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TAXAS DE CRESCIMENTO DE BERINJELA IRRIGADA POR GOTEJAMENTO E PULSO UTILIZANDO NÍVEIS DE ÁGUA SALOBRA*

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**Este artigo é proveniente da dissertação do primeiro autor.*

1 RESUMO

A berinjela é uma cultura moderadamente sensível à salinidade e seu crescimento e produção são comprometidos pelo teor inadequado de umidade no solo. Objetivou-se avaliar os efeitos da aplicação de água salobra via combinação de gotejamento e por pulsos no crescimento da berinjela. O delineamento experimental foi blocos casualizados, em esquema fatorial 4 × 4, com cinco repetições. Os tratamentos resultaram da combinação entre quatro formas de aplicação de água: gotejamento durante todo o ciclo, pulso durante todo o ciclo, gotejamento na fase inicial seguido por pulsos na fase final (reprodutiva) e pulso na fase inicial seguido por gotejamento na reprodutiva; e quatro níveis de condutividade elétrica de água de irrigação – CEa (0,3; 1,5; 3,0; 4,5 dS m^{-1}). O aumento da CEa reduziu o crescimento da berinjela, a aplicação de água por sequência gotejamento/pulsos proporcionou maior área foliar com água de baixa salinidade, além de maior massa seca da parte aérea com o aumento da salinidade. A irrigação exclusivamente por pulso utilizando CEa de até 1,5 dS m^{-1} proporcionou as maiores taxas de crescimento absoluto e relativo da altura e área foliar e reduziu o diâmetro do caule, em comparação às outras combinações de irrigação.

Palavras-chave: *Solanum melongena* L., salinidade, fases fenológicas.

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GROWTH RATES OF IRRIGATED EGGPLANT UNDER DRIP AND PULSE UTILISING BRACKISH WATER LEVELS

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2 ABSTRACT

The eggplant is a moderately salt-sensitive crop and its growth and production are compromised by inadequate moisture content in the soil. In the present study, the effects of the application of brackish water via a combination of drip and pulse irrigation on eggplant growth were evaluated. The experimental design was randomized blocks, in a 4 x 4 factorial scheme, with five replications. The treatments resulted from the combination of four forms of water application (drip throughout the crop cycle, pulse throughout the crop cycle, drip in the initial phase followed by the pulse in the final phase (reproductive), and pulse in the initial phase followed by drip in the reproductive phase: and four levels of electrical conductivity of irrigation water - ECw (0.3, 1.5, 3.0, and 4.5 dS m^{-1}). The increase in the ECw reduced the growth of eggplant, and the application of water in the drip/pulse sequence promoted a greater leaf area with low salinity water, besides a greater shoot dry mass with increasing water salinity. Pulse irrigation using ECw of up to 1.5 dS m^{-1} promoted the highest absolute and relative growth rates in height and leaf area and, reduced the stem diameter compared with other combinations of irrigation.

Keywords: *Solanum melongena* L., salinity, phenological phases.

3 INTRODUCTION

Owing to the scarcity of good-quality water resources (low salinity), especially in arid and semiarid regions, the use of brackish water can be an alternative for farmers. However, the dissolved salts in these waters can exacerbate soil salinization, causing severe damage to plants, especially in regions with high evapotranspiration rates (LIMA et al., 2015).

Salinization has adverse effects on the soil, affecting plants through increased osmotic pressure and hindering water absorption. Furthermore, it causes toxicity due to the absorption of excess specific ions, the interference of salts in physiological processes, and nutritional imbalances in plants (DIAS et al., 2016). Therefore, the adoption of soil–water-plant management strategies is necessary to mitigate the effects of salinity when brackish water is used for irrigation.

Pulse irrigation has emerged as a water management strategy that consists of a short period of water application, followed by an interval and another short period of irrigation. This sequence is repeated until all the water required by the plant is applied (ALMEIDA et al., 2018). This technique has shown positive results in terms of product productivity and quality, savings in water use, maintenance of soil moisture, and reduction in the impacts of salinity (EID; BAKRY; TAHA, 2016; ALMEIDA et al., 2018). Therefore, it is necessary to use irrigation strategies that help save water by maintaining an adequate moisture content in the root zone, avoiding water deficit in crops (WAKCHAURE et al., 2020).

Eggplant (*Solanum melongena* L.), whose global production in 2019 was 55.2 million tons, has great medicinal and nutritional importance (FAOSTAT, 2021). Eggplant is a solanaceous plant native to tropical regions of East China, whose fruits are fleshy berries, elongated in shape and varied in color, usually dark purple with green calyxes (FILGUEIRA, 2007).

Inadequate soil moisture during eggplant cultivation, especially during flowering and fruit development, is one of the main limitations for eggplant production (BILIBIO et al., 2010). Arriero et al. (2020) reported that, in eggplant cultivation, pulse irrigation, compared with continuous drip irrigation, allowed greater commercial production and water use efficiency when irrigated with wastewater compared with brackish water prepared with sodium chloride (NaCl) and calcium chloride ($CaCl_2$). The drip and pulse water application methods did not influence the quality of the eggplant fruit, but increasing the salinity of the irrigation water to 4.5 dS m $^{-1}$ increased the amount of total soluble solids and total titratable acidity (DAMASCENO et al., 2021).

Another factor that affects eggplant production is the quality of the water used for irrigation, since saline stress causes morphophysiological changes, and eggplant is considered a moderately sensitive crop to salinity; however, the intensity of the salinity effect can vary depending on environmental and genetic factors (cultivars), crop development stages, irrigation management and soil and climate conditions (PARIDA; DAS, 2005; ÜNLÜNKARA et al., 2010).

In this context, the objective of this study was to evaluate the biometric variables and the absolute and relative growth rates of eggplant under saline stress via irrigation with different combinations of drip and pulses.

4 MATERIALS AND METHODS

The work was developed in a protected environment belonging to the experimental area of the Water and Soil Engineering Center of the Federal University of Recôncavo da Bahia, located in the municipality of Cruz das Almas, BA (12°40'39” S, 39°40'23” W, average altitude of 212 m), situated in the Recôncavo Baiano region. During the experiment, from early April to mid-July 2019, the air temperature inside the greenhouse varied between 24.8 and 25.2°C, and the relative humidity varied between 76 and 83%.

