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Production and water relations of peanut irrigated with brackish water under pulse and continuous drip[1]

Produção e relações hídricas do amendoim irrigado com águas salobras sob gotejamento pulso e contínuo

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HIGHLIGHTS:

Under brackish water irrigation, pulse drip irrigation favored water use efficiency and grain production of peanut.
The form of drip irrigation - continuous or pulse - did not influence the osmotic adjustment of the peanut plants.
Pulse drip irrigation did not influence transpiration, but the increasing salinity in the water resulted in its lower rate.

ABSTRACT: An efficient water management in irrigation is essential to optimize water efficiency, especially when using brackish water. Thus, the present study was carried out aiming to analyze gas exchanges, pod production, and the water status of peanut plants under increasing levels of salinity (electrical conductivity of 0.12, 1.6, 2.8, 4.0, and 5.2 dS m^{-1}) and the application of the irrigation depth via pulses. A randomized block design in a 5 × 2 factorial scheme was used with four replications, adding up to forty experimental units. The experiment was carried out in drainage lysimeters, at the Federal Rural University of Pernambuco, in open fields from September to November 2019. It was concluded that the use of pulse drip irrigation did not mitigate the deleterious effect of salinity but promoted higher grain and pod production compared to continuous drip irrigation. It was also found that the use of brackish water via pulse drip irrigation promotes greater water use efficiency compared to continuous drip irrigation, and that the increase in the electrical conductivity of the water reduced the water, pressure, and osmotic potentials, along with the osmotic adjustment.

Key words: *Arachis hypogaea*, salt tolerance, salinity stress

RESUMO: Um eficiente manejo da água na irrigação é fundamental para a otimização da eficiência hídrica, especialmente quando se utiliza águas salobras. Neste sentido, o presente estudo foi desenvolvido com o objetivo de avaliar as trocas gasosas, produção de vagens e grãos e o estado hídrico de plantas de amendoim sob níveis crescentes de salinidade (condutividade elétrica de 0,12; 1,6; 2,8; 4,0 e 5,2 dS m^{-1}) e a aplicação da lâmina de irrigação via pulsos. O delineamento experimental adotado foi em blocos ao acaso, analisado em esquema fatorial 5 × 2 com quatro repetições, totalizando quarenta unidades experimentais. O experimento foi realizado em lisímetros de drenagem, na Universidade Federal Rural de Pernambuco, em campo aberto, entre os meses de setembro a novembro de 2019. O uso de pulsos de irrigação não mitigou o efeito deletério da salinidade, mas proporcionou maior produção de grãos e vagens em relação ao gotejo contínuo. A aplicação de águas salobras via gotejamento por pulsos proporcionou maior eficiência de uso da água em relação ao gotejo contínuo e o aumento da condutividade elétrica da água reduziu os potenciais hídrico, de pressão e osmótico, bem como no ajustamento osmótico.

Palavras-chave: *Arachis hypogaea*, tolerância à salinidade, estresse salino

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Introduction

In the northeast of Brazil, the states of Bahia, Ceará and Paraíba are largest producers of peanut (*Arachis hypogaea*). The crop in these places has great economic relevance and social importance since most peanut producers from the semi-arid region are family farmers, who use little technology (Barbosa et al., 2018).

On the other hand, in these regions, the use of brackish waters in irrigation of crops is one of the main factors that has compromised the growth, development, and yield in the context of family farming, since the sustainable use of these waters demands the use of technologies and irrigation management strategies that favor the balance of salts (Ochoa-Noriega et al., 2020).

Among these technologies, the use of salt-tolerant crops (Bhardwaj & Kapoor, 2021) and water management practices, such as pulse drip irrigation (Cruz et al., 2018), can be mentioned. Peanut is a crop moderately sensitive to salinity (Yasmine et al., 2019), as already verified in other studies (Alves et al., 2016; Cruz et al., 2018; Yasmine et al., 2019). Therefore, salt stress causes damage to the growth and morphogenesis of peanut, reducing the germination of the seeds and the accumulation of dry matter, influencing the establishment of the morphology of the seedlings and inducing damage to the photosynthetic apparatus (Tian et al., 2019).

On the other hand, pulse irrigation is defined as the application of the water depth based on an on-off pulse modulation technique, and it stands out as an alternative to mitigate the effects of salts on plants (Ibrahimova et al., 2021). Studies have highlighted the positive effects of pulse irrigation on product quality and increased yield of crops (Almeida et al., 2018, Bath et al., 2021).

Studies on the use of brackish water along with pulse irrigation management are still scarce in literature. Therefore, this study aims to analyze gas exchange, pod, and grain production, and water status of peanut plants under increasing levels of water salinity and the application of the irrigation depth via pulse drip irrigation.

Material and Methods

The experiment was carried out between September and November 2019, in drainage lysimeters arranged in an open field, at the Fertigation and Salinity Laboratory - DEAGRI/UFRPE, Dois Irmãos Campus, Recife - Pernambuco (08º 01' 05" S, 34º 56' 48" W and 6.5 m of altitude).

Meteorological variables were monitored during the experimental period (Figure 1) and phytosanitary problems were monitored and controlled with products based on Deltamethrin and Methomyl.

