Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Morphology of 'Crioula' guava seedlings under irrigation with increasing salinity water and nitrogen/potassium fertilization

Morfologia de goiabeira 'Crioula' sob irrigação com águas de salinidades crescentes e adubação nitrogenada-potássica

R. A. Rodrigues-Filho[a*], R. G. Nobre[b], A. S. Santos[a], A. D. S. Teixeira[a], A. P. N. Ferreira[a], L. A. A. Soares[c], G. S. Lima[d], W. A. Guedes[a], E. S. Vasconcelos[e], L. A. Silva[d] and K. F. P. Araújo[a]

[a]Universidade Federal Rural do Semiárido, Programa de Pós-graduação em Manejo de Solo e Água – PPMSA, Mossoró, RN, Brasil
[b]Universidade Federal Rural do Semiárido, Departamento de Ciência e Tecnologia, Caraúbas, RN, Brasil
[c]Universidade Federal de Campina Grande, Centro de Ciência e Tecnologia Agroalimentar, Pombal, PB, Brasil
[d]Universidade Federal de Campina Grande, Programa de Pós-graduação em Engenharia Agrícola – PPGEA, Campina Grande, PB, Brasil
[e]Universidade Federal de Alagoas, Programa de Pós-graduação em Agronomia – PPGA, Maceió, AL, Brasil

Abstract

Several studies have been conducted evaluating the management of fertilizers as strategies to mitigate the deleterious effects of salt stress, so the objective of this work was to evaluate the quality of 'Crioula' guava seedlings under irrigation with water of different salinity levels and fertilized with combinations of nitrogen and potassium. The experiment was performed in a protected (screened) environment using a randomized block design and analyzed in a 5 × 4 factorial scheme, with four replicates, with the plot formed by two plants. The treatments were formed from the combination of the factor electrical conductivity of irrigation water (ECw 0.3, 1.1, 1.9, 2.7 and 3.5 dS m^{-1}), with the factor combinations (C) of nitrogen (N) and potassium (K_2O) doses, being C1 = 70% N + 50% K_2O, C2 = 100% N + 75% K_2O, C3= 130% N + 100% K_2O and C4= 160% N + 125% K_2O. The recommended dose of 100% N and K, respectively, was 541.1 mg N dm^{-3} soil and 798.6 mg K dm^{-3} soil. The combinations of N and K fertilization corresponding to 70% N + 50% K_2O and 100% N + 75% K_2O of the recommended doses promoted greater growth of 'Crioula' guava seedlings. Water with ECw of 2.1 dS m^{-1} promotes the formation of quality 'Crioula' guava seedlings.

Keywords: *Psidium guajava* L., plant nutrition, salt stress, Semiarid.

Resumo

Diversos estudos vêm sendo desenvolvido avaliando o manejo de adubos como estratégias para mitigar os efeitos deletérios do estresse salino, neste sentido, objetivou-se com este trabalho avaliar a qualidade de mudas de goiabeira Crioula sob irrigação com águas de diferentes níveis salinos e adubadas com combinações de nitrogênio e potássio. O experimento foi conduzido em ambiente protegido (telado) utilizando-se o delineamento de blocos casualizados e analisados em esquema fatorial 5 × 4, com quatro repetições, com a parcela formada por duas plantas. Os tratamentos foram formados pela combinação do fator condutividade elétrica da água de irrigação (CEa), com valores de 0,3; 1,1; 1,9; 2,7 e 3,5 dS m^{-1}; e o fator combinações (C) de doses de nitrogênio (N) e potássio (K_2O), sendo C1 = 70% N + 50% K_2O; C2 = 100% N + 75% K_2O; C3= 130% N + 100% K_2O e C4= 160% N + 125% K_2O. A dose recomendada de 100% de N e K, respectivamente, foi de 541,1 e 798,6 mg de K dm^{-3} de solo. As combinações de adubação nitrogenada e potássica de 70% N + 50% K_2O e 100% N + 75% K_2O, em relação às doses recomendadas, resultaram em um maior crescimento de mudas de goiabeira Crioula. Água com CEa média de 2,1 dS m^{-1} foi capaz de promove a formação de mudas de qualidade de goiabeira Crioula.

Palavras-chave: *Psidium guajava* L., nutrição de plantas, estresse salino, Semiárido.

1. Introduction

The guava (*Psidium guajava* L.) is cultivated in several countries in tropical and subtropical regions, presenting adaptability to a wide range of climates and soil types. Its production can be found at altitudes ranging from 0 to 2,000 meters, with annual rainfall ranging between 1,000 and 2,000 mm and average temperatures ranging from 15 to 30 °C (Fischer and Melgarejo, 2021). Most of the varieties marketed in Europe are produced in South Africa and Brazil, standing out essentially for the significant amount of vitamins, minerals, fibers, proteins and antioxidants, being considered a fruit crop with nutraceutical and food characteristics (Angulo-Lopez et al., 2021).

*e-mail: ricardoarf100@yahoo.com.br
Received: June 1, 2023 – Accepted: July 17, 2023

For the production of quality seedlings of fruit crops, the nurseries must provide good conditions for the growth and development of plants, so it is necessary to adopt techniques of fertilization, irrigation and phytosanitary treatments, making the environment free of pests and diseases, since about 60% of the success of commercial production depends on the quality of the seedlings (Almeida et al., 2019).

The Brazilian northeast stands out nationally in guava production, but this region is characterized by water deficit caused by low precipitation and high evapotranspiration, intensifying soil salinization due to agricultural use. Moreover, the scarcity of non-brackish water has led many farmers to use water of inferior quality in the expansion of these irrigated areas. In saline environments, ionic interactions occur that affect the availability of nutrients due to the greater accumulation of Na^+ and Cl^-, which may also cause toxic and osmotic effects on plants, so the adoption of fertilization helps to reduce the nutritional imbalance (Sousa et al., 2022), with nitrogen (N) and potassium (K) being two of the main elements necessary to improve plant development.

Mineral fertilization can be a practice to mitigate the nutritional imbalance and the osmotic effect caused by salinity (Sousa et al., 2022), and several studies evaluating the effect of N doses to mitigate salt stress on guava have been carried out. Souza et al. (2017) concluded that doses of 70% of N recommendation for 'Crioula' guava stimulated greater growth, shoot biomass accumulation and quality of rootstocks. Bonifácio et al. (2018) observed that K doses above 1,161.6 mg of K dm^{-3} of substrate did not attenuate the effect of salts on guava plants cv. 'Paluma', finding ECw of 1.9 dS m^{-1} as a limit for the exploitation of this genetic material.

These fertilizers are essential to agricultural exploitation, as adequate N concentrations can assist in the activity of enzymes, proteins and amino acid synthesis, besides promoting better osmotic adjustment in plants grown under salt stress conditions (Silva et al., 2019). In addition, K is considered an extremely important macronutrient because it performs functions related to osmotic adjustment, turgor and regulation of membrane potential, in addition to acting on protein synthesis and enzymatic activation of plants under abiotic stress (Almeida et al., 2017).

