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Original Article

The impact of saline and water stress on the agronomic performance of beet crops

O impacto do estresse salino e hídrico no desempenho agronômico da cultura da beterraba

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Abstract

Excessive salts in irrigation water and water stress have a negative impact on the productive yield of agricultural crops. In this regard, the objective was to evaluate the effect of combined saline and water stress on the agronomic performance of the beet crop. The experiment was conducted in a greenhouse located at the Universidade da Integração Internacional da Lusofonia Afro-Brasileira, in Redenção, Ceará. The experimental design used was completely randomized with split-plots arrangement. The main plots were formed by the electrical conductivities of the irrigation water (0.8, 1.5, 3.0, 4.5, and 6.0 dS m^{-1}), while the irrigation depths of 50 and 100% of the crop evapotranspiration (ETc) were the subplots, with 6 replications. Saline stress negatively affected growth, biomass, tuber root length, and productivity, while increasing the soluble solids of the beet crop. Excessive salts in the irrigation water caused reductions in physiological indices of the beet crop, although with less severity under the 100% ETc.

Keywords: *Beta vulgaris* L, salinity, water deficit.

Resumo

O excesso de sais na água de irrigação e o estresse hídrico, afetam negativamente o rendimento produtivo das culturas agrícolas. Neste sentido, objetivou-se avaliar o efeito do estresse salino associado ao hídrico no desempenho agronômico da cultura da beterraba. O experimento foi conduzido em casa de vegetação, em área pertencente a Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Redenção, Ceará. O delineamento experimental utilizado foi inteiramente casualizado, em parcelas subdivididas. As parcelas foram formadas pelas condutividades elétricas da água de irrigação (0,8; 1,5; 3,0; 4,5 e 6,0 dS m^{-1}), enquanto os regimes hídricos de 50 e 100% da evapotranspiração da cultura (Etc), foram as subparcelas, com 6 repetições. O estresse salino afetou negativamente o crescimento, a biomassa, o comprimento da raiz tuberosa e a produtividade e aumentou os sólidos solúveis da cultura da beterraba. O excesso de sais da água de irrigação provoca reduções nos índices fisiológicas da cultura da beterraba, porém com menor severidade no regime hídrico de 100% da ETc.

Palavras-chave: *Beta vulgaris* L, salinidade, déficit hídrico.

1. Introduction

Beet (*Beta vulgaris* L.) belongs to the Chenopodiaceae family and is native to European and North African regions with a temperate climate. The tuberous root, as well as the veins and petioles of the leaves, are used for sugar production, forage, or human consumption. In Brazil, beets are primarily cultivated for human consumption and are considered one of the main vegetables, with a national productivity ranging from 20 to 35 t ha^{-1} (IBGE, 2018).

Irrigation is a way to ensure agricultural production in the Brazilian Northeast. However, the potential evapotranspiration rate exceeds precipitation for most of the year, resulting in water deficit for plants (Oliveira et al., 2015; Silva et al., 2019). Nevertheless, water quality in this region fluctuates during certain times of the year, with brackish water being used during periods of water scarcity or low demand for good quality water (Gadelha et al., 2021; Santos et al., 2019).

Salinity negatively affects plant growth and metabolism and is one of the reasons responsible for reduced productivity and post-harvest quality, leading to reductions in fruit size, quality, and soluble solids content (Santos et al.,

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2016; Silva et al., 2022). However, these effects depend on the crop's development stage, duration of exposure to stress, type of salt present in the environment, and environmental, cultural, and irrigation management conditions (Lima et al., 2021; Silva et al., 2022; Wu et al., 2022).

Therefore, strategies to mitigate salt stress and improve water use efficiency are essential. One of these strategies is the reduction of water regimes, which implies the rational use of water. However, both excess and lack of water lead to decreased growth and productivity, but these effects vary according to the crop and the edaphoclimatic conditions during the cultivation period (Basílio et al., 2019; Pereira Filho et al., 2019).