The experimental design was a randomized block design (16 treatments) with 5 replications, consisting of four forms of water application: dripping throughout the cycle (G); pulses throughout the cycle (P); dripping in the vegetative phase followed by pulses in the reproductive phase (G/P) and pulses in the vegetative phase followed by dripping in the reproductive phase (P/G); and four levels of electrical conductivity of irrigation water (ECa (0.3 - control, supply water; 1.5, 3.0 and 4.5 dS m $^{-1)}$, totaling 80 experimental units. To prepare brackish water, local supply water and sodium chloride (NaCl) were used, with salt commonly found in saline soils.

At 65 days after transplanting (DAT), the water application method was reversed from drip irrigation to pulse irrigation and vice versa. Therefore, for the biometric evaluations performed before this date, only two treatments (G and P) were considered.

The soil used in the test was classified as a typical Ditrocohesive Yellow Latosol (Densic Ferralsol; Oxisol, as classified by the U.S. Soil Survey Staff, 2014), with low fertility and cohesive subsurface horizons, with the following characteristics: CEes = 0.65 dS m $^{-1}$; pH = 5.1; P = 1.3 mg dm $^{-3}$; K^+ = 48 mg dm $^{-3}$; Na^+ = 0.04 cmol $_c$ dm $^{-3}$; Ca^{2+} = 1.0 cmol $_c$ dm $^{-3}$; Mg^{2+} = 0.5 cmol $_c$ dm $^{-3}$; Al^{3+} = 0.2 cmol $_c$ dm $^{-3}$; H^+ +Al^{3+} = 3.0 cmol $_c$ dm $^{-3}$; organic matter = 11.8 g kg $^{-1}$; and the sand, silt and clay contents were 682.5, 202.2 and 115.3 g kg $^{-1}$, respectively. One hundred L plastic boxes were used, which were filled with a 0.05 m layer of gravel and approximately 150 kg of soil (density = 1.5 kg dm $^{-3}$) from the 0–0.20 m layer, properly broken down and homogenized. The gravel layer and the soil were separated by a screen, and a 16 mm hose was also installed at the bottom of each box for drainage.

Liming was performed 60 days before transplanting, and 65 g of dolomitic limestone was used per box to increase the base saturation to 70% (TRANI, 2014). Foundation fertilization consisted of 46 g of monoammonium phosphate (MAP) and 13 g of potassium chloride (KCl) per box, in addition to 2 L of cured manure containing, on average, 0.3 N, 0.17 P_2O and 0.1% K_2O, on the basis of soil chemical analysis and recommendations by Trani (2014). Topdressing fertilization was performed at 30, 60, and 90 DAT, with 3.3 g of urea and 2.5 g of KCl per box, following the recommendations of Trani (2014) for the crop. To calculate the degree of fertilization, the box area was considered equal to 0.5 ^{m2}.

The cultivar used was the Florida market, which has open pollination, oblong fruits, a bright dark wine color, greenish-white flesh, high productivity, fruits weighing 200 to 250 g, and resistance to phomopsis rot and is very vigorous (EMBRAPA HORTALIÇAS, 2022). Sowing was carried out in polyethylene trays with 50 cells containing coconut fiber and earthworm humus at a 2:1 ratio (volume basis). The seedlings were transplanted when the plants had four definitive leaves, which occurred 30 days after sowing (DAS).

To calculate the irrigation depth, the characteristic curve of water retention in the soil was used, according to the van Genuchten model (1980) presented by Equation 1:

$$\theta = 0,101 + \left(\frac{0,486 - 0,101}{\left[1 + (0,056\ |\Psi|)^{1,345}\right]^{0,256}} \right) \quad (1)$$

where θ is the soil moisture ($cm^3\ cm^{-3}$) and Ψ is the matric potential (kPa).

A tensiometer was installed at a depth of 0.15 m in three replicates of each treatment, totaling 48 tensiometers. Daily readings were taken from the tensiometers, and irrigation was carried out when the average tension was ≥ 15 kPa, on the basis of the soil characteristic curve, according to Bilibio et al. (2010) is the stress of greatest growth and productivity of eggplant plants, with the soil moisture content increasing to 10 kPa (corresponding to field capacity). The irrigation time was calculated from the determined gross depth, considering the effective depth of the root system equal to 0.30 m and the flow rate of the drippers used.

The irrigation system was a drip system, with one emitter per conventional self-compensating dripper nozzle and an average flow rate of 2.1 L $h^{-1.}$ The average Christiansen uniformity coefficient was 91%, which was obtained through tests performed at the beginning of the experiment to maintain uniform soil moisture within the same treatment. Five millimeter microtubes were connected to the emitters, which were connected to 20 mm diameter polyethylene tubing. For pulse irrigation, the total irrigation time was divided into six pulses, with a 30-minute interval between pulses. A digital controller with four outputs and 24 programs was used to control the pulse irrigation.

Cultural treatments consisted of staking the plant, removing lateral shoots on the main stem before the first flower and preventing the application of insecticides and fungicides.

Biometric variables were evaluated at the beginning of flowering and at harvest, corresponding to 60 and 100 DAT, with the following parameters: plant height (AP, cm); stem diameter (DC, mm); and leaf area (AF, m^2), estimated according to the equation AF = 0.4395 × L × $W^{1.0055}$, as recommended by Hinnah et al. (2014), where C is the length and L is the width of the leaf, and shoot dry mass (SDM) considers the leaves and stems at 100 DAT. The absolute growth rate (AGR) and relative growth rate (RGR) with respect to height, stem diameter and leaf area were determined according to Equations 2 and 3 (BENINCASA, 2003). These rates were calculated for the 20–60 and 60–100 DAT evaluations.

$$TCA = \frac{(V2 - V1)}{(T2 - T1)} \quad (2)$$

$$TCR = \frac{(Ln(V2) - Ln(V1))}{(T2\ n- T1)} \quad (3)$$

where V1 is the variable at time T1 and V2 is the same variable at time T2.

The data were subjected to analysis of variance. When significant according to the F test, the mean data for the water application methods were compared via Tukey's test at the 0.05 probability level, whereas the salinity levels were analyzed via polynomial regression (linear and quadratic). When there was a significant interaction between the factors, regression analysis was performed, prioritizing polynomial regression and comparing different water application methods on the basis of adjusted models. All the statistical analyses were performed via the SISVAR statistical program, version 5.6 (FERREIRA, 2019).

