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Cultivation of West Indian cherry irrigated with saline water under phosphorus and nitrogen proportions

Cultivo da aceroleira irrigada com água salina sob proporções de fósforo e nitrogênio

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Highlights:
Synergism between phosphorus and nitrogen in salt stress mitigation.
Increased phosphorus dose reduced sodium content in West Indian cherry leaves.
Increased phosphorus and nitrogen mitigate saline stress with water of 3.0 dS m^{-1}.

Abstract

The objective of this work was to evaluate the effect of water salinity and phosphorus:nitrogen ratios on growth, leaf macronutrients and sodium and the West Indian cherry production. The research was carried out in a protected environment, in lysimeters filled with a Regolithic Neosol of loamy clay texture and low initial phosphorus content. The experiment was carried out in a protected environment, in a randomized complete block design with treatments arranged in a 5 × 4 factorial scheme, with differing electrical conductivity levels of the irrigation water ECw (0.6, 1.4, 2.2, 3.0 and 3.8 dS m^{-1}) and four proportions of phosphorus and nitrogen P/N (100:100, 140:100, 100:140 and 140:140% of P/N), with three replicates and one plant per replicate. Phosphorus and nitrogen doses corresponding to 100% of the recommendation for phosphate and nitrogen fertilization were 45.0 g of P_2O_5 per plant year and 23.85 g of N per plant year, respectively. The West Indian cherry plants were maintained under irrigation with saline water for 365 days, where they were evaluated the growth characteristics, foliar mineral composition, and production. The increase of the salinity of irrigation water increases the levels of sodium in the tissues to levels detrimental to growth, foliar mineral composition and the production of the West Indian cherry. Fertilization with 140% of the phosphorus and nitrogen recommendation inhibits the action of saline stress, promoting greater production of West Indian cherry irrigated water plants with water up to 3.0 dS m^{-1}.
Key words: *Malphigia emarginata*. Mineral nutrition. Irrigation. Saline stress. Fertilization.

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Resumo

Objetivou-se com este trabalho avaliar o efeito da salinidade de água e proporções fósforo/nitrogênio sobre o crescimento, composição foliar de macronutrientes e sódio e a produção da aceroleira. A pesquisa foi realizada em ambiente protegido, em lisímetros preenchidos com Neossolo Regolítico de textura franco-argilosa e baixo teor inicial de fósforo. O experimento foi desenvolvido em ambiente protegido, em lisímetros com Neossolo Regolítico; o delineamento foi o de blocos casualizados com os tratamentos arranjados em esquema fatorial 5 x 4, referente aos níveis níveis de condutividade elétrica da água de irrigação - CEa (0,6; 1,4; 2,2; 3,0 e 3,8 dS m^{-1}) e quatro proporções percentuais de fósforo e nitrogênio P/N (100:100; 140:100; 100:140 e 140:140% P/N), com três repetições. As doses de fósforo e nitrogênio correspondentes a 100% da recomendação de adubação fosfatada e nitrogenada foram de 45,0 g de P_2O_5 planta ano^{-1} e 23,85 g de N planta ano^{-1}, respectivamente. As plantas de aceroleira foram conduzidas sob irrigação com água salina durante 365 dias, onde foram avaliadas quanto às características de crescimento, composição mineral foliar e produção. O aumento da salinidade da água de irrigação aumenta os teores de sódio nos tecidos a níveis prejudiciais ao crescimento, composição mineral foliar e produção da aceroleira. Adubação com 140% da recomendação de fósforo e de nitrogênio inibe a ação do estresse salino, promovendo maior produção das plantas de aceroleira irrigadas com água de até 3,0 dS m^{-1}.

Palavras-chave: *Malphigia emarginata*. Nutrição mineral. Irrigação. Estresse salino. Adubação.

Introduction

West Indian cherry (*Malpighia emarginata* DC.) is a tropical climate plant originating in northern South America, Central America and the Caribbean Islands, which is cultivated in Brazil, especially in its Northeast region, which has 64% of the national planted area (Adriano & Leonel, 2012). Among the fruits produced in Brazil, West Indian cherry has been gaining more and more space in the market, due to its high content of vitamin C (ascorbic acid), ranging from 695 to 4827 mg 100 mL^{-1} of pulp, and it is considered a product of high quality that stands out in the field of functional foods (Adriano, Leonel, & Evangelista, 2011; Calgaro & Braga, 2012).