A study conducted by Sousa et al. (2022) revealed that an irrigation of 50% ETc associated with the use of brackish water increased the internal carbon concentration in zucchini plants but reduced the assimilation rate of CO_2, transpiration, and instantaneous water use efficiency. On the other hand, Barbosa et al. (2022), evaluating gas exchange and growth of peanuts under saline and water stress, found that using water with lower salinity under an irrigation of 100% ETc resulted in increased plant height and photosynthesis.

Therefore, the objective of this study was to evaluate the effect of combined saline and water stress on the agronomic performance of beet crop.

2. Material and Methods

The experiment was conducted in the greenhouse of the Unidade de Produção de Mudas das Auroras, belonging to the Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Auroras Campus, Redenção, - CE. The municipality of Redenção is located at a latitude of 04°13°33S, longitude of 38º43º50W, with an average altitude of 88 m. The climate of the region is classified as hot humid tropical and hot sub-humid tropical, with an average precipitation of 1,062 mm and average temperature ranging from 26 to 28 °C (IPECE, 2017). Figure 1 presents the meteorological data during the experiment period (August to November 2020).

The experimental design used was a completely randomized design with split plots. The main plots were formed by the electrical conductivities of irrigation water (0.8, 1.5, 3.0, 4.5, and 6.0 dS m^{-1}), while the irrigation depths of 50 and 100% of crop evapotranspiration (ETc) were the subplots, with 6 replications.

The cultivar used was 'Early Wonder Tall Top'. Sowing was done in styrofoam trays with 200 cells of 40 cm^3 volume, with each cell receiving one seed at a depth of 2 cm. At 20 days after sowing, the seedlings were transplanted into 12 L plastic pots, which were filled with a substrate in a ratio of 5:3:2, corresponding to 5 parts of soil, 3 parts of sand, and 2 parts of bovine manure. The substrate used had the following chemical attributes, as shown in Table 1.

In the preparation of brackish waters, the amount of salts was obtained according to the methodology suggested by Rhoades et al. (2000), using NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ salts in a ratio of 7:2:1, respectively, simulating to the brackish waters found in the Northeast region of Brazil, and the electrical conductivity commonly found in well waters of the Brazilian semi-arid region.

Irrigation was carried out manually, based on the daily estimation of reference evapotranspiration (ETo) calculated through the water balance, following the principle of the drainage lysimeter, according to Equation 1.

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

where: VI: Volume of water to be applied in the irrigation event (mL); Vp: Volume of water applied in the previous irrigation event (mL); Vd: Volume of water drained (mL); and LF: Leaching fraction of 0.15.

With ETo data, it was possible to calculate the ETc using the crop coefficient (Kc) according to Equation 2. The crop coefficients used were 0.50, 1.05, and 0.95 for the initial, middle, and final stages, respectively, with a daily irrigation frequency.

Crop evapotranspiration was determined by Equation 2, which involves reference evapotranspiration and the crop coefficient of 0.50, 1.05, and 0.95 for the initial, middle, and final stages, respectively (Allen et al., 1998), with a daily irrigation frequency.

$$ETc = ETo \times Kc \tag{2}$$

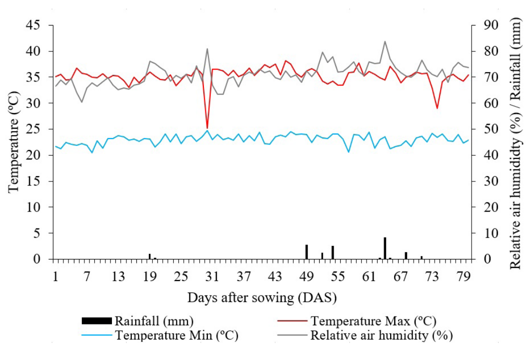

Figure 1. Meteorological data during the experiment.

Table 1. Chemical attributes of the substrate used in the research.