The evaluation of the mitigating effect of combined nitrogen and potassium fertilization on guava seedlings under irrigation with saline water is still an incipient area of study. Therefore, the objective of this work was to evaluate how different levels of salinity of irrigation water affect the quality of 'Crioula' guava seedlings when subjected to different combinations of fertilization with doses of nitrogen (N) and potassium (K).

2. Material and Methods

The experiment was performed in a screened environment in 2021 at the Federal Rural University of the Semi-Arid Region - UFERSA, Multidisciplinary Center of Caraúbas, (05° 46' 23" S and 37° 34' 12" W, at an average altitude of 144 m). The climate of the region is classified according to Köppen as BSh, hot semi-arid (Alvares et al., 2013). Climatological data (Figure 1) were collected during the study period from the automatic weather station located at UFERSA, Caraúbas campus, in an area close to the experimental site.

The treatments were arranged in randomized blocks, 5 x 4 factorial scheme, referring to five salinity levels of irrigation water, with electrical conductivity of water (ECw0.3, 1.1, 1.9, 2.7 and 3.5 dS m^{-1}), and four combinations (C) of fertilization with nitrogen (N) and potassium (K_2O): C1 = 70% N + 50% K_2O; C2 = 100% N + 75% K_2O; C3 = 130% N + 100% K_2O and C4 = 160% N + 125% K_2O. There were twenty combinations of treatments, with four replicates, and each plot consisted of two plants.

The fertilization recommendations used were 541.1 mg of N dm^{-3} of soil for nitrogen (Souza et al., 2017) and 798.6 mg of K dm^{-3} of soil for potassium (Bonifácio et al., 2018), equivalent to the doses with 100% of N and K. Thus, the N and K doses (in mg of N and K dm^{-3} of soil, respectively) used were 378.8 and 399.3, 541.1 and 598.9, 703.4 and 798.6, and 865.8 and 998.25. Urea (45% N) and potassium chloride (60% K_2O) were used as sources of N and K, respectively.

These salinity levels were selected based on studies that indicate that guava is considered moderately sensitive to irrigation water salinity, as water salinity above 1.5 dS m^{-1} reduces its growth, development and production (Freire et al., 2014; Bezerra et al., 2018). The study involving the interaction between salinity levels in irrigation water and the different combinations of N and K fertilization is due to the fact that fertilization can attenuate the effect of salt stress.

The different irrigation waters were prepared by the addition of NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$, introduced into the water from the supply system of the local company (0.3 dS m^{-1}) with a salt ratio equal to 7:2:1, respectively, following the relationship between ECw and salt concentration ($mmol_c$ L^{-1} = EC x 10) proposed by Richards (1954). This proportion of salts was adopted following the predominant condition in the main sources of water used for irrigation in the Northeast region (Medeiros, 1992).

The genotype 'Crioula' was selected due to its hardiness and adaptation to the climate and soil conditions of the semi-arid Northeast. According to the mentioned study (Cavalcante et al., 2005), this genotype is widely used in the production of rootstocks in seedling nurseries in the region.

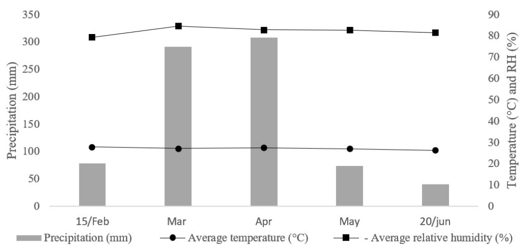

Figure 1. Precipitation, average temperature and average relative humidity (RH) data collected from February 15 to June 20, 2021, obtained through the automatic weather station of UFERSA, Caraúbas, *Campus* – RN.

Sowing was carried out in plastic bags with capacity of 1150 mL, filled with substrate formed by soil material collected at 0-30 cm depth, from the municipality of Caraúbas - RN, aged cattle manure, crushed carnauba palm straw and coal powder, at 2:2:2:1 ratio. The bags were arranged on wooden platforms, at 0.3 m height from the ground. Surplus water was drained through holes at the base of the bags and, in each one, three seeds were sown at 1.0 cm depth. Thinning was performed after stabilization of emergence and when plants had two pairs of true leaves, leaving only the most developed plant in the bag.

At the beginning of the experiment, the chemical and physical-hydraulic characteristics of the substrate were analyzed (Table 1) according to the methodologies proposed by Teixeira et al. (2017). During the experimental period, the substrate was kept with moisture close to field capacity. Until 30 days after sowing (DAS), the plants were irrigated using water with ECw of 0.3 dS m^1 and, after this period, they were irrigated with water according to the respective treatments. The volume to be applied in each irrigation was determined based on the drainage lysimetry process of a sample of bags of each treatment, with weekly evaluation according to plant growth, providing daily the evapotranspired volume of each type of water, in order to raise the soil moisture content to the level corresponding to field capacity.

Combinations of N and K doses were applied at 30 DAS and later at 7-day intervals. Foliar fertilization (N - 10%, P_2O_5 - 52%, K_2O - 10%, Ca - 0.1%, Zn - 0.02%, B - 0.02%, Fe - 0.15%, Mn - 0.1%, Cu - 0.02% and Mo - 0.005%) was performed at 45 DAS and 60 DAS, using a proportion of 1 g of fertilizer to 1 L of water, applied using a backpack sprayer, distributing 5 L in the plants. of which 62,5 ml per plant. To mitigate the damage caused by pests and diseases, phytosanitary control was carried out preventively and/or curatively with monitoring along the experiment. Weeds were eliminated manually whenever necessary.

At 125 DAS, the following growth variables were evaluated: number of leaves (NL), plant height (PH), stem diameter (SD) and leaf area (LA). To determine the number of leaves, only those with a fully expanded leaf blade were counted. SD was determined 3 cm above the plant collar, and PH was determined by measuring the distance between the collar and the insertion point of the youngest leaf. LA was determined using the methodology of Lima et al. (2012) according to Equation 1:

$$LA = 0.3205 \times L^{2.0412} \tag{1}$$

Where: LA = leaf area (cm^2); L = leaf midrib length (cm).

The relative and absolute growth rates of stem diameter in the interval from 85 to 125 DAS was also measured, according to Benincasa (2003), as described in Equations 2 and 3.

$$AGR_{sd} = \frac{(SD_2 - SD_1)}{t_2 - t_1} \tag{2}$$

Where: AGR_{sd} - Absolute growth rate of stem diameter, in mm day^{-1};
SD_1 and SD_2 – Stem diameter at times t_1 and t_2, in mm.

$$RGR_{sd} = \frac{\ln SD_f - \ln SD_i}{t_2 - t_1} \tag{3}$$

Where: SD_1 and SD_2 – Stem diameter at times t_1 and t_2, mm mm^{-1} day^{-1};
RGR_{sd} - Relative growth rate of stem diameter, mm mm^{-1} day^{-1}.