The experimental units consisted of drainage lysimeters of 288 L, adapted with a drainage system at the bottom. Each unit had an internal diameter at the upper edge of 0.57 m and was placed on a 0.40-m-high concrete plateform, which was 1.0 m equidistant in all directions. The lysimeters were filled with a 7-cm-thick layer of gravel, size four (25 mm), at the bottom; geotextile fabric, and 195 kg of dried soil, with a density of 1.5 kg dm^{-3}.

The seeds of peanuts cultivar BR-1 were used. The treatments consisted of five levels of electrical conductivity of irrigation water (EC = 0.12 - control treatment; 1.6, 2.8, 4.0, and 5.2 dS m^{-1}) applied by pulse and continuous drip irrigation. The experimental design adopted was in randomized blocks, analyzed in a 5 × 2 factorial scheme, with four replications, consisting of 40 experimental units.

The soil was collected in the municipality of Goiana-PE (7º 33' 38" S and 35º 00' 09" W, average altitude of 13 m) and characterized as a Spodosol (US Soil Survey Staff, 2014), with average values for sand, silt, and clay of 952, 22 and 26 g kg^{-1}, respectively; 1.5 kg dm^{-3} density, 43.6% total porosity,0.038 g g^{-1} maximum water retention capacity and 0.025 g g^{-1} permanent

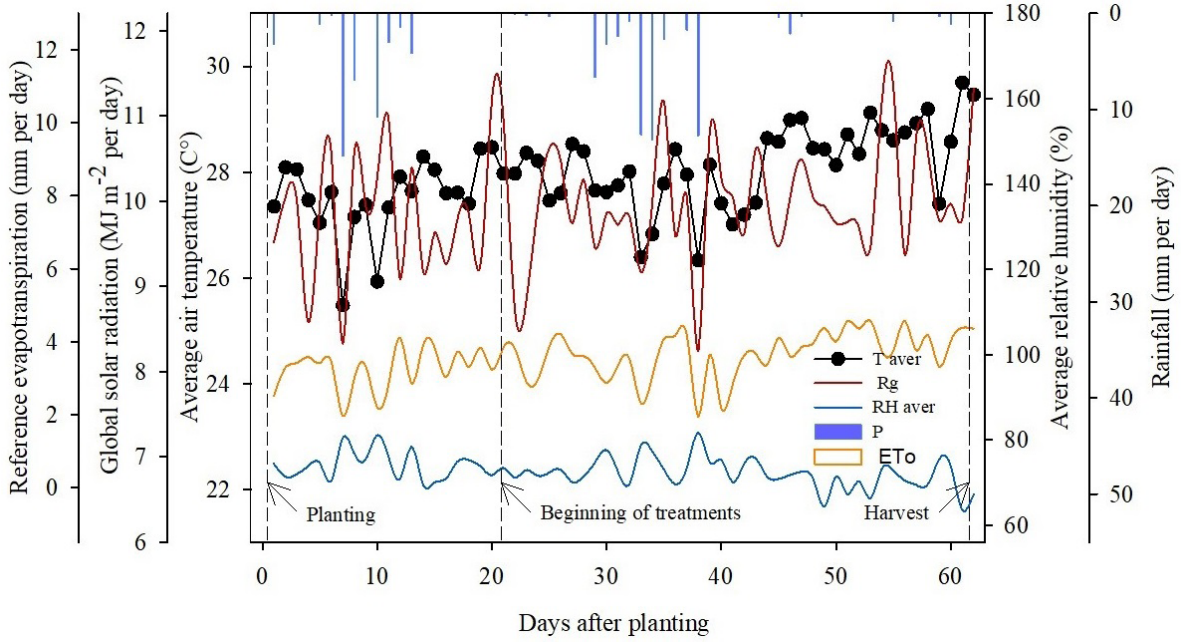


Figure 1. Reference evapotranspiration – ETo (mm per day), solar radiation – Rg (MJ m^{-2} per day), average air temperature – T aver (ºC), average relative humidity – RH aver (%), rainfall – P (mm per day) observed during the experimental period

wilting point (PWP). The following values were also quantified according to the methodology of Filizola et al. (2006): $pH_{1:2.5}$ in water (6.5), P (5.03 mg dm^{-3}), K^+ (0.07 $cmol_c\ dm^{-3}$), Ca^{+2} (1.75 $cmol_c\ dm^{-3}$), Mg^{+2} (0.55 $cmol_c\ dm^{-3}$), Na^+ (0.08 $cmol_c\ dm^{-3}$), Al^{+3} (0 $cmol_c\ dm^{-3}$), $H + Al^{+3}$ (0.69 $cmol_c\ dm^{-3}$), organic carbon (3.21 g kg^{-1}), organic matter (5.53 g kg^{-1}), dispersed clay (0.05 kg kg^{-1}), EC (0.58 dS m^{-1}), CEC (8.93 $cmol_c\ dm^{-3}$), and ESP (0.67%).