OM	P	Mg	K	Ca	Na	H⁺+Al³⁺	pH	ECse (dS m^{-1})
g kg^{-1}	mg kg^{-1}	-------------------- cmol$_c$ dm^{-3} ------------------------					H_2O	
14.59	27	0.70	0.78	4.50	0.67	1.49	6.4	0.08

MO = organic matter; ECse = electrical conductivity of the substrate saturation extract.

where: ETc: evapotranspiration of crop (mm); ETo: reference evapotranspiration of water balance (mm); and Kc: Crop coefficients.

At 30 days after transplanting (DAT), the following variables were analyzed: leaf area (LA) following the methodology of (Simões et al., 2016) according to Equation 3, and plant height (PH) measured with a measuring tape to the emergence of the last leaves. For obtaining the dry matter of the shoot (DMS) and root (DMR), the plants were placed in paper bags for a period of 72 hours in a circulating air oven until reaching constant mass. Weighing was performed using a precision balance.

$$LA = \left(SL \times SW\right) \times NS \times CF \tag{3}$$

where: LA: Leaf area; SL: Sheet length; SW: Sheet width; NS: Number of sheets; and CF: Correction factor, the correction factor being 0.692, recommended for beetroot.

At 50 DAT, gas exchange measurements were conducted: photosynthesis (*A*), stomatal conductance (*gs*), transpiration (*E*), and based on these data, instantaneous water use efficiency (WUE) was determined. Measurements were performed using an infrared gas analyzer (LCi System, ADC, Hoddesdon, UK) in an open system with an airflow of 300 mL min^{-1}. Measurements were taken between 10 a.m. and 11 a.m. using an artificial radiation source (approximately 1200 µmol m^{-2} s^{-1}).

At 80 DAT, the following variables were assessed upon harvesting: yield (Y) based on tuberous root mass, soluble solids content (ºBrix) using a portable refractometer (Minolta) with juice extracted by compressing a 3 mm thick slice taken from the equatorial portion of the tuberous root, diameter (TRD) and length of the tuberous root (TRL) measured with a digital caliper, and pH of the tuberous root (pH R) using a pH meter.

To evaluate normality, the obtained data were subjected to the Kolmogorov-Smirnov test ($p \leq 0.05$). Subsequently, the data were subjected to analysis of variance, and in cases of significant effects for water electrical conductivity or interactions, regression analysis was performed. The data for irrigation depths were subjected to Tukey test with $p < 0.05$ using ASSISTAT software, version 7.7 Beta (Silva and Azevedo, 2016).

3. Results

According to the analysis of variance observed in Table 2, there was a significant isolated effect for water electrical conductivity on the variables leaf area, root dry matter ($p<0.01$), plant height, and shoot dry matter ($p<0.05$). There was an interaction between water electrical conductivity and irrigation depths for photosynthesis, transpiration, stomatal conductance ($p<0.01$), and water use efficiency ($p<0.05$).

In the plant height variable, the decreasing linear model was the best fit for different electrical conductivities of irrigation water in beet crop, where a reduction of 22.77% was observed with the use of ECw of 6.0 dS m^{-1} compared to 0.8 dS m^{-1} (Figure 2A).

The decreasing linear model was the best fit for leaf area (Figure 2B), showing a decline of 45.27% in the leaf area of plants subjected to irrigation with an ECw of 6.0 dS m^{-1} compared to water with 0.8 dS m^{-1}.

The shoot dry matter was affected by the increase in electrical conductivity of irrigation water, resulting in a decrease of 37.72% when using an ECw of 6.0 dS m^{-1} compared to higher values obtained with water of 1.5 dS m^{-1} (Figure 3A).

According to Figure 3B, root dry matter showed a linear decrease, with a 53.34% reduction from the highest to the lowest salinity of irrigation water.

The decreasing linear model best fit the data for photosynthesis under the 50% and 100% ETc irrigation depths, showing a reduction of 80.31% and 82.92% in the photosynthetic rate with the increase of salts in the irrigation water from 0.8 to 6.0 dS m^{-1} under the 50% and 100% ETc regimes (Figure 4A).

