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SALICYLIC ACID AS AN ATTENUATOR OF SALT STRESS IN SOURSOP[1]

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ABSTRACT - The search for alternatives that enable the use of saline waters in agriculture has become constant. In this context, the objective was to evaluate the effects of salicylic acid in mitigating salt stress effects on the growth and gas exchange of soursop cv. 'Morada Nova'. The study was conducted in a greenhouse, in the municipality of Campina Grande - PB, Brazil. Treatments were distributed in randomized blocks, in a 5 x 4 factorial arrangement, corresponding to five levels of electrical conductivity of irrigation water – ECw (0.8; 1.6; 2.4; 3.2 and 4.0 dS m^{-1}) and four concentrations of salicylic acid - SA (0; 1.2; 2.4 and 3.6 mM), with three replicates. Irrigation with saline water compromised the growth and gas exchange of soursop cv. 'Morada Nova'. However, exogenous application of salicylic acid induced tolerance to salt stress in soursop plants, as their growth, transpiration, stomatal conductance, photosynthesis and instantaneous carboxylation efficiency were favored by the application of salicylic acid, even when exposed to water salinity.

Keywords: *Annona muricata* L.. Saline water. Salinity mitigation.

ÁCIDO SALICÍLICO COMO ATENUADOR DO ESTRESSE SALINO DE GRAVIOLEIRA

RESUMO - A busca por alternativas que possibilitem o uso de águas salinas na agricultura tem se tornado constante. Neste contexto, objetivou-se, avaliar os efeitos do ácido salicílico na mitigação do estresse salino no crescimento e nas trocas gasosas da gravioleira cv. Morada Nova. O estudo foi conduzido em casa de vegetação, no município de Campina Grande - PB. Os tratamentos foram distribuídos em blocos casualizados, em arranjo fatorial 5 x 4, sendo cinco níveis de condutividade elétrica da água de irrigação – CEa (0,8; 1,6; 2,4; 3,2 e 4,0 dS m^{-1}) e quatro concentrações de ácido salicílico – AS (0; 1,2; 2,4 e 3,6 mM), com três repetições. A irrigação com águas salinas comprometeu o crescimento e as trocas gasosas da gravioleira cv. Morada Nova. Entretanto, a aplicação exógena do ácido salicílico induziu a tolerância ao estresse salino a gravioleira, visto que, as plantas tiveram seu crescimento, transpiração, condutância estomática, fotossíntese e eficiência instantânea da carboxilação beneficiadas pela aplicação do ácido salicílico, mesmo quando expostas a salinidade da água.

Palavras-chave: *Annona muricata* L.. Águas salinas. Mitigação da salinidade.

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INTRODUCTION

Soursop (*Annona muricata* L.) is a fruit tree belonging to the Annonaceae family, native of the tropical areas of Central America, introduced to Brazil by the Spanish and Portuguese in the 16th century (SÁNCHEZ et al., 2018). Its commercial cultivation is recent; however, its production has increased in recent years due to the advances in the agroindustry and, above all, its use by the pharmaceutical industry (SÃO JOSÉ et al., 2014; BENTO et al., 2016).

Source of vitamin C, calcium, carbohydrates and antioxidant substances such as acetogenins, alkaloids and flavonoids, soursop helps protect the human body against oxidative stress, acting in the prevention of a series of chronic degenerative disorders (DAUDA et al., 2018). Due to population growth, combined with the increase in demand for food and the reduction in water availability both quantitatively and qualitatively, it is necessary to use marginal quality water, that is, waters with high concentrations of salts (RODRIGUES et al., 2020). However, salinity is one of the most challenging and potential threats to agriculture, especially in semi-arid regions (KHAN et al., 2019).

Excess salts in water inhibit plant growth due to some factors such as toxicity of ions (Na^+ and Cl^-), osmotic and oxidative stress, degradation of pigments, alteration of metabolic pathways, and inhibition of photosynthesis and nutrient absorption (BISTGANI et al., 2019; MAGALHÃES et al., 2020). Silva et al. (2018), studying the growth and gas exchange of soursop seedlings under irrigation with saline water, found that water salinity from 0.5 dS m^{-1} negatively affected their gas exchange and growth. Reductions in soursop growth due to the increase in the salinity level of irrigation water were also identified by Veloso et al. (2019).

Thus, it is necessary to seek strategies that enable the cultivation of soursop, and these alternatives particularly include the use of elicitors, such as salicylic acid, which acts in improving the efficiency of metabolic processes, resulting in acclimation to abiotic stresses, including salt and water stresses (SILVA et al., 2019; ANDRADE et al., 2020).

Salicylic acid is a plant hormone that plays several physiological roles in plants, including growth, flower induction, nutrient absorption, ethylene biosynthesis, stomatal closure, and photosynthesis. In addition, it increases the activity of antioxidant enzymes such as peroxidases, superoxide dismutase and catalase (SZEPESI, 2008). Some studies have reported that the exogenous application of salicylic acid may increase tolerance to salt stress in sunflower (NOREEN et al., 2017), barley (PIRASTEH-ANOSHEH et al., 2017) and tomato (GHARBI et al., 2018). However, there is no information on its use in the cultivation of soursop grown under irrigation with saline water.

