Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 06 August 2022
https://doi.org/10.14295/CS.v13.3785

Growth and physicochemical characterization of cherry tomato under irrigation with saline water and nitrogen fertilization

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Abstract

Saline water is an alternative to the low availability of high-quality water in semi-arid regions. However, although these water sources negatively affect most crops, their use allied to management practices aiming to mitigate the effects of salts has been increasingly studied, including nitrogen fertilization. From this perspective, this study aimed to evaluate the growth and physicochemical characterization of cherry tomato plants irrigated with saline water and nitrogen fertilization. The experiment was conducted under field conditions at the Center of Sciences and Agrifood Technology of the Federal University of Campina Grande in Pombal – PB, using a randomized block design arranged as a 5 × 5 factorial referring to five electrical conductivity levels of irrigation water - ECw (0.3, 1.3, 2.3, 3.3, and 4.3 dS m^{-1}) and five nitrogen doses - ND (50, 75, 100, 125, and 150% of the N recommendation), with three replications. The nitrogen doses did not mitigate the effects of salt stress on plant height and stem diameter of cherry tomato. However, irrigation with the electrical conductivity of 3.3 dS m^{-1} increased the soluble solids of cherry tomato fruits.

Keywords: fruit post-harvest, irrigation management, salt stress, *Solanum lycopersicum* var. *cerasiforme*

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetables in Brazil and worldwide. However, its production in the semi-arid region of Northeastern Brazil is limited by the irregularity and distribution of rainfall, resulting in water scarcity (Silva et al., 2020). In this scenario, saline water becomes an essential resource for irrigated crops, especially at drought times. On the other hand, using such water sources causes ion accumulation in the root zone, increasing the risk of soil salinization and numerous types of crop damage (Souza et al., 2017; Sousa et al., 2020).

Osmotic and ionic effects stand out among the main types of direct crop damage caused by saline water. Osmotic effects limit plant growth and yield by reducing the osmotic potential and compromising water and nutrient uptake due to the decrease in the free energy of water and soil water retention caused by salt excess. On the other hand, the ionic effect is divided into competition for nutrients such as potassium and calcium and specific ion toxicity, especially sodium, chorine, and boron (Sá et al., 2018).

Tomato is considered sensitive to salinity, and its water salinity threshold is 2.5 dS m^{-1}, above which several types of damage may occur, ranging from germination and growth to fruit production and quality (Viol et al., 2017; Souza et al., 2019).

However, tomato irrigation management using saline water can be safely performed by adopting handling strategies to minimize the deleterious effects of salt stress. Such strategies include nitrogen fertilization, which promotes plant growth and reduces the adverse effects of salinity (Lima et al., 2018; Silva et al., 2018), given the role of this nutrient as a constituent of various organic compounds, e.g., amino acids and proteins (Bezerra et al., 2018a; Dias et al., 2020).

Received: 28 July 2021
Accepted: 21 February 2022

In this scenario, several studies have been conducted on tomato cultivation under irrigation water salinity (Dandaro et al., 2019) considering the national economic importance of this crop, although information is still scarce with regard to the mitigating action of nitrogen on the negative effects of salinity. From this perspective, this study aimed to evaluate the growth and physicochemical characteristics of cherry tomato plants grown under irrigation with saline water and nitrogen fertilization.

Material and Methods

The experiment was developed from October 2020 to February 2021 at the Center of Sciences and Agrifood Technology of the Federal University of Campina Grande - UFCG, in the municipality of Pombal, Paraíba, located at the following coordinates: 6° 46' 13" S, 37°48'06" W, and at an elevation of 193 m. The region has a dry and hot semi-arid climate, mean annual evaporation of 2000 mm, and mean rainfall of approximately 750 mm year^{-1}, according to the Köppen classification adapted to Brazil (Souza et al., 2015).

The plants were grown under field conditions and 70% shading in the experimental area. The data on the minimum and maximum air temperature, precipitation, and relative air humidity during the experimental period are shown in Figure 1.