West Indian cherry cultivation is significant in the semiarid region of northeastern Brazil, but its cultivation in the semiarid region is at risk due to water limitation, both in qualitative and quantitative aspects (Ayers & Westcot, 1985; Sá et al., 2017). In the regions where evapotranspiration exceeds rainfall, soil and irrigation water salinity is a major obstacle to the production system (Freire, Saraiva, Miranda, & Bruno, 2010; Souza, Nobre, Silva, Sousa, & Silva, 2015). Salinization of irrigated areas is often a consequence of the use of water of inadequate quality, associated with the management of the soil-water-plant system and the insufficiency of the drainage system (Silva et al., 2011).

In general, salt stress reduces the development and yields of vegetables, initially by osmotic effects, causing water deficit and subsequently by ionic effects, hampering the absorption of essential nutrients (Munns & Tester, 2008; Fageria, Gheyi & Moreira, 2011; Habibi & Amiri, 2013; Bezerra et al., 2018). The ionic interactions that affect the availability, absorption, and transport of nutrients are highly complex, regardless of salinity conditions. However, salinity adds an even greater level of complexity, affecting the activity of ions in solution and the processes of absorption, transport, assimilation and distribution (Neves et al., 2009; Silva et al., 2011).

Thus, in view of the numerous changes caused to plant development by salt stress, some management strategies have been studied over the years, such as the choice of tolerant species and varieties, the cyclic use and mixture of water sources with different salt concentrations, and fertilization management, which is one of the main technologies used to increase crop yield and profitability (Lacerda et al., 2009; Lima et al., 2015).

Most studies related to fertilization in saline environments are conducted with nitrogen, a macronutrient required in greater quantity by agricultural crops, due to its functions in plant metabolism, participating in the formation of protein, amino acids and other important compounds of plant metabolism (Marinho et al., 2010; Taiz, Zeiger, Møller, & Murphy, 2017). Recently, some studies have reported the benefits of phosphate fertilization in plants grown in saline media; despite being required in smaller amounts than nitrogen, phosphorus acts in different metabolic and structural functions, including photosynthesis, a vital mechanism for plant survival (Taiz et al., 2017; Sá et al., 2017).

Nonetheless, despite the significance of studies on fertilization management to mitigate the effects of salt stress on crops, studies quantifying the extraction of soil nutrients by plants under salt stress are scarce in the literature, especially those assessing the joint action of more than one nutrient (Neves et al., 2009; Sá et al., 2017). Thus, the objective of this study was to evaluate the effect of water salinity and phosphorus/nitrogen combination on West Indian cherry growth, macronutrient contents, sodium contents in leaf tissues, and production.

Material and Methods

The experiment was carried out in a greenhouse of the Center of Technology and Natural Resources (CTRN) of the Federal University of Campina Grande (UFCG), located in the municipality of Campina Grande, Paraíba-PB, Brazil, with the geographic coordinates 7° 15’ 18” South latitude, 35° 52’ 28” West longitude and an average altitude of 550 m.

The experiment was installed in a randomized block design with treatments arranged in a 5 × 4 factorial scheme with five levels of irrigation water electrical conductivity-ECw (0.6, 1.4, 2.2, 3.0 and 3.8 dS m^{-1}) and four percentage proportions of phosphorus and nitrogen-P/N M1 - 100:100, M2 - 140:100, M3 - 100:140 and M4 - 140:140% P/N, with three replicates and one plant per plot. The 100% phosphate fertilizer (45.0 g of P_2O_5 per plant per year) and nitrogen (23.85 g of N per plant per year) applications were based on the recommendations of Musser (1955).

The soil material used to fill the lysimeters was a *Regolític Neossol* (Entisol) with a clay loam texture (0-30 cm depth), from the municipality of Esperança-PB. Its chemical and physical attributes were determined according to the methodologies described in Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA] (2009), and these attributes are presented in Table 1.