Regarding fertilization, 15 kg ha^{-1} of N in the form of ammonium sulfate, 80 kg ha^{-1} of P_2O_5 in form of single superphosphate, and 30 kg ha^{-1} of K_2O in the form potassium chloride were applied as basal dose, following the recommendation of Alvarez et al. (1999). At 15 days after planting (DAP), topdressing fertilization was performed with 15 kg ha^{-1} of N and 30 kg ha^{-1} of K_2O.

The micronutrients were supplied by foliar fertilization, using the commercial product Amino Agross®, whose composition contains: B-0.2%; Ca-1.0%; Cu-0.2%; organic carbon (OC)-6.0%; S-0.8%; P_2O_5-8.0%; Mg-0.5%; Mn-0.6%; N-5.0%; K_2O-5.0%; Zn-1.0%. Two applications were carried out, the first at 30 days after germination and the second before flowering. The dose used was 125 mL of product for 100 L of water.

The irrigation system consisted of two pressure-compensating drippers per lysimeter with a nominal flow rate of 2.0 L h^{-1} and an application rate of 10.4 mm h^{-1}. Solenoid valves, filters, 0.5 CV pumps, water tanks, and other components were also used. In controlling the application of the irrigation depth, in all treatments, the opening and closing of the solenoid valves, according to previous programming, was done with the aid of an Arduino-type microcontroller.

In the preparation of the brackish waters, the amount of NaCl was estimated based on the relation between salt concentration and electrical conductivity according to Richards (1954), and then the salts were solubilized in the supply water (ECw = 0.12 dS m^{-1}), thus obtaining the pre-established electrical conductivities, according to the treatments.

As for water management, a two-day irrigation interval was established to replenish water up to the maximum water retention capacity of the lysimeter (FC). After calculating the current soil moisture (Tavares et al., 2008), the irrigation depth was determined according to the methodology of Mantovani et al. (2009).

Ten peanut seeds, cultivar BR-1, were distributed at 0.05 m depth in the soil. They were placed and kept at maximum water retention capacity of the soil, using water with EC = 0.12 dS m^{-1} until 20 DAP, and the brackish waters were only applied after 20 DAP, according to each treatment. Thinning was performed every 10 days after sowing - DAS, until one plant per lysimeter was left, at 20 DAS.

Sixty days after planting, the following variables were analyzed: grain yield and pod mass per plant - GYPMP (Mg ha^{-1}); water productivity - WP (g mm^{-1}); CO_2 assimilation rate - A (μmol CO_2 m^{-2} s^{-1}); stomatal conductance - gs [mol H_2O m^{-2} s^{-1}]; transpiration - E [mmol H_2O m^{-2} s^{-1}]; intercellular CO_2 concentration - Ci (μmol CO_2 mol^{-1}); instantaneous water use efficiency – WUEi (A/E) – (μmol CO_2 $mmol^{-1}$); intrinsic water use efficiency WUE (A/gs) - (μmol CO_2 $mmol^{-1}$); leaf succulence - LS [g H_2O dm^{-2}] (Delf, 1912) and relative water content – RWC (%).

GYPMP was calculated by the sum of weight of the grains and pods obtained by area; WP was estimated by the ratio between the production of green grains and pods and total water depth applied; A, Ci, WUEi, WUE, gs, and E were determined using an infrared gas analyzer, with the photosynthetic photon flux adjusted to 1500 μmol m^{-2} s^{-1}, between 9 and 11 a.m. (IRGA, Model Li-6400xt, LI-COR).

In addition, the following parameters were determined: leaf water potential - Ψh (MPa), osmotic potential - Ψo (MPa), pressure potential - Ψp (MPa), based on the difference between Ψh and Ψo, and Osmotic adjustment – OA.

The Ψh was determined using a Scholander Pressure Chamber (model 1515D Pressure Chamber Instrument - PMS Instrument Company), early in the morning, from 1:30 to 4:30 a.m., at the experiment site. Leaves were collected at the reproductive stage R1 of the plant and exposed to constant flow pressures, until the sap was about to leak, and then the pressure was recorded.

Regarding Ψo, the same leaves used to determine Ψh were wrapped in aluminum foils and stored at 4 °C. Later, they were macerated using a pestle and a mortar, and the sap obtained was filtered and then centrifuged at 10,000 g for 10 min at 4 °C. A 10 μL aliquot of the supernatant was used to determine the tissue osmolality in a vapor pressure osmometer (Vapro Wescor Model 5600) (Silveira et al., 2009). The values obtained in millimole per kilogram were converted into osmotic potential using the van't Hoff equation (Eq. 1):

$$\Psi o = -RTC \quad (1)$$

where:

R - general gas constant (0.008314 MPa kg K^{-1} mol^{-1});
T - temperature (K); and,
C - solute concentration, expressed in mol kg^{-1}.

For OA, at the time of leaf collection for the determination of water potential, other nearby and similar leaves were also collected. In the laboratory, they were put to saturate in Petri dishes (filled with distilled water) for 24 hours at 4 °C in the dark.

After reaching full turgor, they were dried with paper towels and macerated with liquid nitrogen, in a mortar with a pestle. The extracted sap was filtered, placed in a microtube and centrifuged at 10,000 g for 10 min at 4 °C.