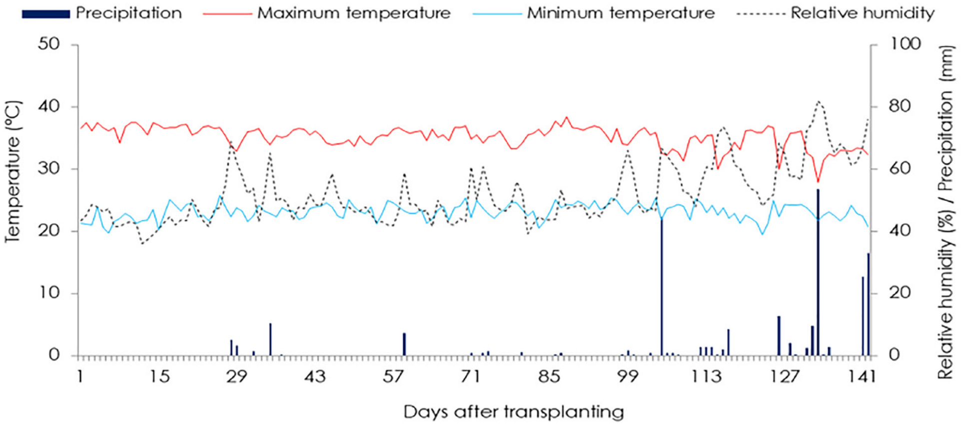

Figure 1. Maximum and minimum air temperature, precipitation and relative air humidity during the experimental period.

The experimental design was in randomized blocks arranged as a 5 × 5 factorial referring to five electrical conductivity levels of irrigation water - ECw (0.3, 1.3, 2.3, 3.3, and 4.3 dS m^{-1}) and five nitrogen doses - ND (50, 75, 100, 125, and 150% N), with three replications and one plant per plot, totaling 75 experimental units arranged in single rows spaced 0.60 m between rows and 0.40 m between plants.

The cultivar Red Cherry Tomato (Tomate Cereja Vermelho) was used in the experiment given its indeterminate growth habit, good adaptation to temperatures between 21 and 28 °C, and globular fruits. Two seeds were sown per 50-mL cell in a 162-cell polyethylene tray, with each cell receiving a substrate composed of sand, soil, and manure at a ratio of 1:1:2.

The seedlings were transplanted to pots adapted as 20-L drainage lysimeters upon reaching 10 cm in height and showing two pairs of true leaves (18 days after sowing). Each lysimeter had a 3-cm gravel layer placed under a geotextile fabric covering the base of the container to avoid soil obstruction. Furthermore, a 15-mm wide hose coupled to a plastic container (2 L) was attached to the base of each lysimeter to collect the drained water. Finally, the pots received 22 kg of a sandy-loam Fulvic Entisol whose physical and chemical characteristics (Table 1) were determined according to Teixeira et al. (2017).

Table 1. Chemical and physical characteristics of the soil used in the experiment.

Chemical characteristics								
pH $H_2O)$ (1:2.5)	OM g kg^{-1}	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+
				....cmol$_c$ kg^{-1}				
5.58	2.93	39.2	0.23	1.64	9.07	2.78	0.0	8.61
.... Chemical characteristics...........				.... Physical characteristics........................				
ECse (dS m^{-1})	CEC cmol$_c$ kg^{-1}	SAR (mmol L^{-1})$^{0.5}$	ESP %	Granulometric fraction (g kg^{-1})			Moisture (dag kg$^{-1)}$	
				Sand	Silt	Clay	33.42 kPa^1	1,519.5 kPa^2
2.15	22.33	0.67	7.34	572.7	100.7	326.6	25.91	12.96

pH – potential of hydrogen, OM. – organic matter: Walkley-Black method; Ca^{2+} and Mg^{2+} extracted with 1 M KCl at pH 7.0; Na^+ and K^+ extracted with 1 M NH_4OAc at pH 7.0; Al^{3+}+H^+ extracted with 0.5 M CaOAc at pH 7.0; ECse – Electrical conductivity of the saturation extract; CEC – Cation exchange capacity; SAR - sodium adsorption ratio of

