which belonged to the UNILAB germplasm bank, originated from the subspecies Fastigiata, and were integrated with the Valencia group. The substrate was composed of a mixture of soil and sand at a 3:2 (w/w) ratio, respectively. A sample of the substrate was sent to the Soil and Water Laboratory of the Department of Soil Sciences of the Federal University of Ceará (UFC) for chemical analysis (Table 1) according to the methodology described in the Embrapa Soil Analysis Methods Manual (Teixeira et al., 2017).

Sowing was performed in plastic pots at a volume of 8 L. Five seeds were sown per pot at a depth of 2 cm. Ten days after sowing (DAS), thinning was performed, leaving only two plants per pot. After this period, the treatments were started.

Irrigation water was prepared by adding NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ to the public supply water having electrical conductivity of 0.5 dS m^{-1} in the equivalent proportion of 7:2:1, respectively, following the correlation of ECw and salt concentration ($mmol_c$ L^{-1} = EC × 10) (Richards, 1954). Manual irrigation was performed daily and the volume applied was calculated according to the drainage lysimeter principle (Bernardo et al., 2019), maintaining the soil at field capacity by applying a fixed leaching fraction of 15% (0.15), as recommended by Ayers & Westcot (1999) according to Eq. 1:

$$VI = \frac{(Vp - Vd)}{(1 - LF)} \quad (1)$$

where:

VI - volume of water to be applied in the irrigation event, mL;

Vp - volume of water applied in the previous irrigation event, mL;

Vd - Volume of water drained, mL; and,

LF - leaching fraction of 0.15.

Fertilization was conducted based on the chemical analysis of the substrate and the nutritional requirement of the crop,

Table 1. Chemical attributes of the substrate

OM ($g\ kg^{-1}$)	K^+	Ca^{2+}	Mg^{2+}	Na^+	$H^+ + Al^{3+}$	Al^{3+}	ESP	pH (in water)	EC_{se} (dS m^{-1})
	($cmol_c\ kg^{-1}$)								
3.21	0.67	1	0.9	0.37	1.26	0.05	9	6.6	0.92

OM - Organic matter; ESP - Exchangeable sodium percentage; EC_{se} - Electrical conductivity of the saturation extract following the maximum recommendation for chemical fertilization described by Fernandes (1993) of 15 kg ha^{-1} of N, 62.5 kg ha^{-1} of P_2O_5, and 50 kg ha^{-1} of K_2O. Therefore, for a 10,000-plant stand, the dosage per pot per plant was 1.5 g of N, 6.25 g of P_2O_5, and 5.0 g of K_2O.

To evaluate the effects of the treatments at 45 DAS, the following growth variables were analyzed: plant height (PH), stem diameter (SD), leaf number (NL), and leaf area (LA) according to the non-destructive method described by Cardozo et al. (2014) (Eq. 2):

$$LA = L \cdot W \cdot N \cdot f \quad (2)$$

where:

- LA - leaf area, cm^2 $plant^{-1}$;
- L - average length of the leaflets, cm (average of six leaflets);
- W - largest width of the leaflet, cm;
- N - number of leaflets per plant; and,
- f - correction factor - 0.71.

Regarding the dry masses of the aerial parts (DMAP) and roots (DMR), samples were collected (at 45 DAS), separated, identified, and dried in an oven at 65 °C with forced air circulation for 72 hours until reaching a constant dry matter, which was determined on a precision scale. The results are expressed in grams (g $plant^{-1}$).

During the same period (at 45 DAS), the following physiological indices of peanuts were analyzed: chlorophyll index (SPAD); CO_2 assimilation rate, A (μmol CO_2 m^{-2} s^{-1}); stomatal conductance, gs (mol H_2O m^{-2}); transpiration, E (mmol H_2O m^{-2} s^{-1}); and internal CO_2 concentration, Ci (μmol CO_2 mol^{-1}) using an Infrared Gas Analyzer (IRGA, LI 6400 XT, LICOR). The measurements were made in an open system with an airflow of 300 mL min^{-1} between 08:00 and 10:00 hours under natural conditions of air temperature and CO_2 concentration. An artificial radiation source of 1,200 μmol m^{-2} s^{-1} was focused on the third leaflet of the fourth compound leaf from the base of the soil of fully expanded sheets.