The increase in irrigation water salinity linearly decreased plant transpiration in beet crop irrigated with 50 and 100% ETc, showing a decrease of 62.03% (100% ETc) and 48.87% (50% ETc) from the lowest to the highest water salinity (Figure 4B).

Table 2. Summary of the analysis of variance for plant height (PH), leaf area (LA), shoot dry matter (SDM), root dry matter (RDM), photosynthesis (A), transpiration (E), stomatal conductance (gs), and water use efficiency (WUE) of beet cultivated under different electrical conductivity of irrigation water (ECw) and irrigation depths (ID).

SV	DF	Mean Square							
		PH	LA	SDM	RDM	*A*	*E*	*Gs*	WUE
ECw	4	42.53*	1637.80**	0.87*	0.046**	7.03**	0.23ns	0.007**	6.42*
Residual (a)	25	11.73	216.19	0.22	0.007	0.5	0.2	0.0006	1.51
ID	1	0.037ns	6.43ns	0.18ns	0.0017ns	3.52ns	0.02ns	0.00008ns	10.15ns
ECw x ID	4	15.09ns	207.86ns	0.20ns	0.0043ns	29.46**	1.43**	0.019**	11.59*
Residual (b)	25	9.39	248.43	0.44	0.011	0.85	0.14	0.0003	3.05
CV% (ECw)		16.77	29.66	32.4	30.12	16.57	30.56	25.71	26.85
CV% (ID)		15.0	31.79	29.73	29.36	21.6	25.9	18.14	32.38

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

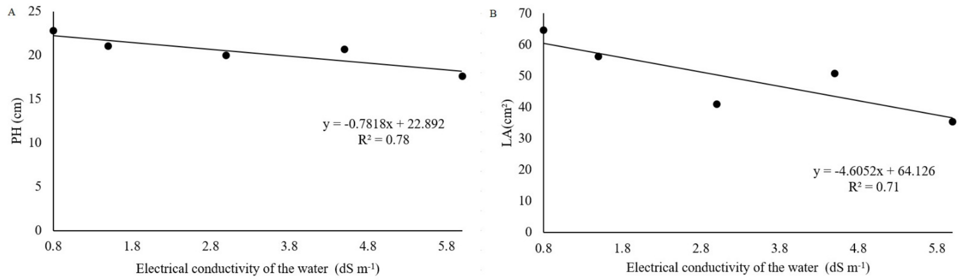

Figure 2. Plant height (A) and leaf area (B) of beet crop cultivated under five electrical conductivities of irrigation water.

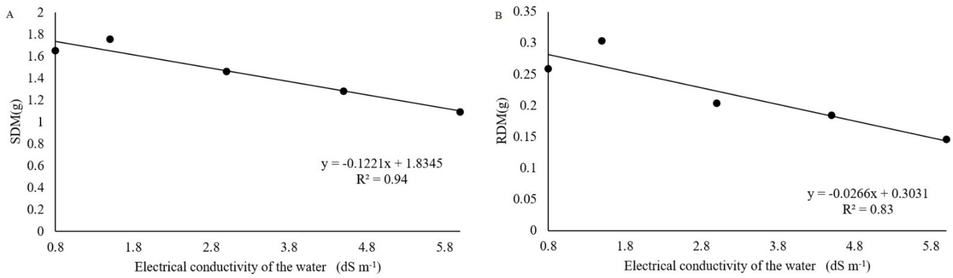

Figure 3. Shoot dry matter (A) and root dry matter (B) of beet crop grown under different electrical conductivity of irrigation water.