It should also be considered that the effect of salicylic acid depends on several factors, including concentration, plant species and stage of development and mode of application (POÓR et al., 2019). In view of the above, the objective of this study was to evaluate the effect of concentration of salicylic acid in mitigating salt stress effects on the growth and gas exchange of soursop cv. 'Morada Nova'.

MATERIAL AND METHODS

The experiment was carried out in a protected environment (greenhouse) belonging to the Academic Unit of Agricultural Engineering - UAEA of the Federal University of Campina Grande - UFCG, located in Campina Grande, Paraíba, Brazil, at the geographical coordinates 7°15'18" South latitude, 35°52'28" West longitude and average altitude of 550 m. Air temperature (maximum and minimum) and relative humidity of air data are shown in Figure 1.

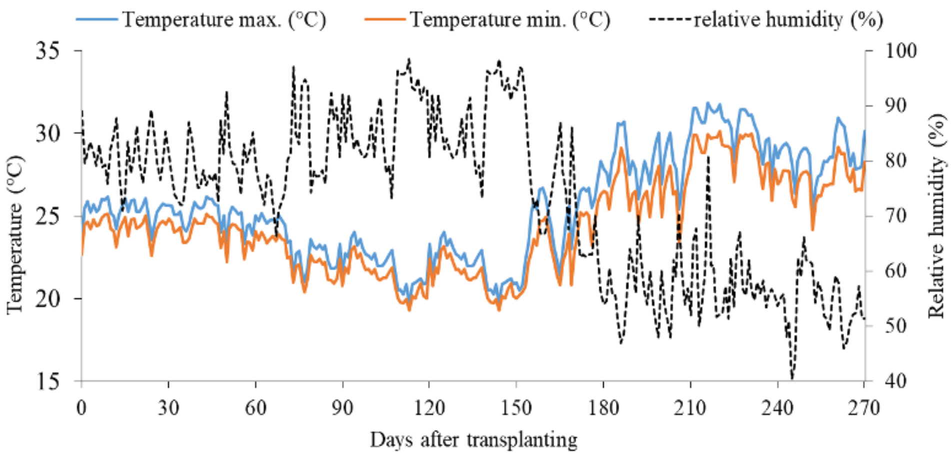


Figure 1. Air temperature (maximum and minimum) and relative humidity of air inside the greenhouse along the experimental period.

The treatments consisted of five levels of electrical conductivity of irrigation water - ECw (0.8; 1.6; 2.4; 3.2 and 4.0 dS m^{-1}) and four concentrations of salicylic acid - SA (0; 1.2; 2.4 and 3.6 mM), in a 5 x 4 factorial arrangement, distributed in randomized blocks, with three replicates, totaling 60 experimental units. Salicylic acid (SA) concentrations were established according to a study conducted by Abbaszadeh et al. (2020).

The cultivar ‘Morada Nova’ was chosen because it is the most appreciated by producers, composing most commercial plantations in Brazil, besides having larger fruits, which can weigh up to 15 kg, and higher production compared to other cultivars (VELOSO et al., 2018). The seedlings were produced sexually over a period of 330 days before transplanting. After this period, they were transplanted to plastic recipients.

During the acclimation period in the greenhouse (30 days), the plants were irrigated with low-salinity water (0.38 dS m^{-1}) and then the treatments were applied.

The experiment was conducted using plastic pots adapted as drainage lysimeters, with capacity of 120-L, filled with a 1.0-kg layer of crushed stone followed by 160 kg of soil classified as *Neossolo Regolítico* (Psamments - UNITED STATES, 2014), collected at 0-30 cm depth in the municipality of Lagoa Seca-PB, whose physico-chemical characteristics (Table 1) were determined according to Teixeira et al. (2017).

Table 1. Chemical and physical attributes of the soil used in the experiment, before the application of the treatments.

Chemical characteristics									
pH (H_2O) (1:2.5)	OM dag kg^{-1}	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	$Al^{3+} + H^+$	PST (%)	ECse (dS m^{-1})
			....................(cmol$_c$ kg^{-1})....................						
5.90	1.36	6.80	0.22	0.16	2.60	3.66	1.93	1.87	1.0

Physical characteristics									
Size fraction (g kg^{-1})			Textural class	Water content (kPa)		AW	Total porosity %	BD	PD
Sand	Silt	Clay		33.42*	1519.5**			(kg dm^{-3})	
				....	dag kg^{-1}	....			
732.9	142.1	125.0	SL	11.98	4.32	7.66	47.74	1.39	2.66

OM - Organic Matter: Walkley-Black Wet Digestion; 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+} and H^+ extracted with 0.5 M CaOAc at pH 7.0; ESP - Exchangeable sodium percentage; ECse - Electrical conductivity of the saturation extract; SL - Sandy loam; AW - Available water; BD - Bulk density; PD - Particle density; * - Field capacity; ** - Permanent wilting point.