5 RESULTS AND DISCUSSION

Table 1 presents a summary of the analysis of variance for the variables studied. The salinity of the irrigation water significantly affected all the variables studied in the different periods evaluated. With respect to water application, only DC and MSPA at 100 DAT and AF significantly influenced the TCA_{AP} and TCR_{AP} at 60 and 100 DAT. Furthermore, there was a significant effect of the interaction effect between the water application method and water salinity on the absolute and relative growth rates at 60--100 days after transplanting (DAT) in terms of plant height (TCA_{AP} and TCR_{AP}), stem diameter (TCA_{DC} and TCR_{DC}), leaf area (TCA_{AF} and TCR_{AF}), and leaf area (AF) and shoot dry mass (MSPA) at 100 DAT.

Table 1. Summary of analysis of variance for plant height (AP), stem diameter (DC), leaf area (AF), shoot dry mass (MSPA) and absolute and relative growth rates of plant height (TCA_{AP} and TCR_{AP}), stem diameter (TCA_{DC} and TCR_{DC}) and leaf area (TCA_{AF} and TCR_{AF}) between evaluations carried out at 20, 60, and 100 days after transplanting (DAT) of eggplants grown under different forms of water application (I) and saline stress (S).

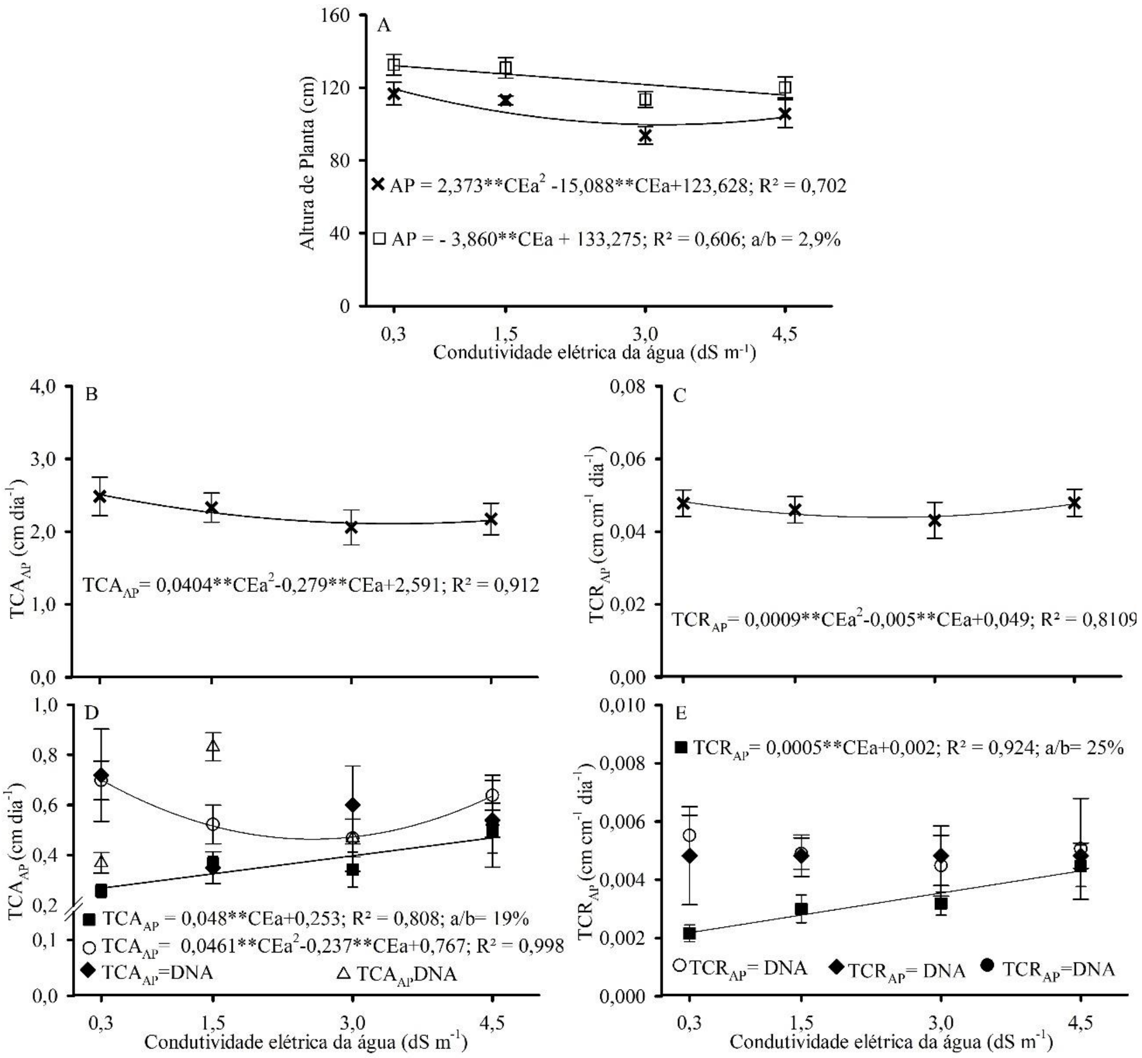
Variable	F Test					
	DAT	Sources of variation			Average	CV (%)
		I	S	I × S		
AP	60	ns	**	ns	107.29 cm	10.84
	100	ns	**	ns	124.30 cm	9.83
TCA_{AP}	20-60	ns	**	ns	2.26 cm dia $^{-1}$	10.29
	60-100	ns	**	**	0.512 cm dia $^{-1}$	19.93
TCR_{AP}	20-60	ns	**	ns	0.046 cm cm $^{-1}$ day $^{-1}$	7.44
	60-100	ns	**	**	0.0045 cm cm $^{-1}$ day $^{-1}$	20.90
A.D	60	ns	**	ns	13.82 mm	9.21
	100	**	**	ns	15.35 mm	8.58
TCA_{DC}	20-60	ns	**	ns	0.215 mm day $^{-1}$	8.23
	60-100	**	**	**	0.051 mm day $^{-1}$	22.77
TCR_{DC}	20-60	ns	**	ns	0.024 mm mm $^{-1}$ day $^{-1}$	8.75
	60-100	**	**	*	0.003 mm mm $^{-1}$ day $^{-1}$	26.53
AF	60	**	**	ns	1.10 m ^{2}	18.64
	100	**	**	**	0.92 m ^{2}	17.05
TCA_{AF}	20-60	**	**	ns	0.0266 m ^{2} day $^{-1}$	17.42
	60-100	**	**	**	0.64 m ^{2} day $^{-1}$	14.32
TCR_{AF}	20-60	**	**	ns	8.3×10^{-6} m ^{2} m $^{-2}$ day $^{-1}$	7.64
	60-100	**	**	**	7.9×10^{-6} m ^{2} m $^{-2}$ day $^{-1}$	5.82
MSPA	100	**	**	**	199.78 g	10.33