The osmolality reading was performed on an osmometer (Vapro Wescor model 5600) in the supernatant remaining from the centrifugation. A 10 μL aliquot of the supernatant was used to determine tissue osmolality in a vapor pressure osmometer (Silveira et al., 2009).

Finally, the values obtained in mmol kg^{-1} were converted into MPa using the van't Hoff equation (Eq. 2). Osmotic adjustment was determined by the difference between the osmotic potentials of the control plants and stressed plants

$$OA = \left(\Psi_{OC}^{100} - \Psi_{OS}^{100}\right) \quad (2)$$

where:

OA - osmotic adjustment;

Ψ_{oc}^{100} - osmotic potential of control plants at full turgor; and,

Ψ_{os}^{100} - osmotic potential of stressed plants at full turgor.

All data underwent normality and homoscedasticity tests (Shapiro-Wilk) and were subjected to analysis of variance by the F test at 0.05 probability level, using the statistical software SISVAR (Ferreira, 2019). In cases in which the electrical conductivity levels of the irrigation water (ECw) resulted in a significant effect, the results were compared through a regression analysis. In cases in which pulse or continuous drip irrigation significantly influenced the variables, the F test was already conclusive.

Results and Discussion

The interaction between the use of brackish water and its management, by pulse or continuous drip irrigation, was significant ($p \leq 0.05$) on the water use efficiency in the production of grains and pods (WP) and on the leaf succulence (LS). The results regarding the production of grains and pods (GYPMP), the instantaneous water use efficiency (A/E), stomatal conductance (gs) and transpiration (E) were influenced ($p \leq 0.01$) by the factor electrical conductivity of the irrigation water, and GYPMP, WP, and LS were affected ($p \leq 0.05$) only by water management (Table 1).

The estimated reduction in GYPMP for each dS m^{-1} increase in irrigation water was 6.24% or 5.34 g per plant, and the estimated gain by pulse drip irrigation was around 27.57%. Under the 0.12 dS m^{-1} ECw, the estimated production was 84.35 g per plant, with an absolute loss of 32.13% being estimated when compared to the GYPMP of plants under 5.2 dS m^{-1} (Figure 2A). The non-occurrence of an interactive effect between ECw and irrigation management may be associated with the leaching of salts induced by the precipitation to which the plants were exposed (Figure 1).

Under pulse drip irrigation, the water use efficiency was minimal (4.74 g mm^{-1}) under an ECw estimated at 2.99 dS m^{-1}, while under continuous drip irrigation there was a minimal WP (2.61 g mm^{-1}) under the ECw of 0.90 dS m^{-1} (Figure 2B). The biological explanation of the model is associated with the nature of this variable, in other words, once the mass of grains and pods is produced, the increasing limitation of water absorption imposed by the osmotic effect causes a gain in WP. However, it reflects the deleterious effect of salinity on water absorption and biomass gain, as observed at the last two levels of ECw tested, whose results did not differ, depending on the management adopted (Bhardwaj & Kapoor, 2021).

Thus, the significant effect ($p \leq 0.05$) of the interaction between ECw and water management on WP may also be attributed to the irrigation interval adopted (every two days) and the differences between the intense deposition of salts in each form of management adopted. In other words, even with salt leaching induced by rainfall (Figure 1), the intensity and differences in salt deposition characterized different WP results depending on the management adopted.

The photosynthetic rate was reduced by 2.87 (12.80%) and 3.90 (15.93%) μmol CO_2 m^{-2} s^{-1} per dS m^{-1} increment, within the range of ECw studied, when the plants were under pulse or continuous drip irrigation, respectively. On the other hand, when the management was analyzed within each ECw, there was only a difference ($p \leq 0.05$) in the photosynthetic rate of plants under pulse and continuous drip irrigation under ECw of 4.0 dS m^{-1} (Figure 2C).

It is evident, in this case, that the reduction in net carbon assimilation was also accompanied by a reduction in transpiration (E), which is also demonstrated by the reduction in stomatal conductance (gs), that is, the stomatal control of transpiration; however, it imposes diffusive limitations to CO_2 that may lead to a decrease in the photosynthetic rate (Silva et al., 2015).