At the end of the experimental period, the leaves and stem of the plants were separated from the roots, placed in previously identified bags, and kept in an air circulation oven, at 65 °C, until reaching a constant mass, to obtain leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM) and total dry mass (TDM), obtained by the sum of LDM, SDM and RDM, whose results were expressed in grams.

Seedling quality was assessed using the Dickson Quality Index (DQI), proposed by Dickson et al. (1960), as described in Equation 4.

$$DQI = \frac{(TDM)}{(PH / SD) + (ShDM / RDM)} \tag{4}$$

Where: DQI = Dickson quality index; TDM = total dry mass (g);
PH = plant height (cm); SD = stem diameter (cm); ShDM = shoot dry mass (g); RDM = root dry mass (g).

The means of the variables were subjected to analysis of variance, with F test ($p \leq 0.05$) and regression studies for salinity levels. Means of the qualitative factor (combination of N and K fertilization) were compared by Tukey test (1 and 5% probability levels), using SISVAR statistical software (Ferreira, 2019).

Table 1. Chemical and physical-hydraulic characteristics of the substrate used for the sowing of 'Crioula' guava.

Sand	**Silt**	**Clay**	**Texture classification**				**ECse**				**pHse**		**OM**	
-------(g kg^{-1})-----							**(dS m^{-1})**				**H_2O**		**(g kg^{-1})**	
447	411	143	Loam				0.68				6.03		37	
	P		K^+	Na^{2+}	Ca^{2+}	Mg^{2+}	Al^{3+}	(H+Al)	SB	t	CEC	V	m	ESP
	(mg dm^{-3})		-----------------------------------				$cmol_c$ dm^{-3}			--------------------------------			------%------	
	134.2		0.87	0.15	17.11	1.14	0.0	0.58	19.27	19.27	19.85	97	0	0.78

Available phosphorus (P) – EMBRAPA methodology; OM – Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1 mol L^{-1} KCl at pH 7.0; Na^+ and K^+ extracted with 1 mol L^{-1} NH_4OAc at pH 7.0; Al^{3+} and (H^++Al^{3+}) extracted with 1 mol L^{-1} CaOAc at pH 7.0; ECse – Electrical conductivity of the substrate saturation extract at 25 °C; pHse – pH of the substrate saturation extract; SB – Sum of bases; t – Effective CEC; CEC – Cation exchange capacity; V – Base saturation; m – Aluminum saturation; ESP – Exchangeable sodium percentage.

3. Results and Discussion

There was significant effect of the interaction between the factors salinity levels of irrigation water and combinations of N and K fertilization only on the relative growth rate of stem diameter (RGRsd) (Table 2). The number of leaves (NL), stem diameter (SD) and plant height (PH) at 125 DAS, leaf area (LA) and absolute growth rate of stem diameter (AGRsd) from 85 to 125 DAS showed significant individual effects caused by the factors water salinity and combination of NK fertilization.

The increase in irrigation water salinity linearly reduced the production of leaves of 'Crioula' guava seedlings at 125 DAS, by 4.66% per unit increase in ECw, that is, plants irrigated using water with salinity of 3.5 dS m^{-1} had a reduction of 14.9% (or 3.4 leaves) compared to those irrigated with ECw of 0.3 dS m^{-1} (Figure 2A). The mechanism of NL reduction is probably an adaptation of plants to salt stress, reducing water loss by transpiration and the amount of salts accumulated in the leaves (Oliveira et al., 2013).

For the combinations of NK fertilization, Figure 2B showed that the combination C1 (70% N + 50% K_2O), despite not differing from the C2 and C3 fertilization managements, promoted the highest values for stem diameter in 'Crioula' guava plants at 125 DAS. When the combination C1 is compared with C4, a decrease of 8.8% is observed in SD. This result shows that the application of doses higher than that recommended for the crop, such as the combination C4 (160% N + 125% K_2O), possibly caused nutritional and osmotic imbalance due to excessive accumulation of NO_3^- and K^+, with inhibition of root growth and affecting the development of plants, reducing the transpiration rate and cell expansion and division, and causing a decrease in the size of vascular cells and tissues in the stem (Freire et al., 2016; Dias et al., 2020).

The increasing salinity of irrigation water, as observed for NL, caused linear reduction in the stem diameter of guava seedlings, 2.79% per unit increase in ECw; plants grown under ECw of 3.5 dS m^{-1} suffered a reduction of 8.94% (0.42 mm) compared to those irrigated using water with ECw of 0.3 dS m^{-1} (Figure 2C). Similar results were observed by Abrantes et al. (2017), who found a linear decrease in the stem diameter of the cultivar 'Paluma' at 100 DAE caused by the increase of ECw; the unit increase of ECw caused a reduction of 2.06% or 0.46 mm when comparing plants under the highest salinity (3.5 dS m^{-1}) with those under ECw of 0.3 dS m^{-1}.

For the variables leaf area (LA) and plant height (PH), the increase of salts in the water caused linear reductions in guava seedlings, 4.85% in LA and 3.05% in PH per unit increase of ECw. When comparing plants under ECw of 3.5 dS m^{-1} and 0.3 dS m^{-1}, reductions of 15.54% in stem diameter (Figure 2D) and 9.76% in plant height (Figure 2E) were observed.

Excess salts in the root zone of crops can cause deleterious effects on their growth, as they will affect the flow of water into the plant and cell turgor due to the osmotic effect, explaining the reduction caused in the variables SD, PH and LA (Tavares-Filho et al., 2020).

Regarding the combination of fertilization (Figure 2F), it was verified that the fertilization managements C1 (70% N + 50% K_2O) and C2 (100% N + 75% K_2O) promoted higher means for PH, not differing statistically from C3. On the other hand, plants under C4 had the lowest value, and the combinations C1 and C2 outperformed C4 by 13.38 and 12.26%, respectively. Increments in N and K doses above the requirements of the plants can increase salinity in the substrate, consequently affecting plant growth.

When evaluating the response of plants to the combination of NK fertilization based on the variables stem diameter (Figure 2B) and plant height (Figure 2F), it was observed that the higher values of NK fertilization by the C4 fertilization management (160% N + 125% K_2O) resulted in lower values for both variables. Coelho (2006) mentions that the accumulation of nutrients and the nutritional requirements of crops vary in the different stages of plant development, so it is important to apply correct doses to avoid antagonistic effect of excess fertilization.

Bonifácio et al. (2018) observed that increasing doses of K up to 1161.8 mg of K dm^{-3} of substrate did not mitigate the deleterious effect of salinity on growth variables in rootstocks of guava cv. 'Paluma' at 120 and 225 DAE.