Fertilization was performed according to the recommendations of Trani et al. (2015). Urea was used as the nitrogen source by applying 19.25, 28.88, 38.9, 48.1, and 57.57 g per plant for the N levels of 50, 75, 100, 125, and 150%, respectively. The 100% level corresponded to 19.74 g of N per plant, starting 10 days after transplanting (DAT). The phosphorus recommendations were met by applying 20.35 g of monoammonium phosphate (12.44 g of P_2O_5 per plant), previously discounting the nitrogen provided by this source. Potassium was provided by applying 65.94 g of potassium chloride (39.56 g of K_2O per plant) as topdressing in weekly applications via irrigation water. Micronutrients were supplied 10 days after transplanting via foliar application on the adaxial and abaxial surfaces of the leaves. This procedure was repeated every 15 days using the commercial product Dripsol Micro Rexene®, containing Mg – 1.2%, B – 0.85%, Zn – 4.2%, Fe – 3.4%, Mn – 3.2%, Cu – 0.5%, and Mo – 0.06%.

At the moment of transplantation, the soil moisture content was increased to a level corresponding to maximum water retention capacity (0.3 dS m^{-1}), and irrigation was performed daily with low electrical conductivity water until 17 DAT. After this period, irrigation with the different salinity levels was performed by applying a sufficient water volume to meet the water requirements of the plants. This information was obtained based on Eq. 1:

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

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);

LF = leaching fraction of 0.15, provided every 15 days to minimize salt accumulation in the root zone.

The lowest irrigation water salinity (0.3 dS m^{-1}) was obtained from the public water supply of Pombal-PB, whereas the remaining ECw levels were prepared by dissolving sodium chloride (NaCl) according to the relationship between the ECw and the concentration of salts: Q ($mmol_c$ L^{-1}) = 10 × ECw. The different electrical conductivity levels applied in irrigation were based on Vieira et al. (2016).

Apical dominance was removed in the 75 cherry tomato plants by pruning the terminal bud 67 days after transplanting. Daily pruning of sprouts in the leaf axils (suckers) occurred until 45 DAT (Takahashi, 2014). Pest and disease control was performed by chemical intervention using appropriate insecticides and fungicides. The plant material removed from the experimental area was used as mulch to provide milder thermal conditions.

Tomato growth was analyzed 45 days after transplanting by evaluating the number of leaves (NL, counted manually considering all leaves longer than 3 cm), plant height (pH, measured in cm from the base of the plant to the insertion of the apical bud of the main branch using a ruler), and stem diameter (SD, measured in mm with a digital caliper at 2 cm from the ground).

Fruit harvest began 59 days after transplanting and continued until 141 DAT, totaling ten harvests in which fruits were taken from the plants upon reaching maturity stage R4 (ripe red), according to the recommendations of Monteiro et al. (2018). After harvest, the fruits were sent to the Laboratory of Hydraulics and Irrigation at the CCTA of UFCG, where the lateral (LD) and transverse (TD) fruit diameters (mm) were determined using a digital caliper. The potential of hydrogen - pH was determined using a potentiometer in a sample containing 5 g of fruit and 50 mL of distilled water, according to the technique recommended by the Adolfo Lutz Institute (2005). Finally, the soluble solids – TSS (Brix°) were determined in ground fruit samples using a manual refractometer, following the standardized techniques of the Adolfo Lutz Institute (2005).

The data obtained were subjected to analysis of variance (F-test) at 0.05 and 0.01 probability. In cases of significance, linear and quadratic polynomial regression analyses were performed using the statistical software SISVAR.

Results and Discussion

The interaction between factors (SL × ND) significantly affected plant height, stem diameter, and the pH of cherry tomato plants. On the other hand, the N doses promoted a significant difference only in the stem diameter and soluble solids of this crop. The different salinity levels significantly influenced all studied variables (Table 2).