Irrigation waters with different levels of electrical conductivity were prepared by dissolving in local supply water (ECw = 0.38 dS m^{-1}) the salts NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$, respectively in the equivalent proportion of 7:2:1, which is commonly found in sources of water used for irrigation in small farms in the Northeast region (MEDEIROS, 1992), based on the relationship between ECw (dS m^{-1}) and the concentration of salts (mmol$_c$ L^{-1} = 10*ECw) recommended by Richards et al. (1954).

At 30 days after transplanting, irrigation began with the saline waters, adopting an irrigation interval of three days, applying water in each lysimeter according to treatment in order to keep the soil moisture close to field capacity and avoid excessive accumulation of salts in the soil. The volume of water to be applied was determined according to the water needs of the plants, estimated by the water balance, using by Equation 1:

$$VI = \frac{(Va - Vd)}{(1 - LF)} \quad (1)$$

Where:

VI = volume of water to be applied in the irrigation event (mL);

Va = volume applied in the previous irrigation event (mL);

Vd = volume drained (mL);

LF = Leaching fraction of 0.15, applied every 15 days.

Salicylic acid concentrations were obtained by dissolution in 30% ethyl alcohol (95.5%) in distilled water, as it is a substance with low solubility in water at room temperature. The adjuvant Wil fix at a concentration of 0.5 mL L^{-1} of solution was used to reduce the surface tension of the drops on the leaf surface in the preparation of the solution.

Foliar applications began at 60 days after transplanting (DAT), with sprays on the abaxial and adaxial faces of the leaves, at intervals of 30 days, using a backpack sprayer between 17:00 and 17:45 h. The sprayer used is a Jacto XP model from Jacto® with capacity of 12-L, working pressure (maximum) of 88 psi (6 bar) and JD 12P nozzle, and the average volume applied per plant was 400 mL.

Nitrogen, phosphorus and potassium

fertilizations were based on the recommendation of Cavalcante (2008) for soursop. Urea, monoammonium phosphate and potassium chloride were used as sources of nitrogen, phosphorus and potassium.

To meet the requirement of micronutrients, a nutrient solution with 1.0 g L^{-1} containing: N (15%), P_2O_5 (15%), K_2O (15%), Ca (1%), Mg (1.4%), S (2.7%), Zn (0.5%), B (0.05%), Fe (0.5%), Mn (0.05%), Cu (0.5%) and Mo (0.02%) was applied on the leaves, adaxial and abaxial sides, using a backpack sprayer.

During the experiment, all the tillage and phytosanitary practices recommended for the crop were performed, monitoring the emergence of pests and diseases and adopting control measures when necessary.

Treatment effects were evaluated based on gas exchange: stomatal conductance (*gs*), transpiration (*E*), CO_2 assimilation rate (*A*), internal CO_2 concentration (*Ci*), instantaneous water use efficiency (*WUEi*) and instantaneous efficiency of carboxylation (*CEi*); and on growth variables: plant height (PH), stem diameter (SD), relative growth rate in plant height (RGR_{PH}) and relative growth rate in stem diameter (RGR_{SD}).

Gas exchange was determined at 180 DAT, in the third leaf, counted from the apex of the main branch of the plant, using irradiation of 1200 μmol photons m^{-2} s^{-1} and airflow of 200 mL min^{-1}, using the portable photosynthesis meter "LCPro+" from ADC BioScientific Ltda.

Growth was measured at 210 and 270 DAT. PH was measured using as reference the distance from the plant collar to the insertion of the apical meristem, while SD (mm) was measured two centimeters above the plant collar. Plant height and stem diameter data were used to calculate the relative growth rate, a variable that verifies the growth speed of the plants when comparing the final height with the initial height. The relative growth rate was determined according to the methodology described by Benincasa (2003), using Equation 2:

$$RGR = \frac{(lnA_2 - lnA_1)}{(T_2 - T_1)} \qquad (2)$$

Where:
RGR – relative growth rate;
A_1 – variable at time t_1;
A_2 – variable at time t_2;
T_1 – time 1 in days;
T_2 – time 2 in days;

The data obtained were evaluated by analysis of variance at 0.05 probability level and, in cases of significance; linear and quadratic regression analysis was performed, using the statistical program SISVAR-ESAL (FERREIRA, 2019). In addition to R^2, the choice of model was made based on the biological significance of the phenomenon. In case of significance of the interaction between factors, TableCurve 3D software was used to obtain the response surface curves.

RESULTS AND DISCUSSION

According to the summary of the analysis of variance (Table 2), the interaction between salinity levels (SL) and salicylic acid concentrations (SA) significantly ($p < 0.01$) influenced all variables analyzed, except the internal CO_2 concentration (*Ci*) and instantaneous water use efficiency (*WUEi*). The salinity levels, on the other hand, significantly affected the *Ci*, transpiration (*E*), stomatal conductance (*gs*), CO_2 assimilation rate (*A*) and *CEi* of soursop plants cv. 'Morada Nova', at 180 days after transplanting. The concentrations of salicylic acid had significant effect on *gs*, *A* and *CEi*.