Table 2. Summary of the analysis of variance for number of leaves (NL), plant height (PH), stem diameter (SD) and leaf area (LA) at 125 DAS and absolute growth rate (AGRsd) and relative growth rate of stem diameter (RGRsd) measured from 85 to 125 DAS of guava seedlings cultivated under different salinity levels of irrigation water and combinations of nitrogen-potassium fertilization.

Source of Variation	DF	Mean Square					
		NL	PH	SD	LA	AGRsd	RGRsd
		nº	cm	mm	cm²	mm day^{-1}	mm mm^{-1} day^{-1}
Salinity levels (S)	4	28.005**	48.616**	0.448*	27439.692**	0.0001ns	0.00004*
Linear Reg.	1	99.761**	171.603*	1.714**	88964.982*	0.0001ns	0.00001ns
Quadratic Reg.	1	9.5783ns	2.537ns	0.0611ns	245.764ns	0.0002ns	0.00014**
NK doses	3	5.617ns	135.334**	0.587*	31766.691ns	0.0003*	0.00004ns
Interaction (S x NK)	12	2.289ns	19.495ns	0.128ns	7988.012ns	0.0001ns	0.00003*
Blocks	3	7.191ns	76.479*	1.543**	9862.055ns	0.0001ns	0.00001ns
CV (%)		12.07	12.92	8.85	21.03	18.50	19.05

nsNot significant. **Significant at $p \leq 0.01$. *Significant at $p \leq 0.05$. CV – Coefficient of variation.

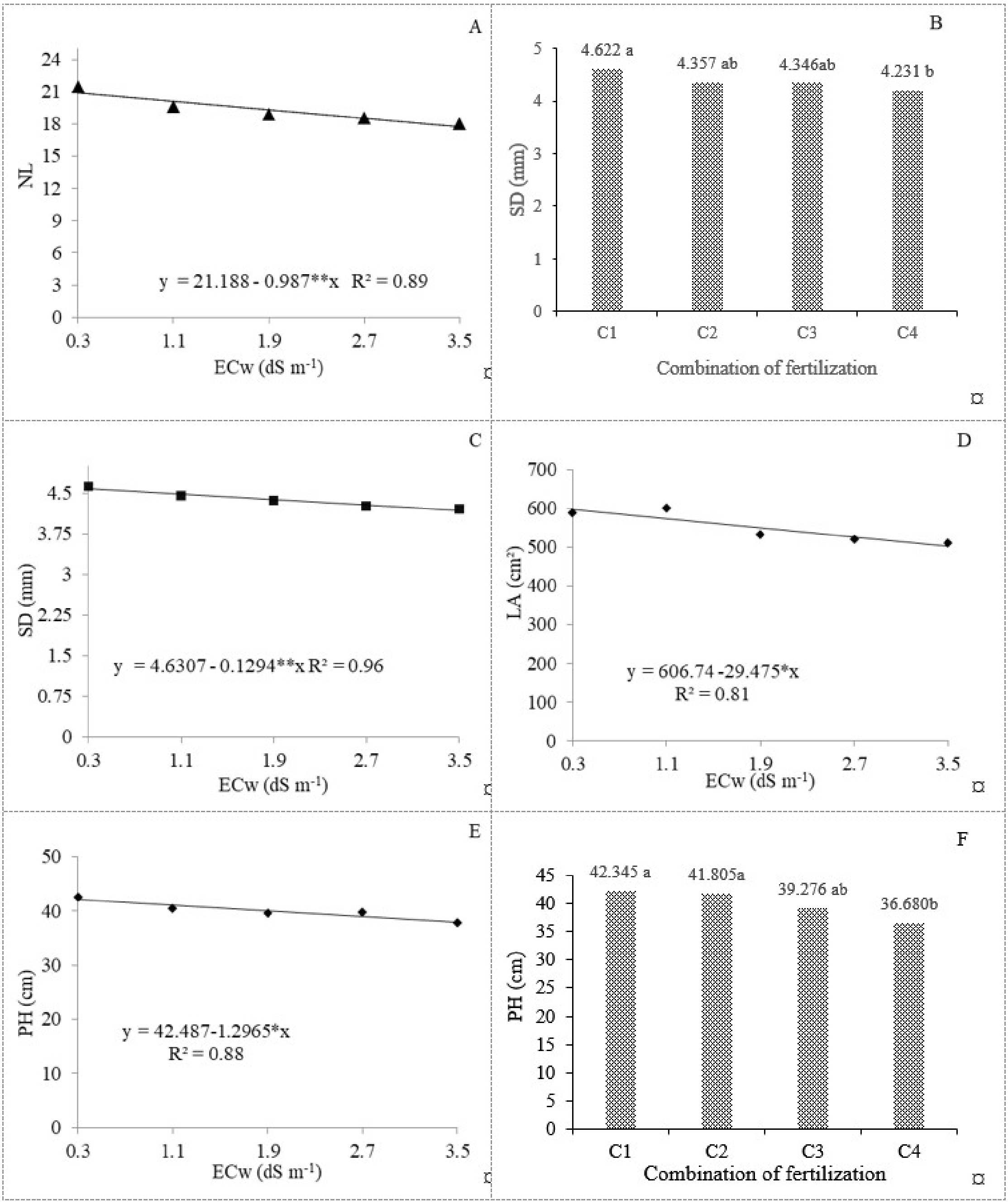

Figure 2. Number of leaves – NL (A), stem diameter – SD (C), leaf area – LA (D) and plant height – PH (E) of 'Crioula' guava as a function of the electrical conductivity of irrigation water (ECw), and stem diameter (B) and plant height – PH (F) as a function of the combination of nitrogen-potassium fertilization (C1, C2, C3 and C4) at 125 days after sowing. Note: C1 = 70% N + 50% K_2O; C2 = 100% N + 75% K_2O; C3 = 130% N + 100% K_2O; C4 = 160% N + 125% K_2O. Means followed by different letters indicate a significant difference between treatments by Tukey test (p≤0.05 probability).

In addition, high doses of K can have a negative effect on plants, as the application of fertilizer can induce an increase in soil salinity (Kawavata et al., 2017). Despite the decrease in SD, as observed for NL, 'Crioula' guava can be irrigated in the seedling production stage using water with average ECw of 2.9 dS m^{-1}, as it causes acceptable losses of 10% in these variables (Ayers and Westcot, 1999).

Figure 3A shows that plants grown under the fertilization combination C1 (70% N + 50% K_2O) had a higher absolute growth rate of stem diameter and did not differ statistically from C2, while the treatment with increment only of N fertilization above the recommended dose (C3) and C4 led to lower values of AGRsd from 85 to 125 DAS. This result indicates that the increase in N and K doses may have increased soil salinity and caused lower absolute growth rate of stem diameter. Regarding N fertilization, Souza et al. (2017) found that every 30% increment in N dose caused a linear reduction of 7.93% in the absolute growth rate of stem diameter, as found in the present study, where the 30% increase in N doses reduced AGRsd from 85 to 125 DAS.