*, ** - significant at $p \leq 0.05$ and $p \leq 0.01$, respectively; ns – not significant. **Source**: The authors (2022)

For AP at 60 DAT, a quadratic response was observed (Figure 1A), in which the minimum estimated height occurred at an ECa of 3.18 dS m $^{-1}$ (99 cm), whereas at 100 DAT, the plant height showed a reduction of 3.86 cm or 2.90% per unit increase in ECa, representing a decrease of 12.27% in plants irrigated with water of higher salinity (ECa = 4.5 dS m $^{-1}$), compared with the control treatment (ECa = 0.3 dS m $^{-1}$). Thus, the negative effect of irrigation water salinity on the height of eggplant plants increases with increasing duration of exposure to salt. These results corroborate those observed by Oliveira et al. (2011) and Lima et al. . (2015), who reported reductions of 9.63% and 4.87%, respectively, per unit increase in the effect of irrigation water salinity on the height of eggplant plants. Arriero (2019) reported eggplant cv. Florida market heights (at 114 DAT) of 134.7 and 137.15 cm, with irrigation water salinities of 2.5 dS m $^{-1}$ prepared with $CaCl_2$ and NaCl, respectively.

The reduction in plant height may have occurred due to a decrease in soil water potential due to the accumulation of salts, affecting water availability for plants and, subsequently, due to the absorption and excessive accumulation of ions (Na+ and Cl^-) in the cells, causing toxic effects (KATUWAL; XIAO; JESPERSEN, 2020). In addition, the reduction in water absorption causes a decrease in leaf turgor and closure of stomata, leading to a reduction in transpiration and photosynthesis and, consequently, inhibition of plant growth (MASTROGIANNIDOU et al., 2016; HANNACHI; VAN LABEKE, 2018).

Figure 1. Average plant height - AP of eggplant at 60 and 100 days after transplanting (DAT) as a function of the electrical conductivity of the water used for irrigation (A) and the absolute height growth rates - TCA $_{AP}$ (B) and relative - TCR $_{AP}$ (C) in the period 20--60 days after transplanting (DAT), and breakdown of the interaction between irrigation methods and water electrical conductivity for TCA $_{AP}$ (D) and TCR $_{AP}$ (E) in the period 60--100 DAT.



For DNA, * and ** indicate that the data did not fit and were significant at p ≤0.05 and p ≤0.01, respectively. Plants irrigated by drip - G (■); by pulses - P (○); by drip followed by pulses - G/P (◆) and by pulses followed by drip - P/G (△); (×) and (□) APs at 60 and 100 DAT, respectively. The vertical bar in each observation represents the standard deviation (n=5). **Source**: The authors (2022)

The analysis of the growth rates revealed that from 20--60 DAT, the TCA $_{AP}$ and TCR $_{AP}$ reached minimum estimated values at an ECa of 3.45 dS m $^{-1}$ (2.10 cm day $^{-1}$) and at an ECa of 2.5 dS m $^{-1}$ (0.043 cm cm $^{-1}$ day $^{-1}$), respectively (Figure 1B and 1C). For the period from 60--100 DAT, there was an interaction effect between salinity and the irrigation method on these variables (Figure 1D and 1E). Thus, plants irrigated with salinities of 0.3 and 1.5 dS m $^{-1}$ per pulse (P) presented increases of 162 and 59%, respectively, in the TCA $_{AP}$ in relation to those under drip irrigation (G), but the difference decreased with increasing salinity.