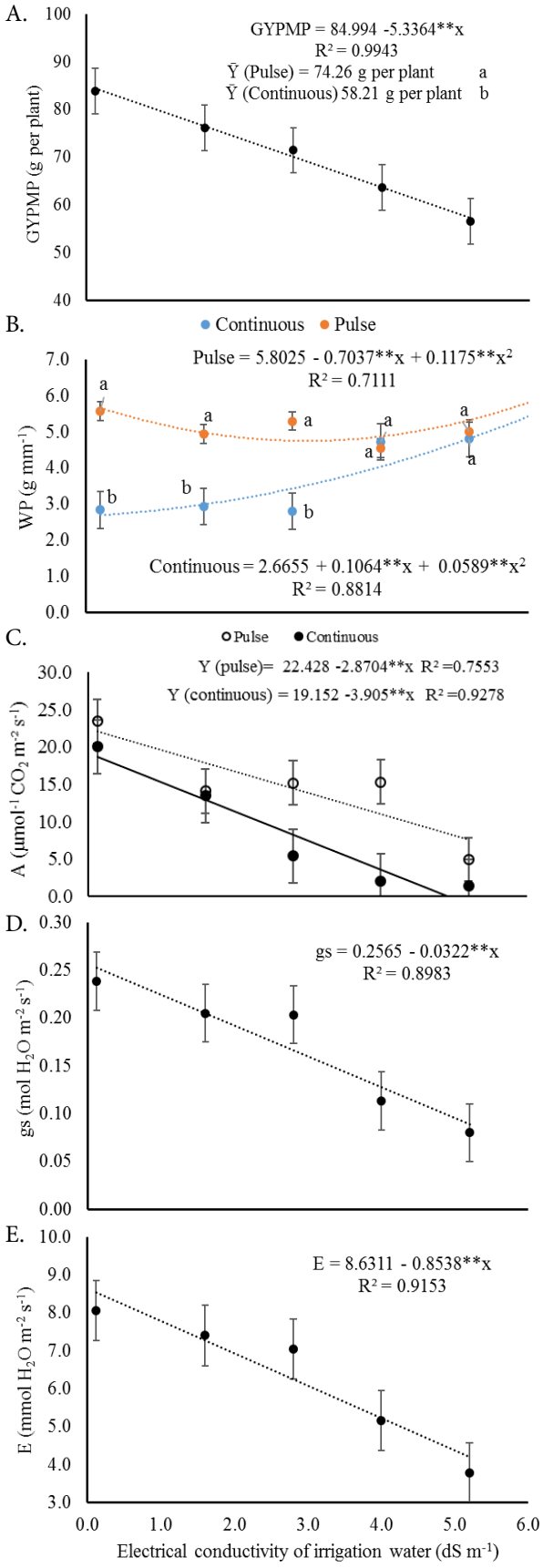
Thus, pulse or continuous drip irrigation did not influence ($p > 0.05$) the gs (Figure 2D) and E (Figure 2E), although these variables were reduced by each increment in dS m^{-1}, at rates of 0.03 (12.55%) and 0.85 (9.89%) mmol H_2O m^{-2} s^{-1}, respectively. This tendency explains the deleterious effect of salinity on GYPMP and, at the same time, it also shows that the form of deposition of salts due to drip irrigation by pulses or continuous did not affect ($p > 0.05$) the transpiration process at 60 DAP.

After splitting analysis, it was found that under pulse drip irrigation, Ci was not affected ($p > 0.05$) within the ECw interval studied. On the other hand, it was maximal (319.02 μmol CO_2 mol^{-1}) at the estimated ECw of 5.2 dS m^{-1}, when the plants were exposed to continuous drip irrigation, within the studied ECw interval. When comparing continuous and pulse drip within each ECw, it appears that plants exposed to continuous drip irrigation had higher Ci at the highest ECw levels tested (Figure 3A).

Table 1. Summary of the analysis of variance for grain and pod yield per plant (GYPMP), water productivity (WP), CO_2 assimilation rate (A), stomatal conductance (gs), transpiration (E), intercellular CO_2 concentration (Ci), instantaneous water use efficiency (WUEi), intrinsic water use efficiency (WUE), and leaf succulence (LS) in peanut plants, cultivar BR-1, irrigated with brackish water (ECw) via pulse and continuous drip irrigation (D)