The plant height (PH) data of cherry tomato plants fertilized with 50% N fit the quadratic model, with a maximum estimated value of 78.83 cm in the plants irrigated with the ECw of 2.3 dS m^{-1}, decreasing above this salinity level. In contrast, the plants grown under 75, 100, and 125% N showed a linear decreasing behavior, with respective reductions of 4.99, 3.18, and 4.38% per unit increase in the ECw. The data did not successfully fit the tested models in plants fertilized with 150% N, reaching a mean value of 67.5 cm (Figure 2A). The deleterious effect of salt stress is possibly related to the osmotic effect caused by salt excess in the water and soil, restricting water and nutrient uptake and consequently inhibiting cell division, elongation, and plant growth (Santos et al., 2016). From this perspective, Viol et al. (2017) investigated the growth of tomato plants irrigated with saline water and observed that increasing ECw levels from 0.5 dS m^{-1} inhibited plant growth in height 45, 55, 65, and 75 days after transplanting. Moreover, Souza et al. (2019) studied the behavior of tomato plants grown under different water salinities and also observed plant growth reduction at electrical conductivity levels higher than 0.8 dS m^{-1}.

Table 2. Summary of the analysis of variance for plant height (PH, cm), stem diameter (SD, mm), number of leaves (NL), soluble solids (SS), potential of hydrogen (pH), lateral diameter (LD, mm), and transverse diameter (TD, mm) of cherry tomato grown under different water salinity and nitrogen doses.

Source of variation	DF	Mean squares						
		PH	SD	NL	SS	pH	LD	TD
Saline levels (SL)	4	268.3033**	2.9689**	31.1633**	1.975**	0.087**	7.581**	21.334*
Linear regression	1	708.5066**	6.0661**	80.6666**	4.649**	0.291**	24.670**	75.899**
Quadratic regression	1	85.5047^{ns}	3.1562*	21.3761**	3.118*	0.043^{ns}	0.041^{ns}	8.155^{ns}
Nitrogen doses (ND)	4	59.7866^{ns}	6.2210**	2.7133^{ns}	1.375*	0.039^{ns}	3.100^{ns}	0.778^{ns}
Linear regression	1	72.8016^{ns}	0.1745^{ns}	3.8400^{ns}	2.706*	0.001^{ns}	3.694^{ns}	1.318^{ns}
Quadratic regression	1	56.0583^{ns}	18.1177**	0.2333^{ns}	0.869^{ns}	0.003^{ns}	2.179^{ns}	0.921^{ns}
Interaction (SL × ND)	16	91.4450**	1.6616**	2.6675^{ns}	0.502^{ns}	0.041*	3.014^{ns}	6.893^{ns}
Blocks	2	31.7233^{ns}	0.1575^{ns}	0.7633^{ns}	0.458^{ns}	0.065^{ns}	0.826^{ns}	1.954^{ns}
CV (%)		7.75	7.22	7.11	10.05	4.08	8.49	14.62
Mean		70.60	10.39	19.24	6.64	3.61	15.13	16.73

$^{ns,\ *,\ **,}$ respectively significant and non-significant at $p \leq 0.05$ and ≤ 0.01; CV= coefficient of variation.