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

Chemical characteristics									
pH H_2O 1:2.5	OM dag kg^{-1}	P mg kg^{-1}	K^+	Na^+	Ca^{2+}	Mg^{2+}	$H^+ + Al^{3+}$	ESP	ECse
			......................................$cmol_c$ kg^{-1}...................................					%	dS m^{-1}
5.63	1.830	18.20	0.21	0.17	3.49	2.99	5.81	1.34	0.61
Physical characteristics									
Particle-size fractions (g kg^{-1})			Textural Class	Moisture (kPa)		AW	Total porosity	BD	PD
Sand	Silt	Clay		33.42	1519.5 dag kg^{-1}	....	m^3 m^{-3}	------kg dm^{-3}----	
573	101	326	CL	12.68	4.98	7.70	0.5735	1.13	2.65

OM – Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1 mol L^{-1} KCl pH 7.0; Na^+ and K^+ extracted with 1 mol L^{-1} NH_4OAc pH 7.0; Al^{3+} and (H^++ Al^{3+}) extracted with 1 mol L^{-1} CaOAc pH 7.0; ESP – Exchangeable sodium percentage; ECse – electrical conductivity of the soil saturation extract; CL – Clay Loam; AW – Available water; BD – Bulk density; DP – Particle density.

West Indian cherry plants were grown in lysimeters filled with 235 kg of soil. Each lysimeter had two 18-mm-diameter drains spaced equidistantly at the ends, and on each drain, there was a geotextile (Bidim type) and a 0.5-kg layer of crushed stone. Drainage water was collected with two 2-L PET bottles placed below each lysimeter, and the value of drainage was computed and used in the water balance of the crop.

Seedlings of the West Indian cherry cultivar 'BRS 366-Jaburu' cleft grafted on rootstock rootstock from the Seed Garden of EMBRAPA Tropical Agroindustry, Pacajus CE, were used in the experiment. Grafted seedlings were acquired at the age of 240 days (150 days of rootstock + 90 days of grafting) after and during sowing, they were irrigated with low-salinity water (0.6 dS m^{-1}), and transplanted to lysimeters. After transplanting, the seedlings were acclimatized for a period of 30 days before the salinity treatments began to be applied.

The waters with lower electrical conductivity (ECw) (0.6 and 1.4 dS m^{-1}) were obtained by the dilution of water from the municipal supply (ECw = 1.78 dS m^{-1}) with rainwater (0.04 dS m^{-1}), whereas the waters with the other ECw levels (2.2; 3.0 and 3.8 dS m^{-1}) were prepared by the addition of salts (NaCl, $CaCl_2 \cdot 2H_2O$ and $MgCl_2 \cdot 6H_2O$) to the public-supply water, in the proportion equivalent to 7:2:1 of Na, Ca and Mg ions, respectively. This ratio represents the average composition of the contents of ions present in the waters used for irrigation in the semi-arid region of northeastern Brazil (Medeiros, Lisboa, Oliveira, Silva, & Alves, 2003).

Irrigation with the different levels of water electrical conductivity was performed at three-day intervals, applying in each lysimeter a volume of water in order to keep soil moisture close to its ideal water retention capacity in the soil (33.42 kPa). Each irrigation event applied the volume of water determined to meet the water requirements of the plants, through water balance in the root zone, which was obtained by the difference between the volume applied and volume drained that was calculated every 30 days. In order to avoid the excessive accumulation of salts in the root zone, a leaching fraction of 0.10 was applied every 30 days (Ayers & Westcot, 1985).