The variables studied and measured during the study were analyzed using the Kolmogorov-Smirnov test ($p \leq 0.05$) to assess normality. Data were subjected to analysis of variance (ANOVA) using the F test. When significant, the data referring to ECw were subjected to regression analysis and water regime data to the Tukey test at 0.01 and 0.05 of significance using the statistical program ASSISTAT 7.7 (Silva & Azevedo, 2016).

Results and Discussion

According to the ANOVA (Table 2), there was an isolated significant effect of salinity on the SPAD index, transpiration, and leaf temperature. As for the water regime factor, there was an effect on stomatal conductance and transpiration at 0.01 significance, while on photosynthesis, leaf temperature was significant at 0.05.

Photosynthesis was significantly influenced by water regimes (Table 2), with plants that were subjected to the 50% ETc regime showing a reduction of 31.59% compared to those with 100% ETc. This decrease may be related to the partial closure of stomata (Table 2), which reduces CO_2 uptake and photosynthesis rates (Sousa et al., 2021b).

When evaluating peanut gas exchange in response to water deficiency, Lessa et al. (2021) obtained results similar to those of the present study. The same authors observed a reduction in the photosynthetic rate with an increase in water deficit. Pereira Filho et al. (2019) assessed the physiological responses of bean crops cultivated under water stress and found the highest photosynthetic rates in the 100% ETo water regime.

The peanut plants subjected to the 50% regime had a reduction of 46.15% (0.06 mol m^{-2} s^{-1}) in gs compared to the 100% regime (0.13 mol m^{-2} s^{-1}) (Table 2). Regulation of stomatal opening to control water loss is a mechanism adopted by some plant species to adjust to adverse conditions. Freitas et al. (2021), working in field conditions with peanut crops under water deficit through water regimes, found results similar to those identified in the present study.

Transpiration was also significantly influenced by water regimes (Table 2). Peanut plants that received the 50% water regime obtained a reduction of 25.94% (0.55 mmol m^{-2} s^{-1}) compared to that of the 100% regime (2.12 mmol m^{-2} s^{-1}). The decreased availability of water caused plants to reduce their transpiration rate to reduce water loss and conserve the amount available in the soil (Barbosa et al., 2021).

Table 2. Summary of analysis of variance for CO_2 assimilation rate (A), stomatal conductance (gs), transpiration (E), internal CO_2 concentration (Ci), leaf temperature (LT), and chlorophyll index (SPAD) of peanut plants subjected to irrigation with saline water and two water regimes

SV	DF	Mean square					
		A	gs	E	Ci	LT	SPAD
Salinity (S)	4	3.3251^{ns}	2.1421^{ns}	5.0372^{*}	3254^{*}	6.0110^{**}	5.2342^{*}
Residue	20	1.529.52	0.00868	0.81906	550.48	0.1025	845.275
Plots	24	-	-	-		-	-
Water regimes (WR)	1	16.4219^{**}	6.8420^{*}	5.7069^{*}	1176.88^{ns}	17.8087^{**}	3.1645^{ns}
S × WR	4	1.7331^{ns}	1.4630^{ns}	1.3027^{ns}	6968.64^{**}	2.0587^{ns}	3.2975^{ns}
Residue	20	284.301	0.0039	0.39996		0.1725	976.675
Total	49	-	-	-		-	-
CV-S (%)	-	8.9	5.62	8.95	10.04	0.97	7.53
CV-R (%)	-	25.4	7.4	34.21	10.67	1.25	8.1
		μmol m^{-2} s^{-1}	mol H_2O m^{-2}	mmol H_2O m^{-2} s^{-1}	μmol CO_2 mol^{-1}	°C	SPAD Index
Water regime (50% ETc)		5.39 b	0.07 b	1.57 b	227.44	33.46 b	10.3 b
Water regime (100% ETc)		7.88 a	0.13 a	2.12 a	239.94	32.82 a	11.2 a

SV – Source of variation; DF - Degree of freedom; ** Significant $p < 0.01$; * Significant at $p \leq .05$; ns - Not significant. Means followed by the same letter in the column do not differ statistically by Tukey's test ($p \leq 0.05$)

Similar results were reported by Freitas et al. (2021) in peanut crops under water deficits. Fasolin et al. (2019) evaluated the anatomical and physiological variation of peanuts (cultivar IAPAR 25 Tição) grown under different water regimes (moderate and severe) and observed a reduction in transpiration.