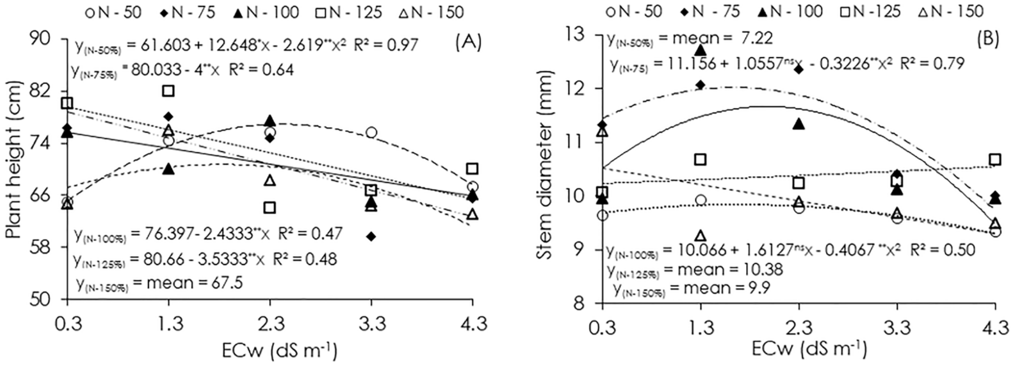

Figure 2. Plant height (A) and stem diameter (B) of cherry tomato plants as a function of the interaction between electrical conductivity levels of irrigation water - ECw and nitrogen doses –ND at 45 days after transplanting.

In the plants fertilized with 75 and 100% of the N recommendation, the data fit the quadratic model for stem diameter (SD) (Figure 2B), with maximum estimated values of 11.98 and 11.62 mm in the plants irrigated with the ECw levels of 1.3 and 2.3 dS m^{-1}, showing an expressive SD reduction above these salinity levels. For the plants fertilized with 50, 125, and 150% N, the data did not fit the tested models, showing mean values of 7.65, 10.38, and 9.90 mm, respectively. According to Paixão et al. (2020), tomato growth in stem diameter could be associated with increased nutrient availability and uptake, which are later converted and synthesized as photoassimilates.

The reduction in the number of leaves of cherry tomato plants caused by water salinity followed a quadratic behavior (Figure 3), reaching the maximum value of 20 leaves in plants irrigated with the ECw of 1.3 dS m^{-1} and decreasing above this salinity level. On the other hand, the plants irrigated with the ECw of 4.3 dS m^{-1} showed three fewer leaves than those grown under the lowest salinity level (0.3 dS m^{-1}). This reduction as a function of the ECw could be an acclimation mechanism to salt stress by reducing the transpiration surface. This reduction is necessary since the osmotic effect caused by salt excess in the soil results in water stress as the plant cannot absorb water at the same rate as transpiration (Bezerra et al., 2018b). Demontiêzo et al. (2016), in a study with the cherry tomato variety ‘Santa Cruz’ irrigated with saline water (ECw ranging from 0.3 to 4.5 dS m^{-1}), also observed that increasing ECw levels reduced the number of leaves.

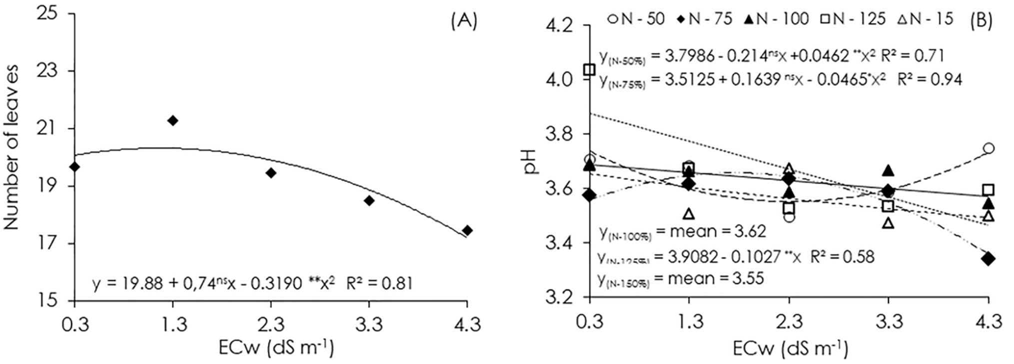

Figure 3. Number of leaves in cherry tomato plants as a function of the electrical conductivity of irrigation water– ECw at 45 days after transplanting, and potential of hydrogen - pH (A) of fresh cherry tomato fruits as a function of the electrical conductivity of irrigation water - ECw and nitrogen doses – ND in harvests performed from 59 to 141 DAT.