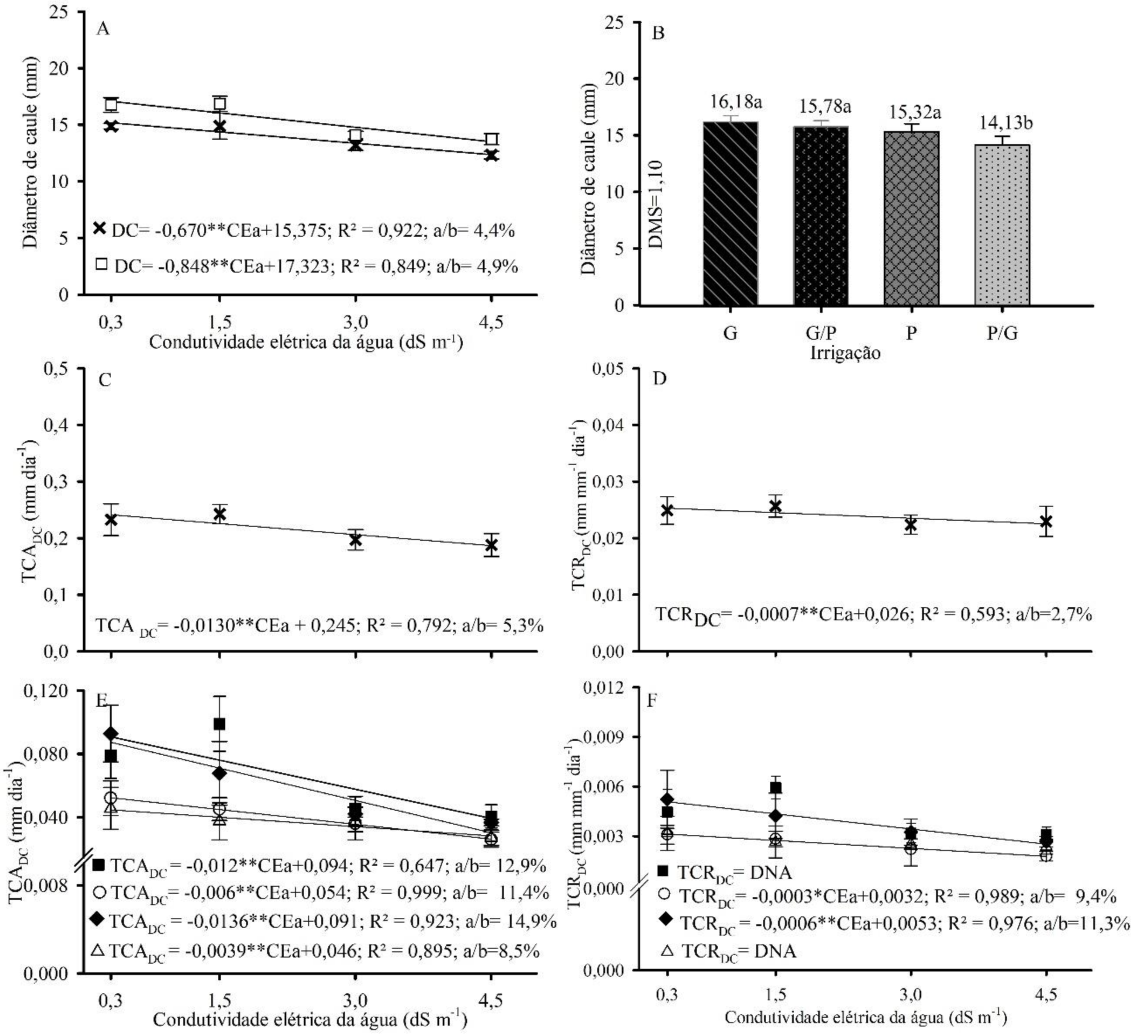
The treatments that changed the irrigation methods (P/G or G/P) did not fit any mathematical model satisfactorily for either growth rate. When the salinity levels within the G treatment were analyzed, increases of 19.0 and 25.0% per unit increment of ECw were observed in the TCA $_{AP}$ and TCR $_{AP}$, respectively. When irrigated by the P treatment, the TCA $_{AP}$ fitted the quadratic model, whose minimum estimated value was obtained at an ECw of 2.57 dS m $^{-1}$, which provided a TCA $_{AP}$ of 0.462 cm day $^{-1}$. Thus, the growth rates of eggplant plants decreased with increasing age (DAT), and when the plants were irrigated with low-salinity water via the P treatment, better results were obtained. Furthermore, it can be inferred that the TCA $_{AP}$ and TCR $_{AP}$ increase with increasing water salinity above 1.5 dS m $^{-1}$ when G irrigation is used. Under certain salinity levels in irrigation water, some cultivars may present satisfactory development in relation to more moderate salinity levels, as reported by Bsoul et al. In eggplant cv. Blacky, they reported higher values of plant height, stem diameter, leaf area, relative growth rate and dry mass of leaves, stems, roots and total mass when the salinity was 4 dS m $^{-1}$ than when the salinity was 2.0 dS m $^{-1}$.

The absolute and relative growth rates of plant height observed for the period from 20--60 DAT corroborate the results presented by Bardiviesso et al. (2014), who did not use brackish water for the cultivation of green eggplant, with different substrates and evaluations every 10 days up to 60 DAT. According to the data presented by these authors, the average TCA was 2.02 cm day $^{-1,}$ and the RCR was 0.046 cm cm $^{-1}$ day $^{-1}$ for plant height. However, during the period from 60--100 DAT, the results of the present study are lower than those reported by these authors, probably because of salt stress.

The growth rates for the period from 60--100 DAT, as expected, were lower than those for the 20--60 DAT period. These results can be attributed to the beginning of flowering/fruiting, which reduces plant growth. During this development phase, the plant needs to translocate photoassimilates for fruit formation and maintenance of the formed structures, as observed by Mesquita et al. (2012). Another possible reason may be the gradual accumulation of salts in the soil over time, reaching a critical level for the crop, as observed by Damasceno et al. (2022).

During the period between 60 and 100 DAT, reductions in stem diameter of 4.36 and 4.89% were observed per unit increase in water salinity, respectively (Figure 2A). A comparison of the control treatments (CEa = 0.3 dS m $^{-1}$) and maximum salinity treatments (CEa = 4.5 dS m $^{-1}$) revealed reductions of 18.54% (60 DAT) and 21% (100 DAT) in stem diameter in both evaluations. These results corroborate those reported by Lima et al. (2015) and Oliveira et al. (2011), who, when brackish water (CEa from 0.5 to 4.5 dS m $^{-1}$) was used, noted significant reductions in eggplant stem diameter of 4.3% and 6.2%, respectively, per unit increase in the salinity of the water used for irrigation. However, Ünlünkara et al. (2010), with CEa varying from 1.5 to 7.0 dS m $^{-1,}$ and Bsoul et al. (2016) used three cultivars, and a CEa between 1.2 and 8.0 dS m $^{-1}$ did not significantly affect this variable. These contrasting responses may be due to the genetic characteristics of the cultivars studied, as stated by Costa et al. (2019).

Figure 2. Stem diameter - DC of eggplant at 60 and 100 days after transplanting (DAT) as a function of the electrical conductivity of the water used for irrigation (A) and for the water application methods at 100 DAT (B); absolute growth rates - TCA $_{DC}$ and relative diameter - TCR $_{DC}$ in the period 20--60 (C and D) as a function of the electrical conductivity of the water used for irrigation and the unfolding of the interaction between the water application methods and electrical conductivity (E and F) for TCA $_{DC}$ and TCR $_{DC}$ in the interval 60--100 DAT.



DNA, * and ** indicate that the data did not fit and were significant at p ≤0.05 and p ≤0.01, respectively; means followed by the same letter do not differ from each other according to Tukey's test (p < 0.05). The vertical bar in each observation represents the standard deviation (n = 5). Plants irrigated by drip - G (■); by pulses - P (○); by drip followed by pulses - G/P (◆) and by pulses followed by drip - P/G (△); (×) and (□) DC at 60 and 100 DAT, respectively. **Source**: The authors (2022)

For the evaluation at 100 DAT, the stem diameter under the P/G treatment was 10.3% smaller than the average diameter under the other treatments, which did not differ from each other, with an average of 15.76 mm (Figure 2B). Overall, DC was the variable least affected by the different forms of water applied with respect to the increase in water salinity.