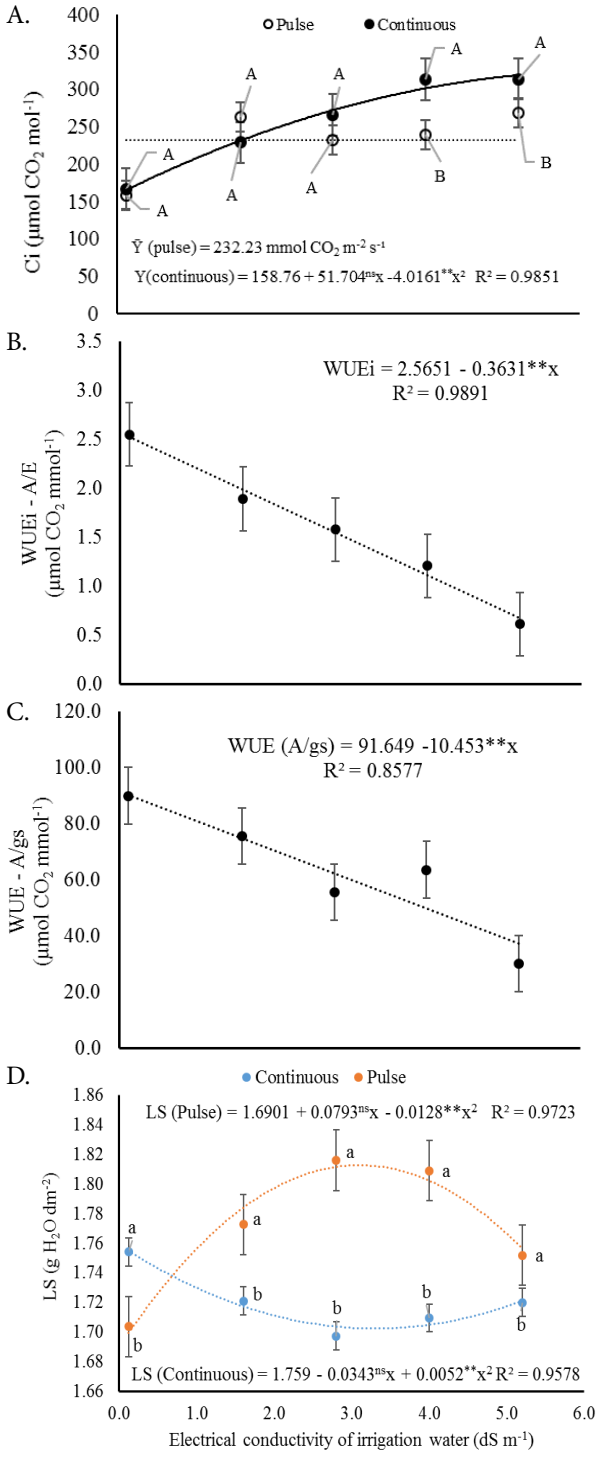
Source of variation	DF	Mean square								
		GYPMP	WP	A	gs	E	Ci	WUEi	WUE	LS
ECw	4	3091**	4.640**	283.15**	0.027**	18.88**	14923.13**	3.150**	3020**	0.001^{ns}
Linear regression	1	-	17.13^{ns}	1088.40**	0.098*	69.13**	51682.11**	12.50**	10362**	0.000^{ns}
Quadratic regression	1	-	5.60**	12.27*	0.004^{ns}	5.095^{ns}	4809.60*	0.003^{ns}	88.84^{ns}	0.003^{ns}
Management (D)	1	1017**	21.28**	280.54**	0.005^{ns}	3.326^{ns}	4864,13*	1.020^{ns}	0.102^{ns}	0.018**
ECw × D	5	52.72^{ns}	3.090**	41.04**	0.001^{ns}	0.701^{ns}	2487.11*	0.240^{ns}	1038^{ns}	0.006**
Residual	18	28.49	0.20	1.69	0.004	2.943	686.63	0.277	704.5	0.001
CV (%)		8.06	9.76	11.31	39.97	27.28	10.70	33.57	42.15	1.97

** - Significant at 0.01; * - Significant at 0.05; ns - Not significant by the F test at the 0.05 probability level. DF - Degrees of freedom; CV (%) - Coefficient of variation



** - Significant at p ≤ 0.01 of probability by F test. Means followed by different letters at the same ECw indicate a significant difference at p ≤ 0.01 by the F test. Vertical bars indicate standard error of mean (n = 4)

Figure 2. (A) Grain yield and pod mass per plant - GYPMP, (B) water productivity - WP, (C) CO_2 assimilation rate - A, (D) stomatal conductance - gs, and (E) transpiration - E in peanut plants, cultivar BR-1, irrigated with brackish water via pulse and continuous drip, 60 days after planting



ns - Not significant (p > 0.05) by F test. ** - Significant at p ≤ 0.01 of probability by F test. Means followed by different letters at the same ECw indicate a significant difference at p ≤ 0.01 by the F test. Vertical bars indicate standard error of mean (n = 4)

Figure 3. (A) Intercellular CO_2 concentration - Ci, (B) instantaneous water use efficiency - WUEi, (C) intrinsic water use efficiency - WUE, and (D) leaf succulence - LS in peanut plants, cultivar BR-1, irrigated with brackish water via pulse and continuous drip, 60 days after planting

The increase in Ci values is usually accompanied by increases in gs and E; nonetheless, like the photosynthetic rate, these variables were reduced with the increase in ECw, which can be attributed to non-stomatal factors (Silva et al., 2015).

On the other hand, the results of GYPMP and WUEi are corroborated by the estimated reduction of 0.3631 (µmol CO_2 mmol^{-1}) (14.16%) (Figure 3B) per dS m^{-1} increment in

the EC of water, in the ratio between the rate of net carbon assimilation and the rate of water transpiration, in other words, in instantaneous water use efficiency (WUEi), but also of 10.453 (μmol CO_2 $mmol^{-1}$) (11.41%) per dS m^{-1} increment in the EC of water, in the intrinsic water use efficiency (WUE) (Figure 3C).

Leaf succulence was influenced by the interaction between ECw and water management (Figure 3D). Under pulse drip irrigation, the maximum (1.81 g dm^{-2}) LS was estimated for an ECw of 3.09 dS m^{-1}, while the minimum (1.70 g dm^{-2}) LS verified in plants under continuous drip irrigation was estimated under an ECw of 3.29 dS m^{-1}. This variation suggests a phenotypic plasticity related to the loss of water, evidenced by A/E, A/gs, gs and E; in other words, pulse drip irrigation favors osmotic adjustment and consequently LS, compared to continuous drip irrigation (Cruz et al., 2018).

When brackish water was not used, the LS of the plants under continuous drip was 3.75% higher; in other words, plants adjusted osmotically under pulse drip irrigation, although at this level of ECw no salt stress was observed.