The potential of hydrogen (pH) of cherry tomato fruits reached the highest values when the plants were irrigated with the water electrical conductivity (ECw) levels of 0.3 and 1.3 dS m^{-1} (3.73 and 3.64) and received 50 and 75% N, respectively. The cherry tomato plants fertilized with 125% N behaved similarly, reducing the pH by 2.6% per unit ECw increase. N fertilization at 100 and 150% of the recommendation satisfactorily fit the tested models, reaching the mean values of 3.62 and 3.55, respectively (Figure 3A). The increase in the ECw also resulted in fruits without the required standards for fresh consumption, whose pH should range between 3.7 and 4.5 and should have a more acid taste, important characteristics to prevent the proliferation of microorganisms and increase fruit shelf life (Araújo et al., 2017). In another study, the fruit pH of cherry tomato grown under the water salinity levels of 1.5, 2.5, 3.5, 4.5, 5.5, and 6.5 dS m^{-1} was not influenced by salinity (Eloi et al., 2011). On the other hand, Sousa et al. (2016) studied watermelon cultivation under different salinity levels (1.0, 2.0, 3.0, 4.0, and 5.0 dS m $^{-1}$) and observed that the increase in irrigation water salinity decreased the fruit pH.

The soluble solids content (SS) of fresh cherry tomato fruits showed a quadratic behavior (Figure 4A) as a function of irrigation with saline water, with the electrical conductivity of 3.3 dS m^{-1} resulting in a mean SS value of 6.9 °Brix. The SS are related to the content of sugars in the fruits, e.g., glucose and fructose, interfering with fruit taste, sweetness, and acidity. Therefore, the increase in salinity resulted in less sweet fruits (Vinha et al., 2014). This response could be related to the reduction in pH with the increase in ECw, resulting in more acid fruits due to the lower accumulation of soluble solids. Moreover, this response could indicate a consequence of the ionic effect caused by salinity due to the competition between potassium (K^+) and sodium (Na^+) since K^+ is essential for sugar and starch formation and their transport to storage organs (Taiz & Zeiger, 2017). Unlike the results of the present study, Silva et al. (2012) studied the cherry tomato cultivar Carolina and observed an increase in the fruit SS as a function of the water electrical conductivity levels of 0.8, 1.6, 2.4, 3.2, and 4.0 dS m^{-1}. In another study, Paiva et al. (2018) observed a reduction in the soluble solids content of the tomato cultivar Supera F1 with the increase in the ECw (0.5, 2.0, 3.5, and 5.0 dS m^{-1}). According to the authors, the soluble solids content of tomato fruits may vary due to the genetic characteristics of the cultivar as well as fertilization, temperature, and the quality of irrigation water.

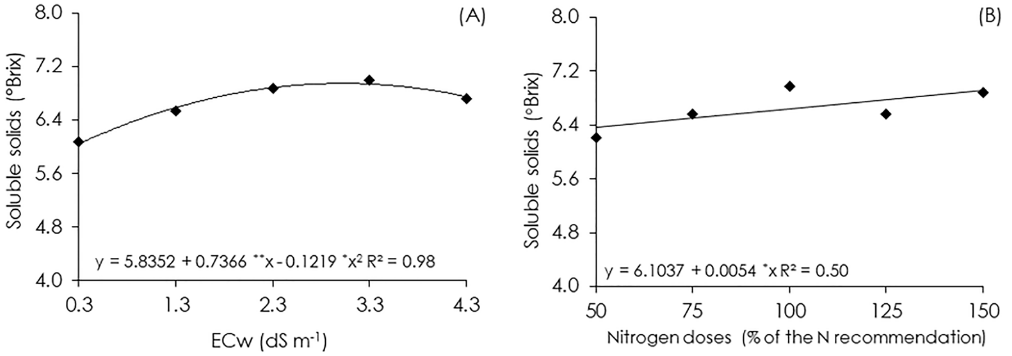

Figure 4. Total soluble solids (SS) of cherry tomato grown under different water electrical conductivities - ECw (A) and nitrogen doses - N (B) from 59 to 141 DAT.