Fertilizations with P and N were performed according to the previously established treatments, using single superphosphate (18% P_2O_5, 18% Ca^{2+}, 12% S) as a source of phosphorus and urea (45% N) as source of nitrogen, based on the recommendation of Musser (1995), and also adding 19.8 g of K_2O per plant per year as potassium chloride (60% K_2O). Regarding fertilization, 250 and 350 g of single superphosphate were applied prior to planting in the treatments of 100 and 140% P, respectively. Nitrogen fertilization was split into 24 equal portions, applied at 15-day intervals along the year, with applications of 2.21 g of urea per plant in the treatment of 100% and 3.09 g of urea per plant in the treatment of 140%, diluted in 100 mL of rainwater (0.04 dS m^{-1}). Potassium fertilization was split into 12 equal portions and monthly applied along the year, at a dose of 2.75 g of KCl per plant, diluted in 100 mL of rainwater (0.04 dS m^{-1}). Fertilization management (N and P) began concomitantly with the transplanting of seedlings to the lysimeters. From the beginning of flowering until the end of the first year of cultivation, the plants received weekly fertilization with micronutrients, using a volume of 15 liters for the entire stand (60 plants) in the proportion of 0.5 g L^{-1}, and the source was the Quimifol Nutri foliar fertilizer, which has 25% potassium (K_2O), 2.5% magnesium, 6.0% sulfur, 2.0% boron, 0.5% copper, 0.3% molybdenum and 5.0% zinc. During the experiment, the cultivation and phytosanitary practices recommended for crop were carried out, by monitoring the emergence of pests and diseases and adopting control measures when necessary.

To analyze the growth of West Indian cherry plants, the diameters of rootstocks and scions were measured at 285 days after the application of salinity levels. Rootstock stem diameter (mm) was measured at 2 cm from the soil and scion stem diameter was measured at 2 cm above the grafting point.

In the same period, that is, at 285 days after irrigation with the salinity levels, which corresponded to the transition between flowering and fruiting stages, leaf samples of West Indian cherry plants were collected, placed in paper bags and dried in an air circulation oven at 65 °C until constant weight. After drying, the material was crushed in a Wiley-type knife mill and subsequently analyzed for nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg) and sodium (Na) contents, following the methodology contained in EMBRAPA (2009) with data expressed in g kg^{-1} of DM. After obtaining the data, the ratios of these ions with sodium ions (Na/N; Na/K; Na/P; Na/Ca and Na/Mg) were determined.

In order to evaluate the production of West Indian cherry plants during the first year of cultivation, all fruits produced by each plant were monitored, harvested individually, and weighed on an analytical scale with precision of 0.0001 g, determining the production per plant (data expressed in grams).

The obtained data were subjected to analysis of variance by F test, and the means of the P/N proportions were compared by Tukey test ($p < 0.05$), whereas those related to the interaction between water salinity and P/N proportions and those related to the single effects of water salinity were compared by regression, using the program Sisvar version 5.1 (Ferreira, 2011).

Results and Discussion

The interaction between water salinity and P/N proportions had significant effects on leaf contents of phosphorus and calcium, on Na/P ratios and on the production per plant (Table 2). There was an isolated effect of water salinity on rootstock and scion stem diameters, sodium content and the Na/N, Na/K, Na/Ca, and Na/Mg ratios in the leaves. The P/N proportions caused an isolated effect on the sodium leaf contents and Na/N ratios in the leaves. Regarding the leaf contents of nitrogen, potassium, and magnesium, there were no significant influences of the sources of variation studied or the interaction between both.