Salinity stress, as explained previously, can cause reduced plant development due to nutritional imbalance, where an excess of one ion can cause deficiency or inhibit the absorption of another. This occurs due to salt precipitation or ion antagonism. For example, excess sodium can affect the absorption of calcium, magnesium, or potassium, with potassium deficiency being associated with thin stems (COSTA, 2014; DIAS et al., 2016).

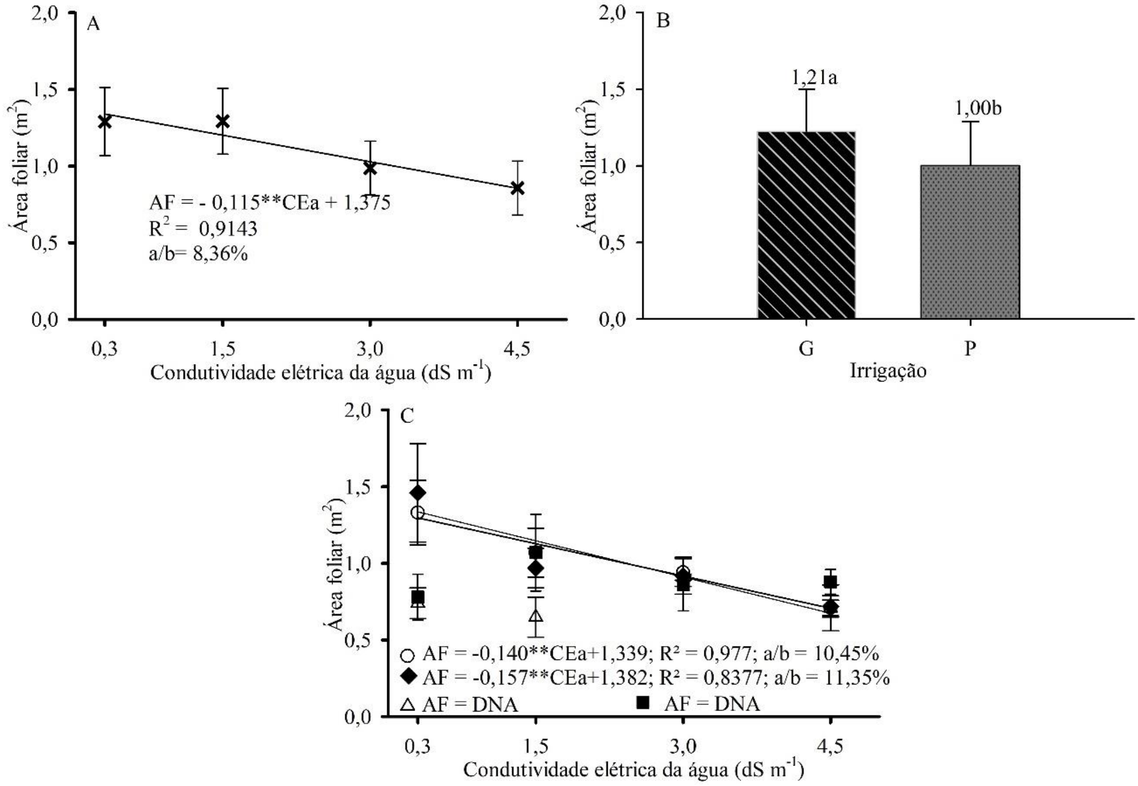
During the initial period (20–60 DAT), the absolute growth rates (TCA_{DC}) and relative growth rates for stem diameter (TCR_{DC}) decreased by 5.3 and 2.7% per unit increase in salinity, respectively (Figures 2C and 2D). During the period of 60–100 DAT, the TCA_{DC} was affected by the increase in ECa, with a linear reduction in all forms of water applied (Figure 2E). The greatest reductions were observed in G/P and G, corresponding to 14.9 and 12.9% per unit increase in ECa, respectively. Notably, despite these results, the treatments presented plants with relatively large diameter values under all levels of water salinity. The $TCR_{DC\ values}$ decreased by 9.4 and 11.3% with increasing salinity in the P and G/P treatments, respectively, whereas for the other irrigation methods, the data did not fit any mathematical model satisfactorily (Figure 2F).

A reduction in the growth rate of stem diameter inhibits plant growth (MOURA et al., 2017). Furthermore, these plants are more prone to tipping over and branch breakage due to the mass of the fruits, especially the cultivar of the present study, which requires more resistant stems because it is a highly productive plant, as observed by Costa et al. (2019).

Reductions in the absolute and relative growth rates of plant height and stem diameter under salt stress have been reported in different crops. Mesquita et al. (2012) reported a decrease in the TCA and TCR for plant height and stem diameter in passion fruit with increasing salinity, but these deleterious effects were attenuated by the application of biofertilizers.

In the case of AF at 60 DAT, the salinity factor was reduced by 8.36% per unit increase in salinity, resulting in a reduction of 36.03% when water with an electrical conductivity of 4.5 dS m^{-1} was used compared with the lowest level of ECa (0.3 dS m^{-1}) (Figure 3A). In turn, in relation to the forms of water application, drip irrigation presented a leaf area 21% larger than that of pulse irrigation (Figure 3B). Notably, since the inversion of the form of water application occurred only at 65 DAT, at this stage, only two forms of irrigation were considered.

Figure 3. Leaf area - AF of eggplant at 60 days after transplanting (DAT) as a function of water electrical conductivity (A) and application methods (B) and breakdown of the interaction between water application methods and water electrical conductivity at 100 DAT (C).