The peanut plants subjected to the 50% water regime showed an increase in temperature of 1.91% (0.64 °C) compared to that of the 100% regime (32.82 °C; Table 2). The increase in leaf temperature in response to water stress correlated to a reduction in latent heat loss through transpiration, which normally decreases under these conditions. Feitosa et al. (2016) highlighted that plants exhibit this behavior due to the closure of stomata to reduce water loss under conditions of water deficiency, thereby maintaining the water status. Similar results were reported by Freitas et al. (2021) in peanut plants subjected to water deficit.

For the transpiration values as a function of the electrical conductivity of the irrigation water, the linear model best fit the data (Figure 2A), and there was a 71% reduction in transpiration between the lowest and highest saline levels. The reduction in transpiration in plants can be caused by the presence of absorbed salts (Sousa et al., 2021b).

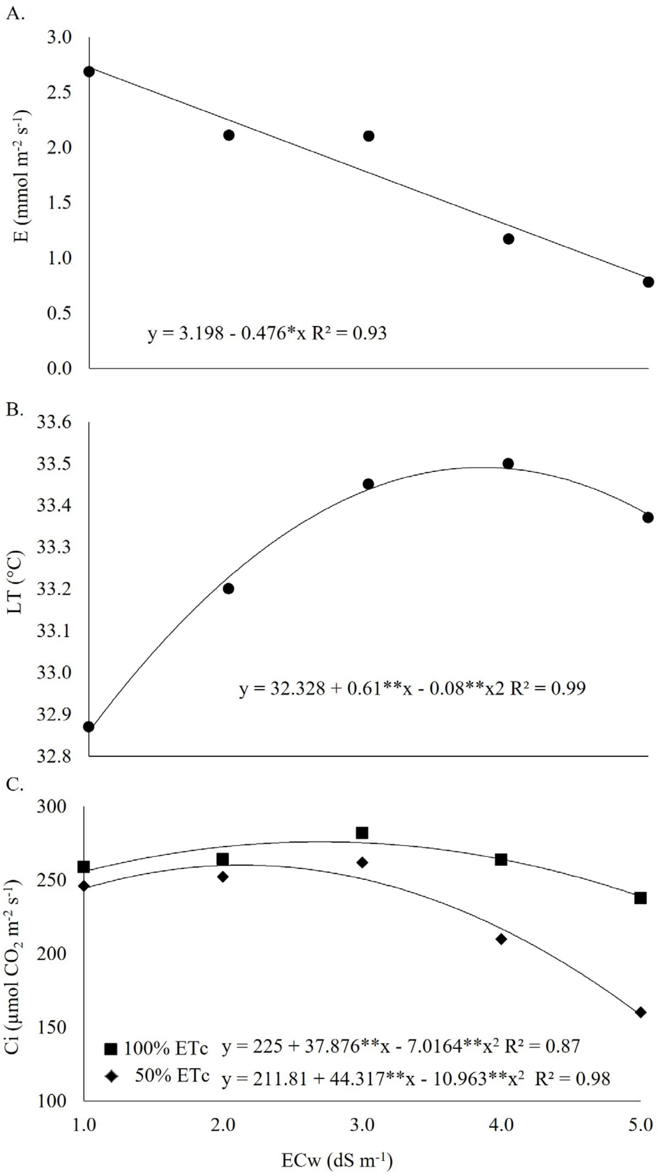
Rodrigues et al. (2021) affirmed that salt stress might reduce the amount of water transpired or absorbed, as well as the transport of K^+ and Mg^{2+} ions into the plants. Pereira Filho et al. (2019) evaluated the physiological responses of bean crops subjected to salt and water stress, and obtained results similar to those of this study. Freitas et al. (2021) evaluated gas exchange in cowpeas under different concentrations of salts in irrigation water and found negative effects on transpiration.