According to Figure 3B, the effect of irrigation water salinity is seen only under the NK fertilization combinations C1 (70% N + 50% K_2O) and C2 (100% N + 75% K_2O), for which the increase in ECw has a quadratic effect on RGRsd. There was no influence of the increase in salinity on the RGRsd of plants fertilized with 130% N + 100% K_2O (C3) and 160% N + 125% K_2O (C4), with averages of 0.025 and 0.015 mm mm^{-1} day^{-1}, respectively. The RGRsd of plants fertilized with C1 was affected by the increase in ECw, and the highest estimated value (0.0108 mm mm^{-1} day^{-1}) was obtained with an ECw of 2.0 dS m^{-1}. Plants fertilized with the proportion 100% N + 75% K_2O had the highest and lowest values of RGRsd, 0.0045 and 0.0007 mm mm^{-1} day^{-1}, for the salinity levels of 1.9 and 3.5 dS m^{-1}, respectively. The highest values were obtained under ECw of 1.9 and 2.0 dS m^{-1}, and these results indicate that the combinations C1 and C2 mitigated the effects of salt stress on this variable.

The relative growth rate of the shoots of plants is influenced by changes in soil water potential due to high salt concentration, causing a reduction in water absorption, besides decreasing turgor pressure and cellular activity in plants, mainly due to the excess of Na^+ ions in the plant tissue, preventing the expansion of cells (Lopes et al., 2019).

According to the analysis of variance summary (Table 3), there were significant ($p \leq 0.01$) effects of the interaction between factors (salinity levels of irrigation water and combinations of N and K fertilization) on root dry mass (RDM), total dry mass (TDM) and Dickson quality index (DQI) and significant effect ($p \leq 0.05$) of the interaction between salinity and fertilization combinations on leaf dry mass (LDM) and stem dry mass (SDM) at 125 DAS.

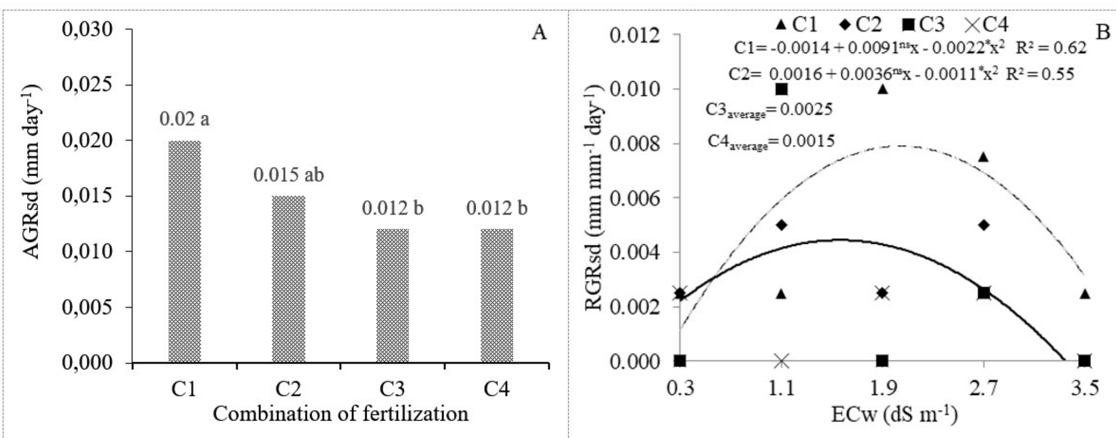

Figure 3. Absolute growth rate of stem diameter - AGRsd (A) and relative growth rate of stem diameter - RGRsd (B) of guava seedlings under irrigation with waters of different salinity levels (ECw) and combinations of nitrogen-potassium fertilization (C1, C2, C3 and C4) from 85 to 125 days after sowing. Note: C1 = 70% N + 50% K_2O; C2 = 100% N + 75% K_2O; C3 = 130% N + 100% K_2O; C4 = 160% N + 125% K_2O. Means followed by different letters indicate a significant difference between treatments by Tukey test ($p \leq 0.05$ probability).

Table 3. Summary of the analysis of variance for leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), total dry mass (TDM) and Dickson quality index (DQI) of 'Crioula' guava seedlings grown under different salinity levels of irrigation water and combinations of nitrogen-potassium fertilization at 125 DAS.

Source of Variation	DF	Mean square				
		LDM	SDM	RDM	TDM	DQI
		g per plant				
Salinity levels (S)	4	2.281**	0.872**	1.692**	13.202**	0.103**
Linear Reg.	1	3.884**	2.632**	5.073**	34.179**	0.277**
Quadratic Reg.	1	1.310ns	0.346ns	1.429*	8.584*	0.086*
NK doses	3	0.255ns	0.222ns	1.427**	4.206ns	0.064**
Interaction (S x NK)	12	1.160*	0.435*	0.706**	4.772**	0.043**
Blocks	3	0.222ns	0.264ns	0.200ns	1.190ns	0.028ns
CV (%)		18.84	22.47	22.09	15.84	17.66

nsNot significant. **Significant at $p \leq 0.01$. *Significant at $p \leq 0.05$. CV – Coefficient of variation.

According to Figure 4A, there was effect of irrigation water salinity only for the combinations C1 (70% N + 50% K_2O) and C4 (160% N + 125% K_2O), under which the increase in ECw had a quadratic effect on LDM. The increase in salinity had no effect on LDM in plants fertilized with C2 (100% N + 75% K_2O), with an average of 3.78 g, and C3 (130% N + 100% K_2O), with an average of 3.58 g. Leaf dry mass in plants fertilized with the C1 combination was negatively affected by the increase in ECw, with the highest value of 4.573 g at an estimated ECw of 0.3 dS m^{-1}, whereas irrigation with 3.5 dS m^{-1} water caused a decrease in LDM to the lowest estimated value of 2.79 g per plant. In plants fertilized with the C4 combination, the highest value for LDM (3.99 g) was obtained in plants under ECw of 1.4 dS m^{-1} and the lowest value (2.89 g per plant) was obtained under ECw of 3.5 dS m^{-1}. For an acceptable reduction of up to 10%, the salinity levels found were 1.40 dS m^{-1} for C1 and 2.7 dS m^{-1} for C4.

According to the regression equations for SDM (Figure 4B), the data showed a quadratic behavior under the combination of NK fertilization in interaction with different salinity levels of the irrigation water, except for the C2 combination, under which there was no significant influence of the increase in ECw on SDM, which averaged 2.04 mm. Under the combinations C1, C3 and C4, SDM was affected by the increase in salinity, and the highest estimated values were 9.7 g (0.4 dS m^{-1}), 8.1 g (0.3 dS m^{-1}) and 8.9 g (1.6 dS m^{-1}). The decrease in dry mass may be a consequence of the decrease in the osmotic potential of the soil, causing reduction in water absorption by plants and, consequently, inhibition of photosynthesis, dehydration of cell membranes and changes in enzymatic activities (Guimarães et al., 2017), as well as changes in ionic balance, closure of stomata, photosynthetic efficiency and carbon allocation (Taiz et al., 2017).