According to the regression equation in Figure 2A, for CO_2 assimilation rate, soursop plants that were not subjected to the application of salicylic acid had their CO_2 assimilation rate reduced when irrigated using water with ECw greater than 1.4 dS m^{-1}, obtaining the lowest value of *A* (4.130 mmol CO_2 m^{-2} s^{-1}) when irrigated with water of 4.0 dS m^{-1}.

On the other hand, the application of salicylic acid up to the concentration of 1.4 mM promoted an increase in CO_2 assimilation rate even when plants were exposed to salinity, and the highest *A* (8.20 mmol CO_2 m^{-2} s^{-1}) was obtained in plants subjected to salicylic acid concentration of 1.4 mM and irrigated with water of 1.4 dS m^{-1}, corresponding to an increase of 9.33% (0.70 mmol H_2O m^{-2} s^{-1}) when compared to plants grown under ECw of 1.4 dS m^{-1} and 0 mM of SA.

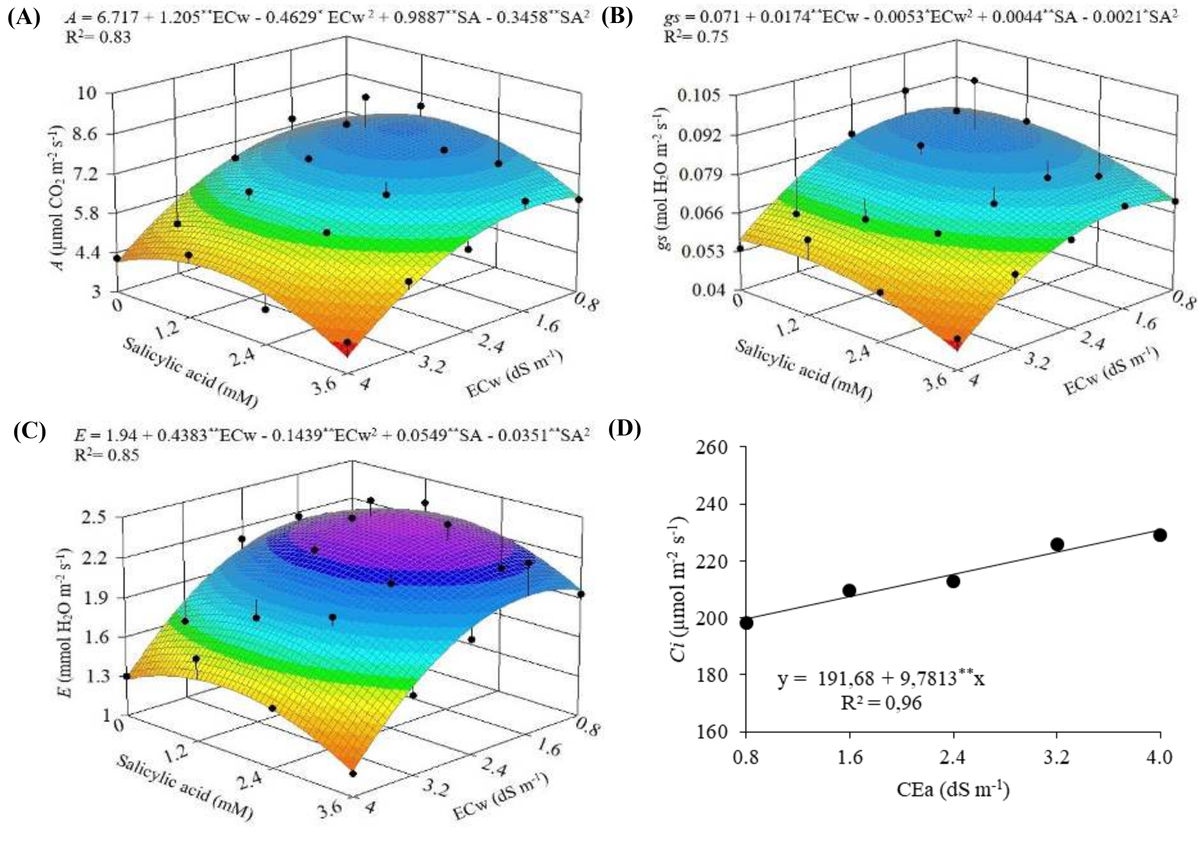
The beneficial effect of salicylic acid on CO_2 assimilation rate, verified in plants subjected to concentrations of up to 1.4 mM, may be related to the capacity of salicylic acid to improve enzymatic and photosynthetic activities, while also maintaining the balance between the production and elimination of reactive oxygen species (BATISTA et al., 2019).