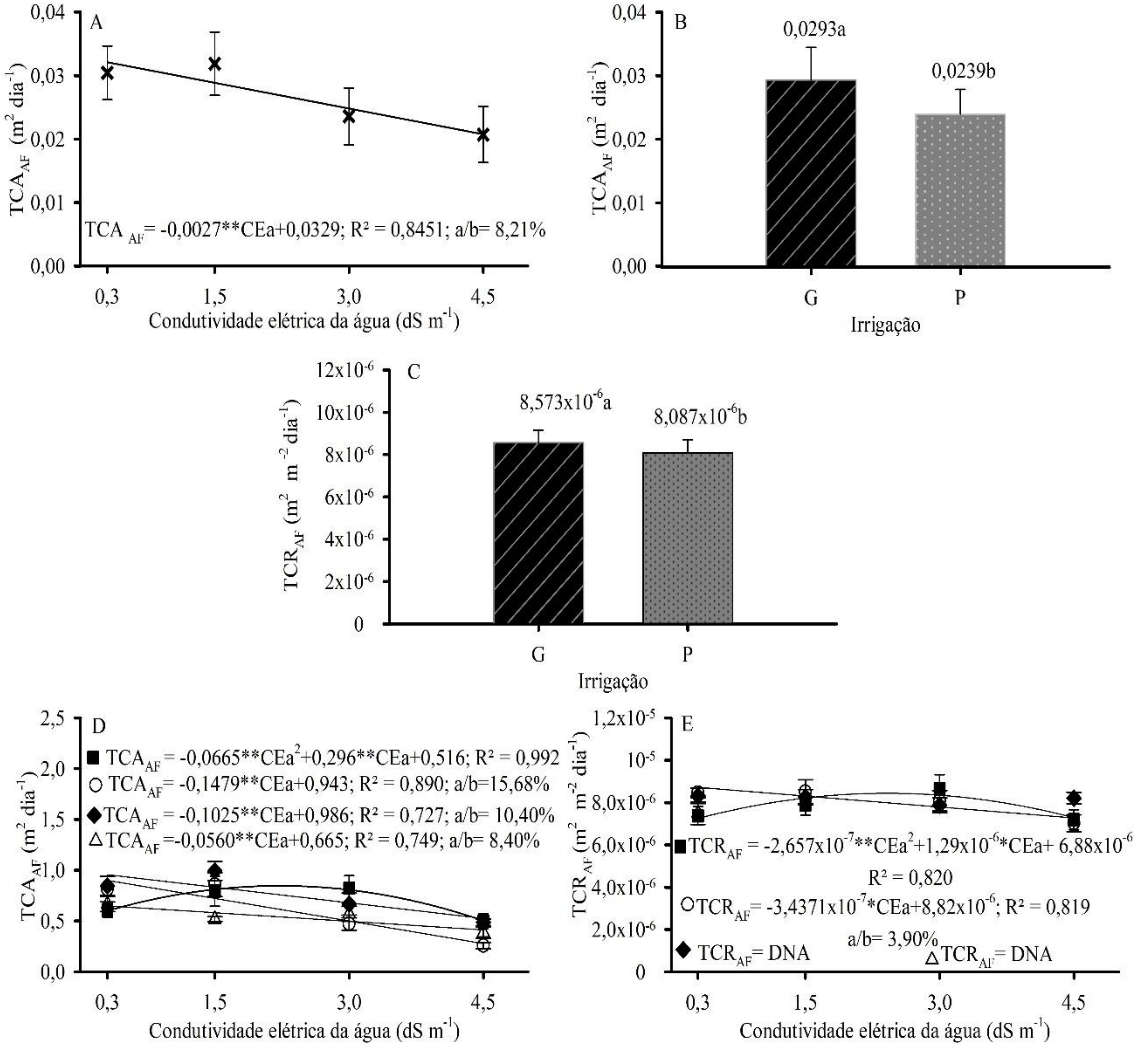
DNA, ^{ns,} * and ** represent data that did not fit, not significant and significant at p ≤0.05 and p ≤0.01, respectively. Plants irrigated by drip - G (■); by pulses - P (○); by drip followed by pulses - G/P (◆); and by pulses followed by drip - P/G (△). The vertical bar in each observation represents the standard deviation (n=5). **Source**: The authors (2022)

For the leaf area at 100 DAT, the interaction analysis revealed that the P and G/P treatments presented a significant model, with linear decreases of 10.45 and 11.35%, respectively, for each unit increase in ECw, whereas the data for G and P/G did not fit satisfactorily with any mathematical model (Figure 3C). An analysis of the water application methods revealed that plants under pulse irrigation (P and G/P) presented relatively large leaf areas. However, at an ECw greater than 3.0 dS m $^{-1,}$ all the treatments were equal (Figure 3C).

The leaf area was negatively affected by salinity, similar to the findings of Lima et al. (2015), who reported a 43.8% reduction between water salinity levels of 0.5 and 6.0 dS m $^{-1}$. A decrease in leaf area is a typical plant response to salt stress. According to Acosta-Motos et al. (2017), the decrease in leaf growth is the earliest response of glycophytic plants exposed to salt stress, in which the reduction can be considered an acclimation mechanism, which reduces water loss through transpiration, partially closing the stomata. Lima et al. (2015) reported that leaves are the most sensitive organs to salinity and that an increase in salt concentration in the soil solution induces premature leaf senescence, reducing the leaf area. However, leaves are responsible for transforming light energy into chemical energy and allocating photoassimilates to the vegetative and reproductive organs of plants (GOMES et al., 2011). Thus, morphological, physiological, and biochemical changes in this organ can affect the growth and productive capacity of the plant.

With respect to the absolute and relative growth rates of the leaf area (TCA $_{AF}$ and TCR $_{AF}$), at 20--60 DAT, the TCA $_{AF}$ decreased by 8.21% per unit increase in ECa (Figure 4A), whereas the TCR $_{AF}$ did not fit any mathematical model. For the water application forms, both the TCA $_{AF}$ and TCR $_{AF}$ were greater when the G treatment was used, with increases of 22.60 and 5.93%, respectively, in relation to P (Figures 4B and 4C).

Figure 4. Absolute growth rate of eggplant leaf area (TCA $_{AF}$) in the period 20--60 days after transplanting (DAT) as a function of the electrical conductivity of the water used in irrigation (A) and the form of water application (B) and relative growth rate (TCR $_{AF}$) for the forms of water application (C) and breakdown of the interaction between the forms of application and electrical conductivity of water for TCA $_{AF}$ (D) and TCR $_{AF}$ (E) in the period of 60--100 DAT.