According to the regression analysis (Figure 4C), there was significant effect of the interaction between irrigation water salinity and the combinations of NK fertilization. The increase in ECw caused quadratic effect on RDM in the treatments C1, C3 and C4, with no significant effect for C2, under which the mean value was 2.3 g. Under all other combinations, RDM was affected by the increase of salts in irrigation water, and its highest values (2.9 g, 2.2 g and 2.7 g) were obtained under ECw of 0.8, 0.3 and 1.4 dS m^{-1}, respectively (Figure 4C). The lower production of root dry mass may be associated with high concentrations of salts due to irrigation with high-ECw water and the increase in N and K doses, which tend to reduce the osmotic potential of the soil, preventing the absorption of water and increasing the concentration of ions in the protoplasm, thus limiting crop growth (Lopes et al., 2014).

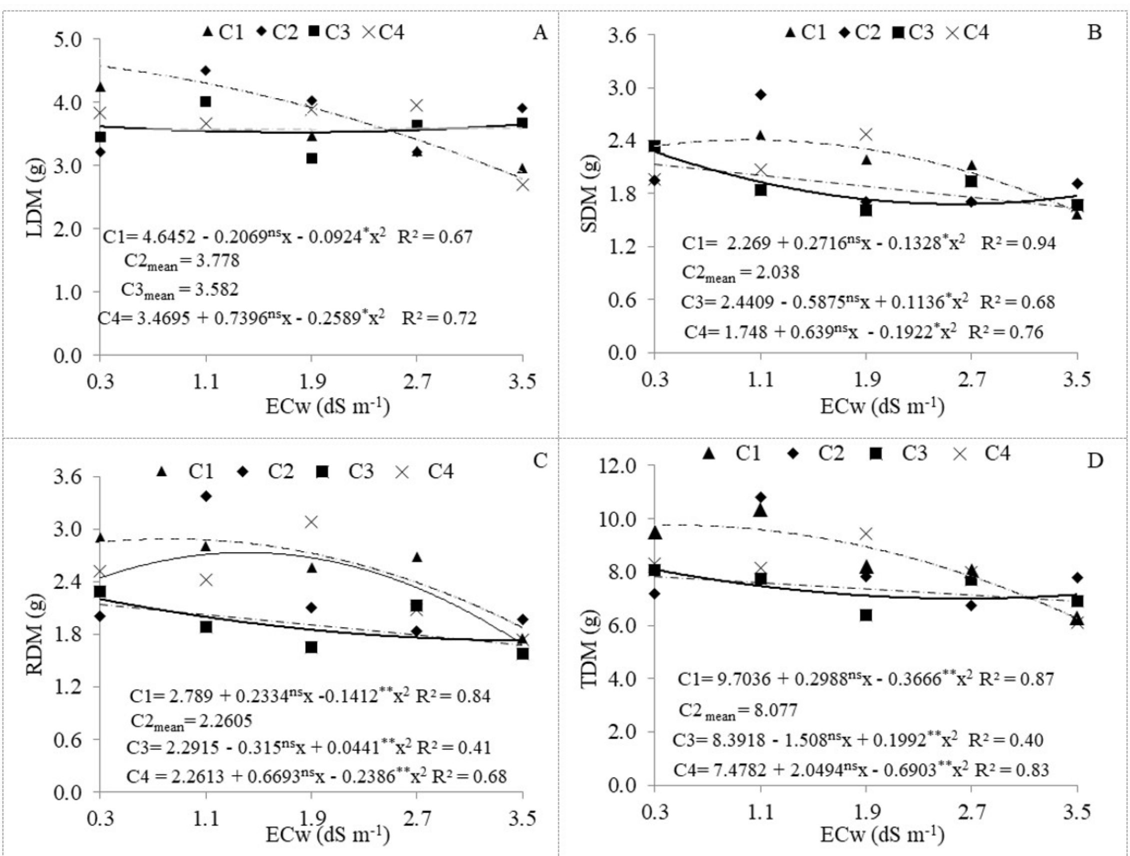

Figure 4. Leaf dry mass – LDM (A), stem dry mass – SDM (B), root dry mass – RDM (C) and total dry mass – TDM (D) of 'Crioula' guava seedlings under interaction between the factors electrical conductivity of irrigation water (ECw) and combinations of nitrogen-potassium fertilization (C1, C2, C3 and C4) at 125 DAS.

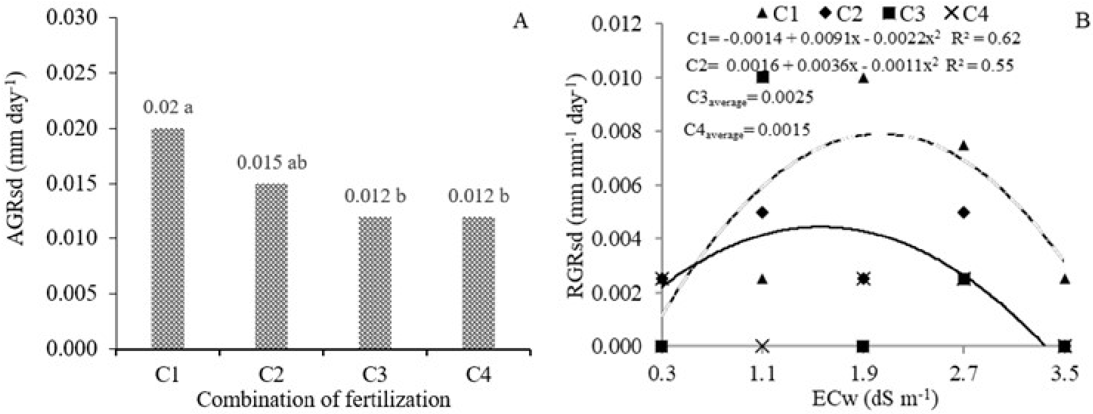

Figure 5. Dickson quality index – DQI of guava seedlings under irrigation with waters of different salinities (ECw) and combinations of nitrogen-potassium fertilization (C1, C2, C3 and C4) at 125 days after sowing.

In the analysis of the interactive effect of the salinity levels of irrigation water as a function of the combinations of NK fertilization on TDM (Figure 4D), the regression equations showed a quadratic behavior for the combinations C1 (70% N + 50% K_2O), C3 (130% N + 100% K_2O) and C4 (160% N + 125% K_2O). There was no significant effect for the C2 treatment on TDM, whose average was 8.08 g. The highest estimated result for TDM in the C1 treatment was 9.7 g, at salinity of 0.4 dS m^{-1}. The C3 combination promoted the highest dry mass (8.9 g) at an ECw of 0.3 dS m^{-1}, and C4 led to the highest value (8.9 g) at ECw of 1.5 dS m^{-1}. The lowest estimated values were verified under water salinity of 3.5 dS m^{-1}. Salt stress causes the plant to use the energy substrate for osmotic adjustment, in addition to altering the process of CO_2 assimilation, where high concentrations of NaCl in the soil reduce the absorption of other ions and cause toxicity by specific ions, leading to the appearance of physiological and nutritional damage in crops and consequently affecting biomass production (Syvertsen and Garcia-Sanchez, 2014; Silva et al., 2021).