For stomatal conductance (Figure 2B), plants subjected to salicylic acid concentrations up to 1.05 mM obtained an increase in *gs*, regardless of the electrical conductivity of irrigation water, and the highest stomatal conductance (0.088 mol H_2O m^{-2} s^{-1}) was obtained in plants subjected to salicylic acid concentration of 1.05 mM and irrigated with water of 1.64 dS m^{-1}. However, the increase in salicylic acid concentrations above 1.05 mM caused reductions in stomatal conductance, with lowest value of *gs* (0.044 mol H_2O m^{-2} s^{-1}) obtained in plants subjected to a concentration of 3.6 mM and irrigated with water of 4.0 dS m^{-1}, corresponding to a reduction of 50% (0.044 mol H_2O m^{-2} s^{-1}) when compared to plants with higher *gs*.

Table 2. Summary of the analysis of variance for CO_2 assimilation rate (*A*), stomatal conductance (*gs*), transpiration (*E*), CO_2 internal concentration (*Ci*), instantaneous carboxylation efficiency (*CEi*) and instantaneous water use efficiency (*WUEi*) of soursop plants irrigated with saline waters and subjected to foliar application of salicylic acid, at 180 days after transplanting.

Source of variation	Mean squares					
	A	*gs*	*E*	*Ci*	*CEi*	*WUEi*
Salinity levels (SL)	17.32^{**}	0.0024^{**}	1.04^{**}	1909.72^{*}	0.0004^{**}	0.88^{ns}
Linear regression	61.02^{**}	0.0047^{**}	3.20^{**}	6795.07^{**}	0.0016^{**}	3.14^{ns}
Quadratic regression	1.24^{ns}	0.0036^{*}	0.40^{ns}	7.29^{ns}	0.0001^{ns}	0.02^{ns}
Salicylic acid (SA)	5.40^{**}	0.0005^{*}	0.23^{ns}	1239.93^{ns}	0.0002^{**}	0.82^{ns}
Linear regression	3.54^{ns}	0.0010^{*}	0.58^{ns}	92.96^{ns}	$3.2\text{x}10^{-5ns}$	0.24^{ns}
Quadratic regression	11.67^{**}	0.0006^{ns}	0.01^{ns}	3420.15^{ns}	$3.5\text{x}10^{-4**}$	0.74^{ns}
Interaction (SL x SA)	3.58^{**}	0.0019^{**}	0.43^{**}	1136.19^{ns}	0.0002^{**}	0.64^{ns}
Blocks	14.58^{**}	0.0013^{**}	0.26^{ns}	5941.55^{**}	0.0002^{**}	6.48^{**}
Residue	1.25	0.0002	0.11	728.25	0.00001	0.57
CV (%)	17.45	18.06	17.30	12.54	20.42	21.82

$^{ns, *, **}$ respectively not significant, significant at p<0.05 and significant at p< 0.01. CV: Coefficient of variation.



$^{*, **}$ - significant at p ≤ 0,05 e p ≤ 0,01, respectively.

Figure 2. CO_2 assimilation rate – *A* (A), stomatal conductance – *gs* (B) and transpiration – *E* (C) of soursop plants, as a function of the interaction between water salinity - ECw and salicylic acid concentrations; and internal CO_2 concentration – *Ci* (D) as a function of the electrical conductivity of water – ECw, at 180 days after transplanting.

The increase in stomatal conductance (Figure 2B) in plants subjected to a concentration of 1.4 mM led to a higher CO_2 assimilation rate (Figure 2A). This response can be attributed to the role of salicylic acid in inducing plant tolerance to salt stress, acting on the increase in the activity of antioxidant enzymes. In addition, salicylic acid induces the alteration of carbohydrate metabolism in plants, and thus the soluble sugars, especially non-reducing sugars, accumulate to function as osmotic regulators (DONG; WANG; SHANG, 2011). Methenni et al. (2018), evaluating the effect of salicylic acid (0; 0.5 and 1.0 mM) on olive plants (*Olea europaea* L.) under salt stress (0 and 200 mM of NaCl), verified that the application of salicylic acid at the concentration of 1.0 mM promoted increments in CO_2 assimilation rate and stomatal conductance, when compared to the control treatment (0 mM).

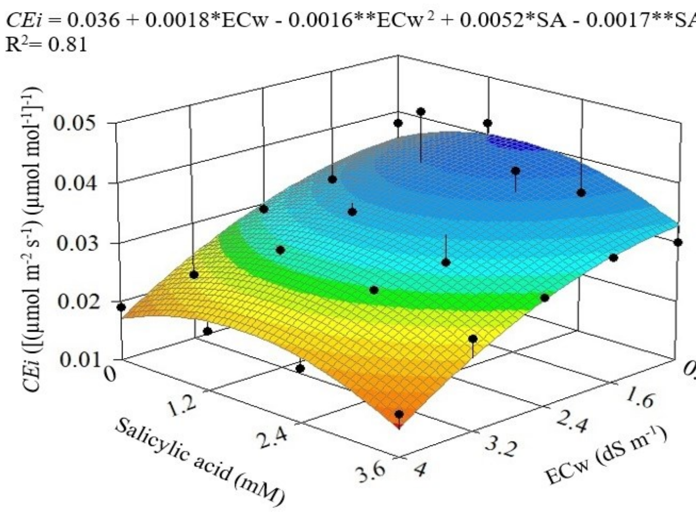
Regarding the transpiration of soursop (Figure 2C), plants that did not receive application of salicylic acid (0 mM) and were irrigated with water of electrical conductivity greater than 1.5 dS m^{-1} showed reduction in *E*, and its lowest value (1.39 mmol H_2O m^{-2} s^{-1}) was obtained in plants grown with water of 4.0 dS m^{-1}. However, it was verified that the plants subjected to SA concentration of 0.8 mM and ECw of 1.5 dS m^{-1} attained the highest transpiration (2.30 mmol H_2O m^{-2} s^{-1}). The reduction of leaf transpiration occurs mainly due to the reduction in the total water potential caused by the increase in salt concentration, and such response stands out as a water saving strategy during the critical period (SOUSA et al., 2014).