The increase in nitrogen availability increased the soluble solids content by 8.47% in fresh cherry tomato fruits fertilized with 150% N (6.74°Brix) compared to those fertilized with 50% N (6.04°Brix), i.e., there was an increase of 0.0884% per 25% increase in the nitrogen doses (Figure 4B). Nitrogen is a constituent of proteins and amino acids, which directly affect the content of soluble solids. Therefore, this increase could be related to increased photosynthesis due to the higher N supply, producing more photoassimilates, some of which can be stored as reducing sugars, leading to greater accumulation of soluble solids in tomato fruits (Wang et al., 2007). Agreeing with the present study, other authors have also observed moderate soluble solids increments in tomato with the increase in N, as reported by Costa (2018), who noted that the SS content of tomato ranged between 4.08 and 4.21°Brix with the increase in N levels (0, 60, 120, and 180 kg ha^{-1}).

Furthermore, the increase in the electrical conductivity of irrigation water (ECw) reduced the longitudinal (Figure 5A) and transverse (Figure 5B) fruit diameter in tomato from 59 to 141 DAT, with reductions of 2.52 and 3.86% per unit increase in the ECw, respectively. The plants irrigated with the ECw of 4.3 dS m^{-1} showed LD and TD reductions of 1.62 and 2.84 mm, respectively, compared to those under the lowest water salinity (0.3 dS m^{-1}).

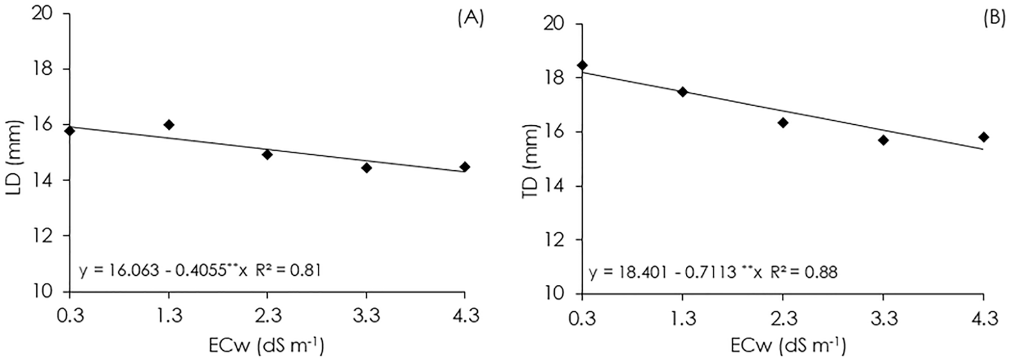

Figure 5. Longitudinal – LD (A) and transverse - TD (B) fruit diameter of cherry tomato grown under different water electrical conductivity levels - ECw from 59 to 141 DAT.

According to Lima et al. (2020), the reduction in fruit size could be related to the excessive production of reactive oxygen species (ROS) in cell compartments such as chloroplasts, mitochondria, and peroxisomes, resulting in photooxidative damage to DNA, protein denaturation, and removal of hydrogen atoms from methylene groups of polyunsaturated fatty acids, triggering lipid peroxidation and resulting in smaller fruits in plants subjected to salt stress.

Conclusions

The number of leaves in cherry tomato plants was negatively affected by the increase in irrigation water salinity at levels higher than 1.3 dS m^{-1}. The nitrogen doses did not mitigate the effects of salt stress on plant height and stem diameter in cherry tomato plants. Irrigation with electrical conductivity levels above the linear crop salinity reduces the pH of cherry tomato fruits. Irrigation with water electrical conductivity levels up to 3.3 dS m^{-1} increases the soluble solids content of cherry tomato fruits. Finally, the increase in nitrogen availability increases the soluble solids content of cherry tomato fruits.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.