For the leaf temperature as a function of the electrical conductivity of the irrigation water, as shown in Figure 2B, the quadratic polynomial model best fitted the data, with a maximum temperature of 33.49 °C at the ECw of 3.81 dS m^{-1}. Leaf temperature is strongly inversely influenced by transpiration; therefore, transpiration acts as a temperature-regulating mechanism (Feitosa et al., 2016).

Sousa et al. (2021a) studied the physiological responses of peanuts under salt stress, and found similar behavior to that of this study, with an increase in the electrical conductivity of irrigation water. Lessa et al. (2021) found no significant effects of saline water irrigation on the leaf temperature of cowpea plants.

An increase in saline concentration correlated to a trend toward water treatments with a 50% regime, with a maximum value of 250.659 μmol CO_2 mol^{-1} (Figure 2C). Water stress associated with saline may reflect a reduced ability to increase the internal concentration of CO_2 since saline stress triggers soil osmotic pressure, thereby restricting gs, and CO_2 assimilation. A similar trend was reported by Amaral et al. (2021) whereby gas exchange in the sunflower crop as a function of the electrical conductivity of the irrigated water and the water regimes of 50 and 100% ETc, showed a reduction in the internal concentration of CO_2.

The linear model showed the best fit for the SPAD index as a function of the electrical conductivity of irrigation water (Figure 3). A 15.3% reduction in chlorophyll occurred with



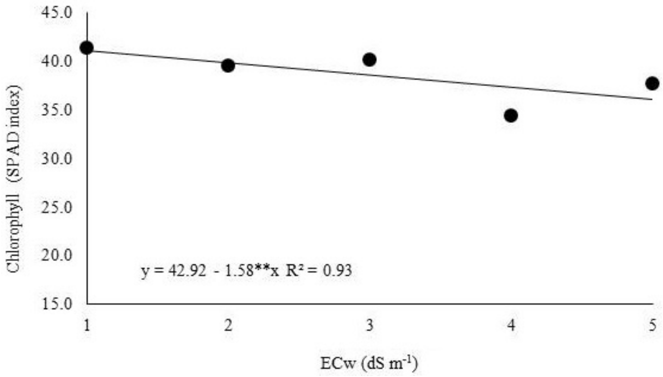
*,** - Significant at $p \leq 0.05$, and at $p \leq 0.01$ by F test, respectively

Figure 2. Transpiration - E (A), leaf temperature - LT (B) and internal concentration of CO_2 – Ci (C) of peanuts plants as a function of the electrical conductivity of irrigation water, at 45 days after sowing

higher salinity water irrigation compared to those of the less saline treatments. This may be related to the climate response to salt stress that leads to greater conservation due to the lower capture of light energy and the consequent reduction of photo-oxidative stress (Sousa et al., 2021b).

Similar results were obtained by Pereira Filho et al. (2019), who evaluated the physiological responses of bean crops subjected to saline and water stress and demonstrated that salt stress causes deleterious effects to the SPAD index values.

The summary of the ANOVA (Table 3) revealed a significant effect of the saline levels of irrigation water (S) on plant height (PH) and leaf number (NL) at a 0.05 probability level of significance, and a 0.01 significance level for the dry mass of the aerial part (DMAP). There was a significant response for the water regime (WR) factor for the variables leaf number (NL), stem diameter (SD), and dry mass of the aerial part (DMAP) at a 0.05 probability level of significance.



** - Significant at p ≤ 0.01 by F test

Figure 3. SPAD Index of peanuts plants as a function of the electrical conductivity of irrigation water, at 45 days after sowing

Stem diameter (Table 3) was higher with the 100% ETc water regime, with a 23.61% (1.32 cm) reduction with the 50% regime. This reduction can be related to the physiological disturbance that the plant suffers when exposed to water deficit, and acclimatization morphologically occurs to reduce these damages. Thus, with lower available water content, plants tend to reduce their cell division processes and, consequently, their growth (Sousa et al., 2021b).