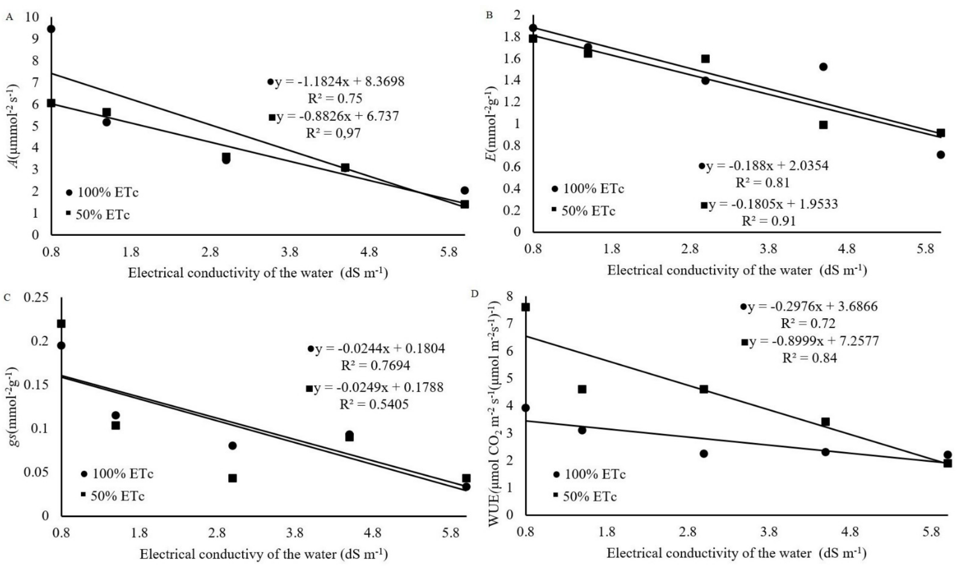

Figure 4. Net photosynthetic rate (A), transpiration (B), stomatal conductance (C), and instantaneous water use efficiency (D) of beet crop grown under five electrical conductivity levels of irrigation water and two irrigation depths.

Stomatal conductance (*gs*) of beet crop was affected by salt stress in both irrigation depths used, but to a greater extent under the 100% ETc, with reductions of 83.07% from the lowest to the highest salinity level. In the 50% ETc, the decrease was 80.45% (Figure 4C).

Instantaneous water use efficiency (WUE) was affected by different ECw levels and irrigation depths in a linear fashion (Figure 4D). Under the 100% ETc, WUE declined by 43.87% from an EC of 0.8 to 6.0 dS m^{-1}. Similarly, under the 50% ETc, instantaneous water use efficiency showed a linear decrease with increasing ECw, resulting in a decrease of 75.24% from the lowest to the highest water salinity.

According to the analysis of variance for yield and post-harvest variables (Table 3), there was a significant

Table 3. Summary of the analysis of variance for tuberous root length (TRL), tuberous root diameter (TRD), yield (Y), soluble solids (SS), and tuberous root pH (TRpH) of beet crop under different electrical conductivity of irrigation water (ECw) and irrigation depths (ID).

SV	DF	Mean Square				
		TRL	TRD	Y	SS	TRpH
ECw	4	4.73**	1637.80ns	0.87*	90.14**	0.18**
Residual	25	0.66	216.19	0.22	9.22	0.3
ID	1	0.72^{ns}	6.43^{ns}	0.18^{ns}	3.65^{ns}	0.00*
CEa X ID	4	1.88^{ns}	207.86^{ns}	0.20^{ns}	14.54^{ns}	0.10*
Residual	25	0.74	248.43	0.44	10.9	0.28
CV% (ECw)		17.18	29.66	32.4	23.33	2.87
CV% (ID)		18.3	31.79	29.73	25.37	2.79