The increase in the electrical conductivity of irrigation water promoted an increase in the internal CO_2 concentration (Figure 2D), equal to 5.10% per unit increment in ECw. In relative terms, there was an increase of 15.69% (31.2 μmol m^{-2} s^{-1}) in the C*i* of plants irrigated with water of highest salinity (4.0 dS m^{-1}) compared to that of plants subjected to the lowest salinity level (0.8 dS m^{-1}).

The increase in *Ci* may be related to the degradation of the photosynthetic apparatus in response to the senescence of leaf tissues, resulting from the stress caused by excess salts (SILVA et al., 2013). Similar results were obtained by Lima et al. (2020) in acerola plants (*Malpighia emarginata*) under salt stress (0.8 and 4.5 dS m^{-1}), where the increase in internal CO_2 concentration in plants irrigated with water of highest salinity (4.5 dS m^{-1}) was attributed to the low activity of the enzyme ribulose-1.5-biphosphate carboxylase oxygenase (RuBisCO).

The instantaneous carboxylation efficiency (*CEi*) was also affected by the interaction between factors (SL x SA) and, according to the regression equations (Figure 3), plants had their *CEi* reduced when irrigated using water with ECw greater than 0.8 dS m^{-1}, regardless of the concentrations of salicylic acid. However, it is noted that the highest *CEi* (0.0404 (μmol m^{-2} s^{-1}) (μmol $mol^{-1})^{-1}$) was obtained in plants subjected to a concentration of 1.4 mM and irrigated with water of 0.8 dS m^{-1}, corresponding to an increase of 10.99% (0.004 (μmol m^{-2} s^{-1}) (μmol $mol^{-1})^{-1}$) in *CEi* when compared to control plants (0 mM) irrigated with 0.8 dS m^{-1} water.

The beneficial effect of salicylic acid on the instantaneous carboxylation efficiency, verified in plants subjected to a concentration of 1.2 mM, may be related to the capacity of salicylic acid to increase RuBisCO activity and stimulate potassium absorption, maintaining a high K^+/Na^+ ratio, consequently increasing the content of ATP in plants (LEE; DAMODARAN; ROH, 2014).



*, ** - significant at p ≤ 0,05 e p ≤ 0,01, respectively.

Figure 3. Instantaneous carboxylation efficiency – *CEi* of soursop plants, as a function of the interaction between water salinity - ECw and salicylic acid concentrations, at 180 days after transplanting.

There was interaction between salinity levels and salicylic acid concentrations only for plant height at 210 and 270 DAT (Table 3). The salinity levels of irrigation water significantly affected ($p<0.01$) all variables analyzed, except the relative growth rate in stem diameter (RGR_{SD}). Salicylic acid concentrations significantly influenced plant height at 210 and 270 DAT, stem diameter at 210 DAT and relative growth rate in stem diameter (RGR_{SD}).

Table 3. Summary of the analysis of variance for plant height (PH), stem diameter (SD) at 210 and 270 days after transplanting (DAT) and relative growth rates in plant height (RGR_{PH}) and in stem diameter (RGR_{SD}) in the period from 210 to 270 DAT, of soursop plants irrigated with saline waters and subjected to foliar application of salicylic acid.

Source of variation	Mean squares					
	PH		SD		RGR_{PH}	RGR_{SD}
	Days after transplanting					
	210	270	210	270		
Salinity levels (SL)	1795.39**	3266.21**	54.46**	73.97**	6x10^-6**	3x10^-6ns
Linear regression	3685.21**	8789.40**	145.81**	234.41**	12x10^-6**	4x10^-6ns
Quadratic regression	2295.48*	1768.01*	51.23*	52.46ns	4x10^-7ns	5x10^-6ns
Salicylic acid (SA)	2689.12**	1219.84**	23.41*	8.46ns	3x10^-7ns	9x10^-6**
Linear regression	206.67ns	590.80ns	0.32ns	0.02ns	2x10^-6ns	5x10^-6ns
Quadratic regression	7459.35**	2653.35**	42.21*	0.74ns	2x10^-6ns	56x10^-5**
Interaction (SL x SA)	311.11*	347.79**	10.22ns	8.69ns	2x10^-7ns	8x10^-6ns
Blocks	108.05ns	83.75ns	17.21ns	222.10**	3x10^-7ns	7x10^-6ns
Residue	140.61	103.36	7.77	8.39	8x10^-7	3x10^-3
CV (%)	7.79	5.66	12.17	10.39	29.74	29.58

ns, *, ** respectively not significant, significant at $p<0.05$ and significant at $p< 0.01$. CV: Coefficient of variation.