A study presented by Freitas et al. (2021) reported a reduction in SD in peanut crops that were subjected to water deficit. Similarly, Fasolin et al. (2019) found that peanut plants maintained at the field capacity had a larger diameter than plants treated with moderate or severe water deficit.

Peanut plants presented a lower NL in the 50% water regime (Table 3), with 100% ETc being statistically higher. The NL of the plants subjected to the 50% regime showed a decline of 37.21% (5.76 leaves) compared to the 100% regime.

This result can be explained by the fact that water stress decreases cell multiplication and division within plant tissues, which leads to a reduction in the growth of the aerial parts, which, when subjected to water reduction, decreases leaf expansion (Souza et al., 2019; Lessa et al., 2021).

This result corroborates that of Dias et al. (2019), who assessed the efficiency of water use by peanut crops under water deficit and observed a reduction in the number of leaves. Similarly, Silva et al. (2022) claimed in their study that water deficit in peanut crops affected the number of leaves.

Regarding the water regime, the peanut plant DMAP exhibited a reduction when irrigated with the lowest regime (Table 3), in which the 50% regime had a 40.51% (0.64 g) decline in mass compared to the 100% regime (1.58 g). This result may be related to the decrease in available water during this period, resulting in lower production of photoassimilates (Arruda et al., 2015). Similarly, when evaluating peanut crops under different water regimes, Dias et al. (2019) found higher production of DMAP at the lowest water deficit level.

The quadratic polynomial model best fitted the response of plant height to salt stress (Figure 4A), with a maximum PH of 4.35 cm at the ECw of 2.24 dS m^{-1}. This reduction in height may be related to the action of salinity to induce osmotic and ionic stress, thereby reducing the absorption of water and/or nutrients, and growth, or causing disturbances in metabolic activities in general (Sousa et al., 2021b).

This reduction in height may be related to salinity which causes osmotic stress and may increase nutrient absorption and growth (Barbosa et al., 2021). A similar trend to this study was observed by Freitas et al. (2021) when irrigating the peanut crop with saline water. Corroborating the result, Pereira Filho et al. (2019) showed a reduction in plant height when estimating the initial growth of cowpea beans subjected to different salinity levels.

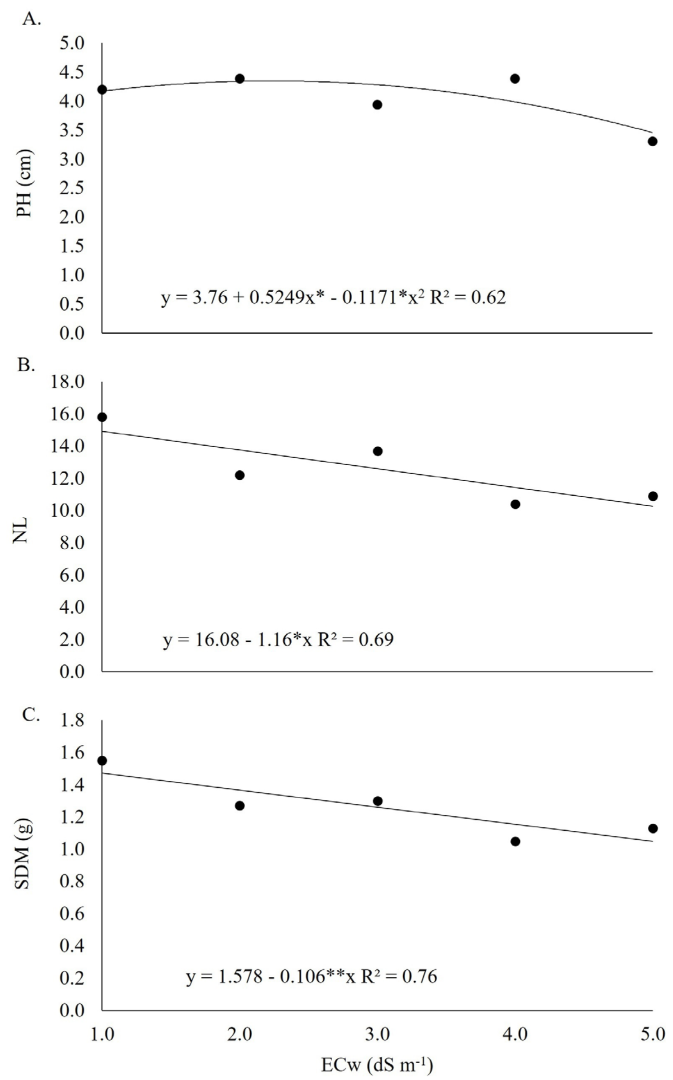
Salinity induced a linear decrease in NL with the increase in ECw (Figure 4B), causing a 31% reduction in the number of leaves with the highest electrical conductivity of water. This reduction in the number of leaves may be associated with morphological strategies that the plant develops under stress conditions that induce reduced leaf expansion, causing stomatal closure, and the consequent reduction in the availability of CO_2 to the leaves (Silva Júnior et al., 2021; Sousa et al., 2021b). Comparable results to the present study were reported by Sá et al. (2020), who evaluated genotypes of peanuts subjected to different levels of salinity, with a reduction in the number of leaves when saline levels increased.