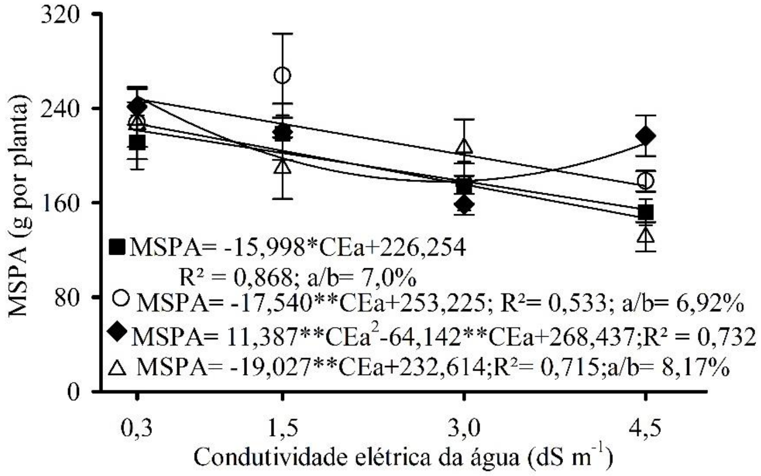
DNA, ^{ns,} * and ** represent data that did not fit, not significant and significant at p ≤0.05 and p ≤0.01, respectively. Plants irrigated by drip - G (■); by pulses - P (○); by drip followed by pulses - G/P (◆); and by pulses followed by drip - P/G (△). The vertical bar in each observation represents the standard deviation (n=5). **Source**: The authors (2022)

The AF TCA and AF TCR (60–100 DAT) for the G irrigation systems were adjusted in a quadratic polynomial manner as a function of increasing salinity, with maximum estimated values of 0.848 m^2 day^{-1} and 8.44 × $^{10-6}$ m^2 m^{-2} day^{-1} for salinities of 2.24 and 2.43 dS m^{-1}, respectively (Figures 4D and 4E). For P irrigation, the AF TCA and AF TCR decreased by 5.68 and 3.90%, respectively, with each increase in salinity. The inversion of the G/P and P/G treatments induced decreases of 10.40 and 8.40% per salinity increase, respectively, in the AF TCA (Figure 4D). Moreover, for the AF TCR, the data did not fit any model satisfactorily (Figure 4E). Thus, treatment inversion (P/G) resulted in a smaller reduction in ACT AF than did P irrigation throughout the cycle. Thus, it can be inferred that for eggplant plants irrigated with low-salinity water, P irrigation is the most recommended method because it maintains greater moisture close to the root system. As the ECW used in irrigation increases, the G treatment is indicated because it keeps the salts further away from the root system.

Andrade, Almeida, and Lima (2014), in a study in a Red Latosol, reported that the bulb was more horizontally elongated under pulse irrigation, tending toward a rectangular shape with a higher moisture content in the surface soil layer, whereas continuous drip irrigation resulted in an elliptical-shaped wet bulb with the highest moisture content in the center of the bulb. Furthermore, under pulse irrigation, because a shallower water depth is applied at each time interval and the wet bulb experiences greater horizontal expansion, evaporation from the soil surface is greater in this area than that under drip irrigation. Thus, it can be inferred that under experimental conditions, pulse irrigation with saline water (ECa = 4.5 dS m^{-1}), although it provided relatively high soil moisture near the root system, also promoted greater salt accumulation, as observed by Damasceno et al. (2022), causing greater damage to the leaf area.

When observing the interaction of factors for MSPA (Figure 5), the G/P treatment presented a quadratic response, reducing to an estimated minimum value of 178.11 g at the ECa level of 2.81 dS m^{-1}. The G, P and P/G treatments presented linear decreases of 15.99, 17.54 and 19.02 g, corresponding to decreases of 7.0, 6.92 and 8.17%, respectively, in dry mass with increasing salinity. Compared with those in the control treatments (ECa = 0.3 dS m^{-1}) and maximum salinity treatments (ECa = 4.5 dS m^{-1}), reductions of 30.34, 29.71, 15.92 and 35.22% were observed in the G, P, G/P and P/G treatments, respectively. Thus, the P/G treatment had a greater effect on dry mass production than the G/P treatment did, with an increase in water salinity, indicating that the P treatment with high CEa in the initial growth phase may not be appropriate for the cultivation of Florida market eggplant under the conditions in which the experiment was conducted.

Figure 5. Breakdown of the interaction between irrigation methods and the electrical conductivity of water for aerial part dry mass (ASM) 100 days after eggplant transplantation.



*, **, respectively, indicate significance at $p < 0.05$ and $p < 0.01$.
Plants irrigated by drip - G (■); by pulses - P (○); by drip followed by pulses - G/P (◆); and by pulses followed by drip - P/G (△). The vertical bar in each observation represents the standard deviation (n=5). **Source**: The authors (2022)

For MSPA, the use of pulse irrigation resulted in higher absolute values than did drip irrigation, even with increased salinity, with a significant difference only at a salinity of 4.5 dS m $^{-1}$, despite having negatively affected the TCA_{AF} and TCR_{AF}. Thus, it can be inferred that the accumulation of toxic ions by eggplant plants when irrigated with saline water may have induced an increase in the sclerophylly index of eggplant leaves, which can result in a smaller leaf area with greater biomass production. This behavior was observed by Cova et al. (2016) in noni plants as an adaptive mechanism to salt stress. Furthermore, as mentioned previously, plants in the reproductive phase allocate photosynthesis to fruit production and plant structure.

In the literature, there are reports of a reduction in MSPA in response to salinity, which is much greater than that reported in the present study. Oliveira et al. (2011), working with eggplant cv. Preta Comprida and water with salinities ranging from 0.5 to 4.5 dS m $^{-1}$, reported relative losses of 54.6% for MSPA. Irrigation with saltwater ranging from 0.5 to 6.0 dS m $^{-1}$ reduced the MSPA of the eggplant Ciça hybrid by 60% (LIMA et al., 2015).

The reduction in plant dry mass under saline stress conditions may be related to low water availability resulting from the osmotic effect, which causes stomatal closure and low CO2 assimilation and a low photosynthetic rate. Another factor is the diversion of energy from growth to maintenance of plant metabolic activities, which is associated with acclimation to salinity and reduced carbon gains (MENEZES et al., 2017).

6 CONCLUSIONS

The increase in electrical conductivity of the irrigation water caused a reduction in eggplant growth, mainly in the stem diameter, leaf area and dry mass of the aerial part, with acceptable reductions (<10%) at a water salinity of 1.5 dS m $^{-1}$.

In the initial growth phase, drip irrigation is most suitable regardless of salinity level, and in the reproductive phase, drip treatments followed by pulses throughout the cycle are the most suitable, as they favor the absolute and relative growth rates of the height and leaf area of Florida market eggplant plants.

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