Plants irrigated with 1.9 dS m^{-1} water and subjected to salicylic acid concentration of 2.0 mM attained the highest growth in plant height (Figure 4A and 4B), equal to 179 and 217 cm, at 210 and 270 DAT, respectively. Plants irrigated with 4.0 dS m^{-1} water and under the control treatment (0 mM) had the lowest PH, equivalent to 115.9 and 144.6 cm, at 210 and 270 DAT, respectively.

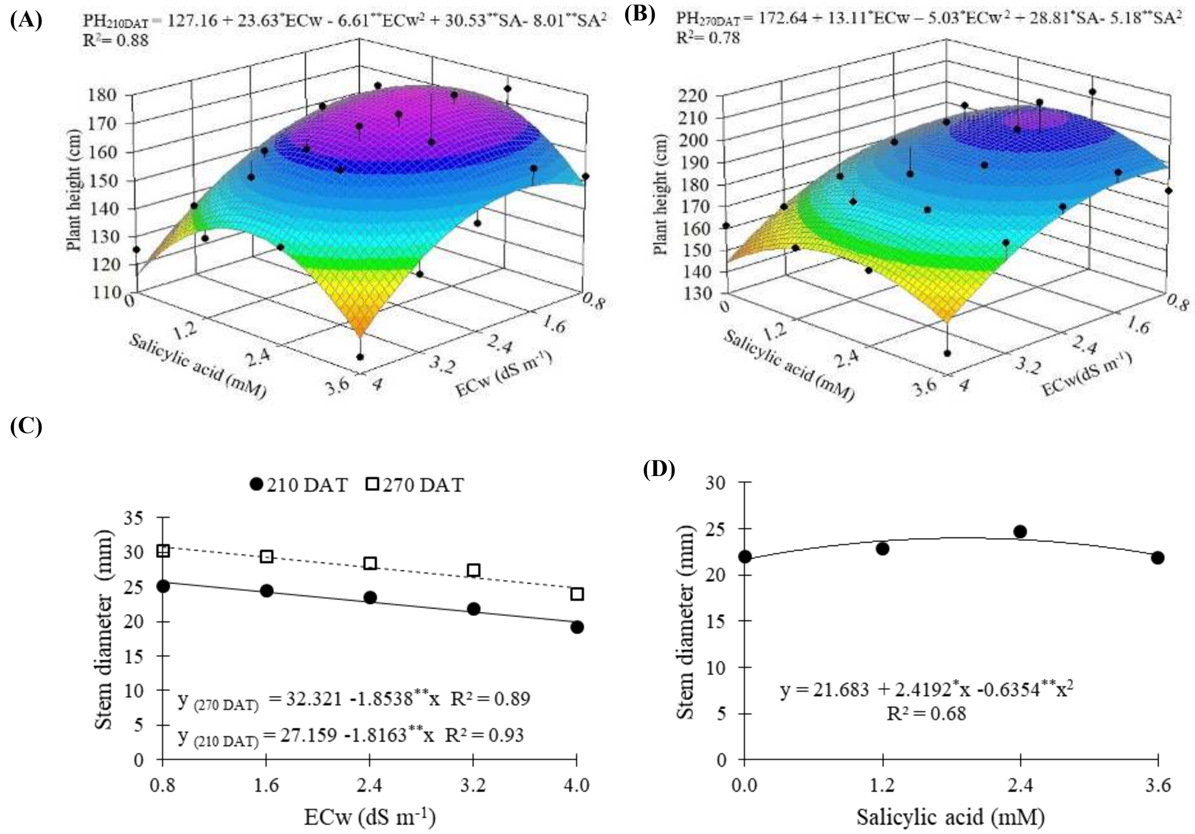
The beneficial effect of salicylic acid at the concentration of 2.0 mM observed on plant height at 210 and 270 DAT may be related to the higher photosynthetic efficiency, along with the best nitrogen fixation capacity induced by salicylic acid (FARHANGI-ABRIZ; GHASSEMI-GOLEZANI 2018). On the other hand, the reduction in PH as a function of salinity occurs due to the water deficit and reduction in nutrient absorption, induced by the osmotic effect and, consequently, restricting gas exchanges, as observed in the present study (Figure 4A, 4B, 4C and 4D).

The increase in saline levels of irrigation water negatively affected the SD (Figure 4C) of soursop cv. 'Morada Nova', at 210 and 270 DAT, with decreases of 6.69 and 5.74% per unit increase in ECw, at 210 and 270 DAS, respectively. The decrease in growth in SD may be related to the increase in the osmotic pressure of soil solution and, consequently, the reduction in the availability of water and nutrients for plants, which results in lower growth (LIMA et al., 2015).