From the results obtained by the regression analysis, it was possible to verify that salinity reduced the DMAP linearly with

Table 3. Summary of analysis of variance for plant height (PH), number of leaves (NL), stem diameter (SD), leaf area (LA), dry mass of aerial part (DMAP), and dry mass of root (DMR) of peanuts plants submitted to irrigation with saline waters and two water regimes

SV	DF	Mean square					
		PH	NL	SD	LA	DMAP	DMR
Salinity (S)	4	2.9455*	3.8131*	0.6101ns	1.6827ns	5.9660**	1.2434ns
Residue	20	0.69	12.68	1.65	35.07	0.06	0.05
Plots	24	-	-	-	-	-	-
Water regimes (WR)	1	0.0002ns	2.35369**	2.41850**	4.1034ns	7.46468**	3.3789ns
S × WR	4	0.1451ns	0.7645ns	1.7593ns	1.4751ns	2.2929ns	1.7153ns
Residue	20	1.3	17.62	0.9	31.81	0.06	0.04
Total	49	-	-	-	-	-	-
CV-S (%)	-	20.53	28.26	26.06	22.57	19.8	25.06
CV-WR (%)	-	28.26	23.31	19.28	31.03	20.79	21.94
		cm		mm	cm^2	g	g
Water regime (50% ETc)		4.04 a	9.72 b	4.27 b	16.56 a	0.94 b	0.35 a
Water regime (100% ETc)		4.08 a	15.48 a	5.59 a	19.79 a	1.58 a	0.46 a

SV – Source of variation; DF - Degree of freedom; ** Significant p ≤ 0.01; * Significant at p ≤ .05; ns - Not significant. Means followed by the same letter in the column do not differ statistically by Tukey's test (p ≤ 0.05)



*,**- Significant at $p \leq 0.05$, and at $p \leq 0.01$ by F test, respectively

Figure 4. Height of plants (A), number of leaves (B) and dry shoot mass (C) of peanuts as a function of the electrical conductivity of irrigation water, at 45 days after sowing

the increase of ECw (Figure 4C), with a reduction of 27.03% in the dry mass of the aerial part at the highest salinity level compared to the treatment with the lowest salinity level. This result is possibly related to the harmful effects of the salts present in the irrigation water absorbed by the plants, which reduce the osmotic adjustment capacity of the crop (Barbosa et al., 2021).

Freitas et al. (2021) found that an increase in salinity of the irrigation water reduced peanut DMAP. Corroborating this study, Barbosa et al. (2021), evaluating cowpea, observed negative effects of salinity on DMAP.

Conclusions

1. Plant height, leaf number, shoot dry matter, relative chlorophyll level, and transpiration were negatively affected by salt stress, while leaf temperature of the peanut plants increased under this condition.

2. The increase in the electrical conductivity of water reduced the internal concentration of CO_2, but with less intensity under the 100% ETc water regime.

3. The water regime of 100% ETc provided better performance for the variables stem diameter, leaf number, and shoot dry mass of peanuts.

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