For the Dickson quality index (DQI) (Figure 5), the effect of irrigation water salinity under each combination of NK fertilization was quadratic, except for C2, under which the mean value of DQI was 0.66. DQI in plants fertilized with the C1 combination was affected by the increase in irrigation water salinity, obtaining the highest value of 0.84 at ECw of 0.9 dS m^{-1}. In C3, the highest estimated value was 0.69, at ECw of 0.3 dS m^{-1}, and C4 led to a maximum DQI of 0.83 at ECw of 1.5 dS m^{-1}.

Souza et al. (2017) found that increased N fertilization linearly reduced DQI. Abrantes et al. (2017) observed a significant effect for the salinity x N fertilization interaction in grafted seedlings of guava cv. 'Paluma', with the highest value of DQI (1.35) under a fertilization management with N 30% above the recommended for an irrigation water salinity of 1.4 dS m^{-1}, similarly to the salinity level of 1.5 dS m^{-1} in the present study, at which the C4 combination led to an estimated result of 0.83.

According to Rudek et al. (2013), the DQI has been used to evaluate the behavior of seedlings of several species, synthesizing the morphological parameters in a single variable, from which it is possible to indicate the vigor and biomass balance. DQI values above 0.2 indicate that the seedlings have good quality, so the values observed under all ECw levels and NK combinations in the present study are higher than that indicated by the authors as good, revealing that the genetic material studied has good tolerance to salt stress.

4. Conclusions

Irrigation water with ECw above 0.3 dS m^{-1} reduces stem diameter, leaf area and plant height of 'Crioula' guava seedlings.

The combinations of nitrogen-potassium fertilization with 70% N + 50% K_2O and 100% N + 75% K_2O of the recommended doses promote greater growth of seedlings of 'Crioula' guava genotype.

Water with an average electrical conductivity of 2.1 dS m^{-1} possibility the formation of quality seedlings of 'Crioula' guava.

Acknowledgements

The authors are thankful to the National Council for Scientific and Technological Development (CNPq) for the financial support to the research and the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting the scholarship to the first author.

References

ABRANTES, D.S., NOBRE, R.G., SOUZA, L.P., SOUZA, A.S., GOMES, E.M. and SOUSA, F.F., 2017. Produção de mudas enxertadas de goiabeira irrigadas com águas salinizadas sob adubação nitrogenada. *Revista Espacios*, vol. 38, no. 31, pp. 6-21.

ALMEIDA, D.M., OLIVEIRA, M.M. and SAIBO, N.J.M., 2017. Regulation of Na^+ and K^+ homeostasis in plants: towards improved salt stress tolerance in crop plants. *Genetics and Molecular Biology*, vol. 40, no. 1, suppl., pp. 326-345. http://dx.doi.org/10.1590/1678-4685-gmb-2016-0106. PMid:28350038.

ALMEIDA, U.O., ANDRADE NETO, R.C., ARAUJO, J.M., COSTA, D.A. and TEIXEIRA JÚNIOR, D.L., 2019. Fertilizantes de liberação lenta na produção de mudas frutíferas. *South African Medical Journal*, vol. 1, no. 6, pp. 1-10.

ALVARES, C.A., STAPE, J.L., SENTELHAS, P.C., GONÇALVES, J.L.M. and SPAROKEV, G., 2013. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, vol. 22, no. 6, pp. 711-728. http://dx.doi.org/10.1127/0941-2948/2013/0507.

ANGULO-LÓPEZ, J.E., FLORES-GALLEGOS, A.C., TORRES-LEÓN, C., RAMÍREZ-GUZMÁN, K.N., MARTÍNEZ, G.A. and AGUILAR, C.N., 2021. Guava (*Psidium guajava* L.) fruit and valorization of industrialization by-products. *Processes*, vol. 9, no. 6, pp. 1075-1092. http://dx.doi.org/10.3390/pr9061075.

AYERS, R.S. and WESTCOT, D.W., 1999. *Qualidade da água na agricultura*. Campina Grande: Universidade Federal da Paraíba. 153 p.

BENINCASA, M.M.P., 2003. *Análise de crescimento de plantas, noções básicas*. 2nd ed. Jaboticabal: FUNEP. 41 p.

BEZERRA, I.L., GHEYI, H.R., NOBRE, R.G., BARBOSA, J.L., FÁTIMA, R.T., ELIAS, J.J., SOUZA, L.P. and AZEVEDO, F.L., 2018. Physiological alterations and production of guava under water salinity and nitrogen fertilizer application. *Semina: Ciências Agrárias*, vol. 39, no. 5, pp. 1945-1956. http://dx.doi.org/10.5433/1679-0359.2018v39n5p1945.

BONIFACIO, B.F., NOBRE, R.G., SOUSA, A.S., GOMES, E.M., SILVA, E.M. and SOUSA, L.P., 2018. Efeitos da adubação potássica e irrigação com águas salinas no crescimento de porta-enxerto de goiabeira. *Revista de Ciências Agrárias*, vol. 41, no. 4, pp. 971-980. http://dx.doi.org/10.19084/RCA18119.

CAVALCANTE, L.F., CAVALCANTE, I.H.L., PEREIRA, K.S.N., OLIVEIRA, F.A., GONDIM, S.C. and ARAÚJO, F.A.R., 2005. Germination and initial growth of guava plants irrigated with saline water. *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 9, no. 4, pp. 515-519. http://dx.doi.org/10.1590/S1415-43662005000400012.

COELHO, A.M., 2006. *Nutrição e adubação do milho*. Sete Lagoas: Embrapa. 10 p.

DIAS, A.S., LIMA, G.S., GHEYI, H.R., SOARES, L.A.A. and FERNANDES, P.D., 2020. Growth and gas exchanges of cotton under water salinity and nitrogen-potassium combination. *Revista Caatinga*, vol. 33, no. 2, pp. 470-479. http://dx.doi.org/10.1590/1983-21252020v33n219rc.

DICKSON, A., LEAF, A.L. and HOSNER, J.F., 1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. *Forestry Chronicle*, vol. 36, no. 1, pp. 10-13. http://dx.doi.org/10.5558/tfc36010-1.

FERREIRA, D.F., 2019. Sisvar: a computer analysis system to fixed effects split plot type designs. *Brazilian Journal of Biometrics*, vol. 37, pp. 529-535. https://doi.org/10.28951/rbb.v37i4.450.