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

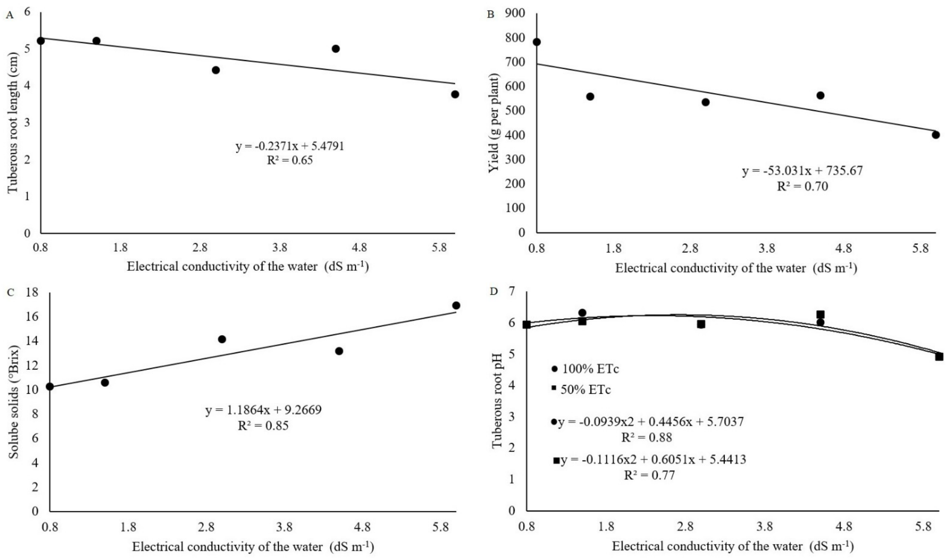

Figure 5. Tuberous root length (A), yield (B), soluble solids (C), and tuberous root pH (D) of beet crop under five electrical conductivity levels of irrigation water and two irrigation depths.

isolated effect of ECw on total soluble solids, tuberous root length ($p>0.01$), and yield ($p>0.05$). The interaction between ECw and irrigation depths was significant for tuberous root pH ($p>0.05$).

For the tuberous root length values as a function of irrigation water conductivity, the linear model best fitted the data, resulting in a reduction of 27.96% from ECw of 0.8 to 6.0 dS m^{-1} (Figure 5A).

The salinity of irrigation water negatively affected beet yield, with a decrease of 48.79% with increasing electrical conductivity (ECw), reaching the lowest value (400.64 g per plant) with the highest salinity water (Figure 5B).

Salinity stress increased the soluble solids content in beet roots (Figure 5C), with the highest values obtained using an ECw of 6.0 dS m^{-1} (16.91 °Brix), representing a 39.39% increase compared to the value obtained with the lowest salinity water (0.8 dS m^{-1}).

The quadratic polynomial model best fitted the tuberous root pH (Figure 5D), showing a maximum hydrogen ion potential of 6.23 for an ECw of 2.37 dS m^{-1} and 6.25 for an ECw of 2.71 dS m^{-1} for irrigation depths the 100 and 50% ETc, respectively.

4. Discussion

The excess salts in the irrigation water reduce the osmotic potential of the soil, limiting the uptake of essential nutrients for plant growth (Taiz et al., 2017). These results are consistent with those found by Silva et al. (2019) in beet crop under salt stress, where a decrease in plant height was observed.

When exposed to salt stress, plants reduce leaf expansion to induce a decrease in transpiration rate, preventing the uptake of harmful salts such as sodium and chlorine (Acosta-Motos et al., 2017). Similarly, Gadelha et al. (2021) observed a decrease in leaf area when evaluating beet crops under salt stress.

The reduction in dry weight due to increased salt content in irrigation water may be related to reduced water uptake induced by a decrease in soil osmotic potential. Similar to the present study, Oliveira et al. (2015) found that beet plants irrigated with water above 4.2 dS m^{-1} experienced reductions of more than 44% in shoot dry matter accumulation. Dias et al. (2022) also observed reductions in shoot dry matter biomass of radish plants with increasing levels of water salinity from 0.5 to 4.5 dS m^{-1}.

The increase in salts in the root zone has a detrimental effect on biomass accumulation and plant growth, manifested by a reduction in transpiration rate and growth (Santos et al., 2016). Similar results were found by Oliveira et al. (2015) in beet crop, with linear reductions of 62% in root dry matter with increasing water salinity.

Salinity stress reduces water availability for plants, leading to stomatal closure and restricting the entry of photosynthetic pigments, electron transport system, and CO_2 uptake in leaf mesophyll cells (Stadnik et al., 2023).