On the other hand, Ziogas et al. (2021) suggest that increasing water content in the leaf promotes the dilution of ions within the cells, which allows the presence of salts at high concentrations in parts of the tissues without causing damage to the cells. In other words, the increase in leaf succulence, which is the water content per unit area, is an indication of osmotic adjustment. It is important to consider that plants with high concentrations of solutes in the intracellular medium and which have OA capacity tend to absorb water to maintain the water content in the leaf tissues.

Ψos was influenced ($p \leq 0.05$) by the interaction between ECw and the adopted water management. Increasing ECw levels significantly influenced ($p \leq 0.01$) Ψh, Ψp, Ψos and OA, while water management influenced Ψp and Ψos individually (Table 2).

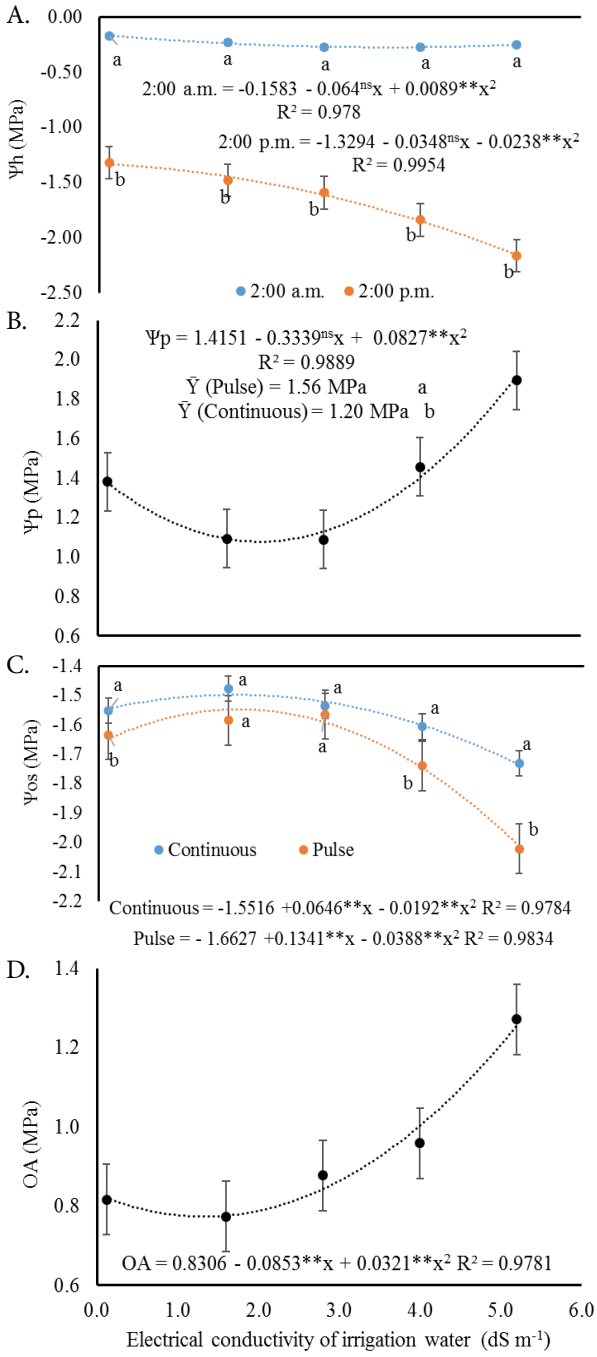
The Ψh was influenced ($p \leq 0.05$) by the increase in ECw, both at 2 a.m. and at 2 p.m. (Figure 4A). During the morning, under the ECw estimated at 3.59 dS m^{-1} the minimum Ψh was 0.27 MPa, whereas in the afternoon, the Ψh was maximal (1.33 MPa) under the ECw estimated at 0.12 dS m^{-1} (Figure 4A).

The increase in water flow and gas exchanges promoted by the increase in temperature until 2 p.m. showed, through the variation observed in water potential, the stress condition imposed by the successive increase in ECw. In other words,

Table 2. Summary of the analysis of variance for leaf water potential – Ψh, osmotic potential (Ψos), pressure potential (Ψp), and osmotic adjustment (OA) in peanut plants, cultivar BR-1, irrigated with brackish water via pulse and continuous drip

Source of variation	DF	Mean square			
		Ψh	Ψp	Ψos	OA
ECw	4	0.383**	096**	0.118**	0.20**
Linear regression	1	1.505**	2.127**	0.283**	0.51**
Quadratic regression	1	0.025ns	1.145**	0.189**	0.26**
Management (D)	1	0.191ns	1.546**	0.125**	0.000ns
ECw × D	4	0.039ns	0.157ns	0.014**	0.001ns
Residual	18	0.260	0.158	0.0037	0.014
CV (%)		26.08	26.88	3.72	10.67

** - Significant at $p \leq 0.01$; * - Significant at $p \leq 0.05$; ns - Not significant by the F test. DF - Degrees of freedom. CV (%) - Coefficient of variation



ns - Not significant ($p > 0.05$) by F test. ** - Significant at $p \leq 0.01$ of probability by F test. Means followed by different letters at the same ECW indicate a significant difference at $p \leq 0.01$ by the F test. Vertical bars indicate standard error of mean (n = 4)