Soursop stem diameter was influenced by the salicylic acid concentrations at 210 DAT, and the regression equation (Figure 4D) shows that plants subjected to the concentration of 1.9 mM stood out with the highest value (23.99 mm). When comparing the SD in relative terms, there was an increase of 9.63% (2.31 mm) in plants subjected to the salicylic acid concentration of 1.9 mM in comparison to those cultivated under the concentration of 0 mM.

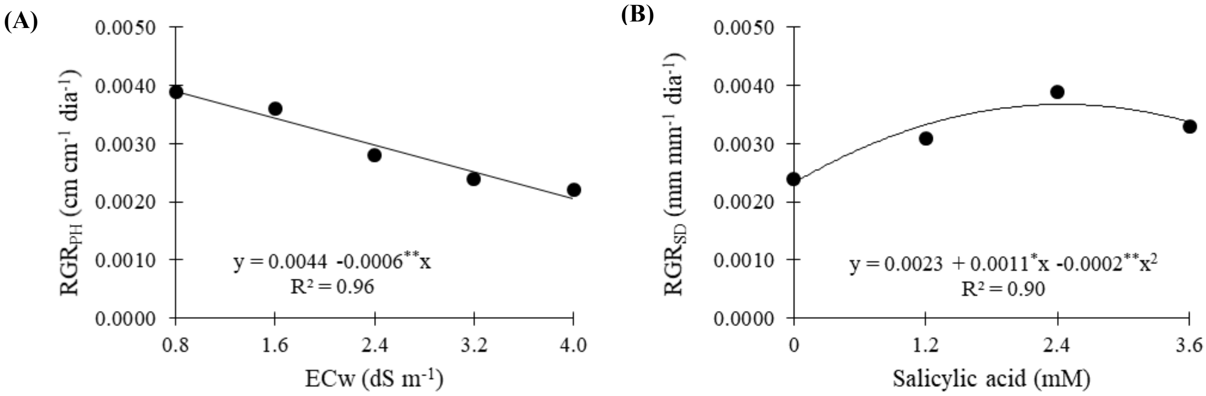
The greater growth in SD at 210 DAT up to the salicylic acid concentration of 1.9 mM (Figure 4D) is related to the regulatory effects on physiological and biochemical processes in plants, such as its ability to prevent the decrease in auxin and cytokinin levels, leading to a better cell division in the apical meristem of the root, thereby promoting plant growth (SHAKIROVA et al., 2003).

The increase in irrigation water salinity reduced the relative growth rate in plant height in the period from 210 to 270 DAT and, according to the regression equation (Figure 5A), there was a 13.64% reduction per unit increase in ECw. In relative terms, there was a reduction of 48.98% (0.0019 cm cm^{-1} day^{-1}) in the RGR_{PH} of plants irrigated with water of highest salinity (4.0 dS m^{-1}) in comparison to those cultivated with the lowest salinity level (0.8 dS m^{-1}).



*, ** - significant at $p \leq 0,05$ e $p \leq 0,01$, respectively.

Figure 4. Plant height - PH of soursop as a function of the interaction between water salinity - ECw and salicylic acid concentrations at 210 (A) and 270 (B) days after transplanting - DAT; stem diameter at 210 and 270 DAT - (C) and stem diameter at 210 DAT (D), respectively as a function of ECw and salicylic acid concentrations.



*, ** - significant at $p \leq 0,05$ e $p \leq 0,01$, respectively.

Figure 5. Relative growth rate of plant height - RGR_{PH} (A) of soursop, as a function of the electrical conductivity of irrigation water and relative growth rate of stem diameter – RGR_{SD} (B) as a function of salicylic acid concentrations, in the period from 210 to 270 days after transplantation.

The concentrations of salicylic acid promoted an increase in the relative growth rate of stem diameter (RGR_{SD}) of the soursop cv. 'Morada Nova' and, according to the regression equation (Figure 5B), plants subjected to a concentration of 2.75 mM stood out with the highest value of RGR_{SD} (0.0038 mm mm^{-1} day^{-1}). There was an increase of 39.47% (0.0015 mm mm^{-1} day^{-1}) in the RGR_{SD} of plants subjected to the salicylic acid concentration of 2.75 mM in comparison to plants subjected to the SA concentration of 0 mM.

The increase in the relative growth rate in stem diameter, observed in plants subjected to concentrations of up to 2.75 mM (Figure 4B), reflects the ability of salicylic acid to prevent the reduction of cytokinin and auxin, which stimulates cell division and consequently plant growth (ESTAJI; NIKNAM, 2020).

CONCLUSIONS

Irrigation with saline water compromises the growth and gas exchange of soursop cv. 'Morada Nova'. Exogenous application of salicylic acid induces tolerance to salt stress in soursop plants, as their relative growth in stem diameter, transpiration, stomatal conductance, photosynthesis and instantaneous carboxylation efficiency were favored by the application of salicylic acid, even when exposed to salinity.

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