Similar trends were reported by Melo et al. (2016) in pepper crop irrigated with saline water. These authors observed reductions in net photosynthesis and consequent dehydration of cell membranes, which reduces permeability to CO_2 influx with increasing ECw levels above 3.0 dS m^{-1}. Similarly, Pereira Filho et al. (2019) observed linear reductions in the photosynthetic rate of beans with increasing water salinity (from 1.1 to 5.1 dS m^{-1}) under 50 and 100% ETc. In contrast, Sousa et al. (2022) found opposite results in beet crop under similar salinity stress conditions.

Taiz et al. (2017) state that under water or salt stress conditions, plants limit water absorption and foliar expansion, resulting in lower stomatal conductance and transpiration to prevent water loss.

Similarly, Sousa et al. (2022), when evaluating saline and water stress in zucchini crop, found that increased irrigation water salinity negatively affected transpiration, although to a lesser extent under the 100% ETc. Linear reductions in transpiration were also observed by Pereira Filho et al. (2019) in bean crop irrigated with brackish water, with the highest values found under the 100% ETc.

The reduction of *gs* is considered one of the main factors restricting photosynthetic activity, decreasing CO_2 influx to the rubisco carboxylation sites within the chloroplasts and causing a decline in the photosynthetic rate (Stadnik et al., 2023).

Studies conducted by Pereira Filho et al. (2019) show the same trend as this study. These authors observed a negative effect of saline and water stress on stomatal conductance in fava bean crop. On the other hand, Barbosa et al. (2022), when evaluating saline and water stress in peanut crop, did not observe any influence of the 50 and 100% ETc on stomatal conductance.

Under saline conditions, increasing water use efficiency is a strategy employed by moderately tolerant crops to mitigate high salt concentrations in the plant area (Fernandes et al., 2016; Oliveira et al., 2022). Likewise, Sousa et al. (2022) also observed reductions in WUE with increasing irrigation water salinity under 50 and 100% ETc in zucchini crop.

Gadelha et al. (2021) observed that the tuberous root length of beet crop was shorter under brackish water (ECw = 5.8 dS m^{-1}), approximately 10% smaller compared to lower salinity water (ECw = 0.3 dS m^{-1}). Similarly, Santos et al. (2016) also found reductions in tuberous root length of beet under salt stress.

The excess of salts in irrigation water reduces the soil water potential, making nutrients in the soil solution unavailable or less available to the plant, resulting in a decrease in yield. Similar trends were observed by Gadelha et al. (2021) in beet crop irrigated with brackish water. These authors reported higher productivity (262.8 g per plant) in treatments with lower salinity water (0.3 dS m^{-1}), while the highest salinity treatment (5.8 dS m^{-1}) yield 198.8 g per plant. Similarly, Wu et al. (2022) found lower productivity in tomato crop irrigated with brackish water.

Salinity induced the production and accumulation of carbohydrates in the tuberous roots to adjust the osmotic potential and ensure water absorption, which is compromised under this type of stress. Gadelha et al. (2021) also observed that salinity stress led to an increase in soluble solids content, with a maximum value of 20.15 °Brix obtained in beet crop irrigated with 5.8 dS m^{-1} water. Consistent with the present study, Lima et al. (2021) also reported an increase in soluble solids in beet when irrigated with saline water compared to the control treatment.

The decrease in fruit pH can be attributed to enzyme synthesis, which leads to the production of acidic compounds such as malic acid (Santos et al., 2019). Similarly, Nascimento et al. (2013), evaluating the post-harvest quality of okra subjected to different irrigation levels and salinity, observed a higher fruit pH in the treatment with an ECw of 2.5 dS m^{-1} and 130% ETc.

5. Conclusions

Salinity stress negatively affected the growth, biomass, tuberous root length, and yield, while increasing the soluble solids content in beet crop.

The excess of salts in irrigation water leads to reductions in physiological indices of beet, although with less severity under the irrigation depth of 100% ETc.

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