Figure 4. (A) Leaf water potential - Ψh, (B) pressure potential - Ψp, (C) osmotic potential – Ψo, and (D) osmotic adjustment - OA in peanut plants, cultivar BR-1, irrigated with brackish water via pulse and continuous drip

the reduction in GYPMP due to the increase of ECw is even more evident when a joint analysis is made with Ψh, gs, and E. In general, the interaction between the increase in leaf water potential and the increase in irrigation water salinity causes greater difficulty in the absorption of water by the plant, in addition to causing osmotic stress and loss of turgor (Oliveira et al., 2016)

The reduction in the leaf water potential observed at 2 a.m., which is the period of highest turgor pressure, differs from the results found for peanut plants by different authors (Kumar et al., 2020; Sarkar et al., 2021), which can also be attributed

to the different experimental conditions. On the other hand, the results verified by Alves et al. (2016) when analyzing the cultivation of peanut, cv. BR-1, the same cultivar used in the experiment, suggest values for water potential close to -1.0 MPa in non-stress conditions, which corroborates the results presented here. Anyway, the values found in the period of greatest stress (2 p.m.), a period in which plants tend to lose more water to the atmosphere, show an even greater reduction in water potential ranging from -1.0 to - 2.16 MPa, as salinity increased.

According to Arif et al. (2020), the leaf water potential decreases as there is a decrease in various physiological processes within the cells, such as photosynthesis, protein synthesis, cell wall synthesis, and cell expansion, which affects the yield of the crop. This analysis can be verified in the present study, since the reduction in water potential is associated with a reduction also observed in stomatal conductance and transpiration.

The pressure potential was minimal (1,078 MPa) under the ECw estimated at 2.02 dS m^{-1} and showed a growth trend with the increase in salinity. In plant cells, due to a rigid cell wall surrounding the plasmalemma, the movements of water entering and leaving the cells are accompanied by important variations in the pressure potential (Arif et al., 2020), as seen in this study (Figure 4B).

The osmotic potential of plants under pulse drip irrigation was lower (except under the 1.6 and 2.8 dS m^{-1} ECw) compared to the results seen in plants under continuous drip irrigation. Peaks of 1.54 and 1.49 MPa were found under the 1.72 and 1.68 dS m^{-1} ECw in plants under pulse and continuous drip irrigation, respectively (Figure 4C).

This value of ECw estimated for the maximum point of the osmotic potential was lower than the soil salinity threshold for the peanut crop, 3.2 dS m^{-1} (Dias et al., 2016), which can suggest some tolerance to salinity. On the other hand, Fageria et al. (2010) classify peanut as a plant very sensitive to salinity and affirm that, for every 1.0 dS m^{-1} above the water salinity threshold, there is a 29% decrease in crop yield, due to the triggering of physiological processes, such as chlorophyll degradation, which will reduce photosynthesis and, finally, production as observed in this study.

The less negative osmotic potential in plants under continuous drip irrigation corroborates the results of leaf succulence and WP, besides helping to explain why the production of grains and pods is higher in plants under pulse drip irrigation. It suggests that pulse drip irrigation causes less osmotic damage and consequently less energy expenditure because, when a plant tissue is placed in a very concentrated solution (very negative ψh), it will tend to lose water, by lowering ψp and, consequently, ψh.

In general, the decrease in the osmotic potential is considered an osmotic adaptation of the plant. It is also considered a defense strategy against salt stress, as it allows the hydration of plant tissues and delays the harmful processes caused by water deficit arising from increased osmotic potential (Bhardwaj & Kapoor, 2021).

The osmotic adjustment was minimal (0.77 MPa) in plants exposed to an ECw estimated at 1.32 dS m^{-1}, reaching up to 1.36 MPa in plants under 5.6 dS m^{-1} ECw. In this case, the accumulation of solutes within the cells, resulting from the increase in ECw, demonstrated a plant strategy through a process in which the water potential could decrease without decreasing the turgor pressure and, in this study, the relative water content verified in the plants was not significantly influenced ($p > 0.05$) by the treatments.

Plants try to develop osmotic adjustments, when under stress conditions, to keep the leaf water potential and turgor pressure of cells close to adequate, which occurs through the production of low-molecular-weight organic solutes in the cytosol, such as proline, soluble sugars, and free amino acids (Silva et al., 2015). This mechanism results in a leaf water potential gradient favorable to water absorption and maintenance of cell turgor (Sheldon et al., 2017). In this context, some studies (Silva et al., 2015; Sarkar et al., 2021) also corroborate the peanut's ability to perform osmotic adjustment when under stress conditions.

Conclusions

1. The use of pulse drip irrigation did not mitigate the deleterious effect of salinity, but promoted a greater production of grains and pods and a greater water use efficiency compared to continuous drip irrigation;

2. Photosynthetic rate, stomatal conductance, and transpiration were reduced by increase in irrigation water salinity in plants exposed to continuous and pulse drip irrigation, but the internal concentration of CO_2 increased under continuous drip irrigation;

3. The increase in the electrical conductivity of the water affected the leaf's water, pressure, and osmotic potentials, as well as the osmotic adjustment.

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