FISCHER, G. and MELGAREJO, L.M., 2021. Ecophysiological aspects of guava (*Psidium guajava* L.). A review. *Revista Colombiana de Ciencias Horticolas*, vol. 15, no. 2, p. e12355. http://dx.doi.org/10.17584/rcch.2021v15i2.12355.

FREIRE, J.L.O., CAVALCANTE, L.F., DANTAS, M.M.M., SILVA, A.G., HENRIQUES, J.S. and ZUZA, J.F.C., 2016. Estresse salino e uso de biofertilizantes como mitigadores dos sais nos componentes morfofisiológicos e de produção de glicófitas. *Revista Principia*, vol. 1, no. 29, pp. 29-38. http://dx.doi.org/10.18265/1517-03062015v1n29p29-38.

FREIRE, J.L.O., DIAS, T.J., CAVALCANTE, L.F., FERNANDES, P.D. and LIMA NETO, A.J., 2014. Rendimento quântico e trocas gasosas em maracujazeiro amarelo sob salinidade hídrica, biofertilização e cobertura morta. *Revista Ciência Agronômica*, vol. 45, no. 1, pp. 82-91. http://dx.doi.org/10.1590/S1806-66902014000100011.

GUIMARÃES, R.F.B., NASCIMENTO, R., RAMOS, J.G., LIMA, S.C., CARDOSO, J.A.F. and MELO, D.F., 2017. Acúmulo de fitomassa de cultivares de alface hidropônica submetidas à salinidade. *Revista Brasileira de Agricultura Irrigada*, vol. 11, no. 8, pp. 2141-2151. http://dx.doi.org/10.7127/rbai.v11n800701.

KAWAVATA, C.K.H., FOIS, D.A.F., COPPO, J.C. and ALVES NETO, A., 2017. Influência de doses e de duas fontes de potássio no sistema radicular do milho e na condutividade elétrica no solo. *Investigación Agraria*, vol. 19, no. 1, pp. 28-34.

LIMA, L.G.S., ANDRADE, A.C., SILVA, R.T.L., FRONZA, D. and NISHIJIMA, T., 2012. Modelos matemáticos para estimativa de área foliar de goiabeira (Psidium guajava L.). In: 64ª Reunião Anual da SBPC, 22-27 July 2012, São Luís, Brazil. São Paulo: SBPC, pp. 1-2.

LOPES, K.P., NASCIMENTO, M.G.R., BARBOSA, R.C.A. and COSTA, C.C., 2014. Salinidade na qualidade fisiológica em sementes de *Brassicas oleracea* L. var. itálica. *Semina: Ciências Agrárias*, vol. 35, no. 5, pp. 2251-2260. http://dx.doi.org/10.5433/1679-0359.2014v35n5p2251.

LOPES, M.F.Q., SILVA, T.I., NÓBREGA, J.S., SILVA, R.T., FIGUEIREDO, F.R.A. and BRUNO, R.L.A., 2019. Crescimento de *Erythrina velutina* willd. submetida a estresse salino e aplicação de ácido salicílico. *Colloquium Agrariae*, vol. 15, no. 4, pp. 31-38. http://dx.doi.org/10.5747/ca.2019.v15.n4.a309.

MEDEIROS, J.F., 1992. *Qualidade de água de irrigação e evolução da salinidade nas propriedades assistidas pelo 'GAT' nos estados de RN, PB e CE*. Campina Grande: Universidade Federal da Paraíba, 173 p. Dissertação de Mestrado.

OLIVEIRA, F.A., MEDEIROS, J.F., OLIVEIRA, M.K.T., SOUZA, A.A.T., FERREIRA, J.A. and SOUZA, M.S., 2013. Interação entre salinidade e bioestimulante na cultura do feijão caupi. *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 17, no. 5, pp. 465-471. http://dx.doi.org/10.1590/S1415-43662013000500001.

RICHARDS, L.A., 1954. *Diagnosis and improvement of saline and alkali soils*. Washington: United States Department of Agriculture, 160 p. http://dx.doi.org/10.1097/00010694-195408000-00012.

RUDEK, A., GARCIA, F.A.O. and BANDEIRA, F.S., 2013. Avalição da qualidade de mudas de eucalipto pela mensuração da área foliar com o uso de imagens digitais. *Enciclopédia Biosfera*, vol. 9, no. 17, pp. 3775-3787.

SILVA, S.S., LIMA, G.S., LIMA, V.L.A., GHEYI, H.R., SOARES, L.A.A. and LUCENA, R.C.M., 2019. Gas exchanges and production of watermelon plant under salinity management and nitrogen fertilization. *Pesquisa Agropecuária Tropical*, vol. 49, p. e54822. http://dx.doi.org/10.1590/1983-40632019v4954822.

SILVA, S.S., LIMA, G.S., LIMA, V.L.A., SOARES, L.A.A., GHEYI, H.R. and FERNANDES, P.D., 2021. Quantum yield, photosynthetic pigments and biomass of mini-watermelon under irrigation strategies and potassium. *Revista Caatinga*, vol. 34, no. 3, pp. 659-669. http://dx.doi.org/10.1590/1983-21252021v34n318rc.

SOUSA, G.G., SOUSA, H.C., SANTOS, M.F., LESSA, C.I.N. and GOMES, S.P., 2022. Saline water and nitrogen fertilization on leaf composition and yield of corn. *Revista Caatinga*, vol. 35, no. 1, pp. 191-198. http://dx.doi.org/10.1590/1983-21252022v35n119rc.

SOUZA, P.S., NOBRE, R.G., SILVA, E.M., GHEYI, H.R. and SOARES, L.A.A., 2017. Produção de porta-enxerto de goiabeira cultivado com águas de diferentes salinidades e doses de nitrogênio. *Revista Ciência Agronômica*, vol. 48, no. 4, pp. 596-604. http://dx.doi.org/10.5935/1806-6690.20170069.

SYVERTSEN, J.P. and GARCIA-SANCHEZ, F., 2014. Multiple abiotic stresses occurring with salinity stress in citrus. *Environmental and Experimental Botany*, vol. 103, pp. 128-137. http://dx.doi.org/10.1016/j.envexpbot.2013.09.015.

TAIZ, L., ZEIGER, E., MØLLER, I.M. and MURPHY, A., 2017. *Fisiologia e desenvolvimento vegetal*. 6th ed. Porto Alegre: Artmed.

TAVARES FILHO, G.S., SILVA, D.F., LINS, R.C., ARAUJO, C.A.S., OLIVEIRA, F.F. and MATIAS, S.S.R., 2020. Desenvolvimento de mudas de Moringa oleífera (LAM) submetida a diferentes níveis de água salina. *Brazilian Journal of Development*, vol. 6, no. 7, pp. 48671-48683. http://dx.doi.org/10.34117/bjdv6n7-493.

TEIXEIRA, P.C., DONAGEMMA, G.K., FONTANA, A. and TEIXEIRA, W.Z., 2017. *Manual de métodos de análise de solo*. 3rd ed. Brasília: Embrapa Solos, 574 p.