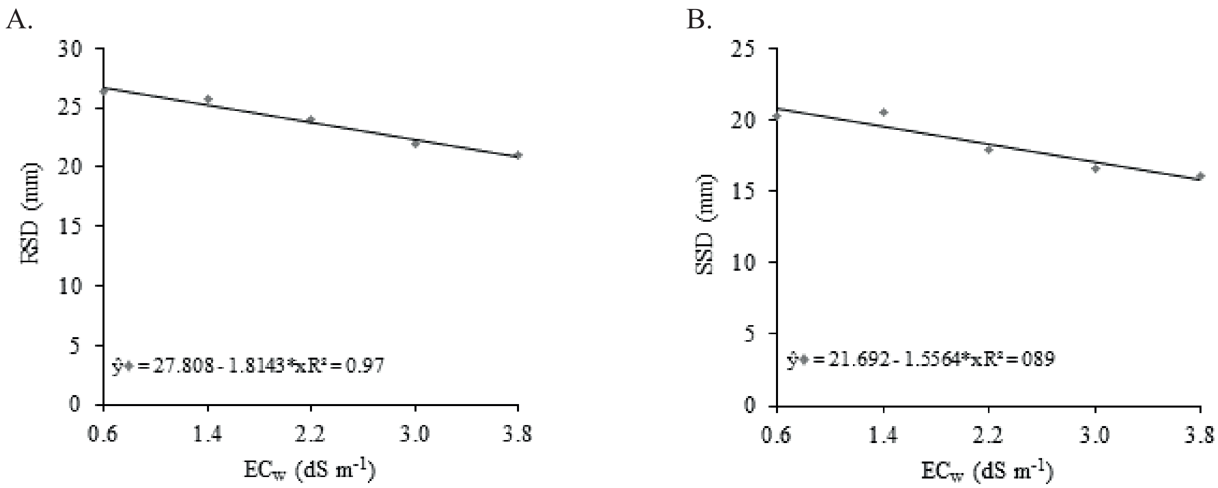
As irrigation water salinity increased, rootstock and scion stem diameters were linearly reduced by 21.74 and 21.38% between plants grown under the highest (3.8 dS m^{-1}) and lowest (0.6 dS m^{-1}) levels of irrigation water salinity (Figures 1A and B). Reduction in the growth of fruit crops under salt stress conditions have also been observed by Brito et al. (2017) and Bezerra et al. (2018) in citrus rootstocks and guava plants, respectively. These authors attribute such reduction in plant growth to the increase of salinity in the root zone, through successive irrigations, which increase soil salinity. The excess of NaCl salts in the root zone enhances the absorption and compartmentalization of these salts in the mesophyll, through competitive inhibition and toxicity by specific ions, triggering a series of physiological and nutritional disorders (Munns & Tester, 2008; Syvertsen & Garcia-Sanchez, 2014), which limited the growth of West Indian cherry plants.

Although not significant, the average contents of nitrogen, potassium, and magnesium equal to 20.73, 12.84 and 4.11 g kg^{-1} of leaf dry mass are consistent with the average contents observed by Lima (2008) when evaluating the mineral nutrition of West Indian cherry progenies in different times of the year. This author obtained ranges of 21.8-30.5 g kg^{-1} of DM for nitrogen, 9.3-29.9 g kg^{-1} of DM for potassium and 3.7-5.1 g kg^{-1} of DM for magnesium in 2.5-year-old plants.

Table 2
Summary of analyses of variance, by F test, for rootstock stem diameter (RSD), scion stem diameter (SSD), contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na), sodium/nitrogen (Na/N), sodium/phosphorus (Na/P), sodium/potassium (Na/K), sodium/calcium (Na/Ca) and sodium/magnesium (Na/Mg) ratios in the leaves at 285 days after application of treatments, and production per West Indian cherry plant irrigated with saline water and fertilized with different phosphorus/nitrogen proportions at 365 days after application of the treatments

SV	DF	F test significance						
		RSD	SSD	N	P	K	Ca	Mg
		--------mm-----		------------------------g kg^{-1} of DM--------------------------				
Block	2	*	ns	ns	*	ns	*	ns
Sal	4	*	*	ns	*	ns	*	ns
Manag.	3	ns	ns	ns	*	ns	*	ns
Sal x Manag.	12	ns	ns	ns	*	ns	*	ns
CV (%)		14.30	16.81	10.56	18.54	20.31	15.12	16.44
Overall mean		23.81	18.27	20.73	1.67	12.84	18.59	4.11
SV	DF	F test significance						
		Na	Na/N	Na/P	Na/K	Na/Ca	Na/Mg	P/P
		g kg^{-1} of DM						---g--
Block	2	ns	ns	ns	ns	ns	ns	ns
Sal	4	*	*	*	*	*	*	*
Manag.	3	*	*	*	ns	ns	ns	*
Sal x Manag.	12	ns	ns	*	ns	ns	ns	*
CV (%)		17.02	22.25	24.79	30.94	20.83	25.43	20.15
Overall mean		16.28	0.79	10.62	1.29	0.92	4.07	414.89

*Significant at 0.05 probability level; ns – Not significant; Sal – Salinity levels; Manag. – Variations in the proportions of P/N fertilization; CV – Coefficient of variation; SV – Sources of variation; DF – Degrees of freedom.



* = Significant at 0.05 probability level.

Figure 1. Rootstock stem diameter - RSD (A) and scion stem diameter - SSD (B) of West Indian cherry plants irrigated with saline water and fertilized with phosphorus and nitrogen proportions at 285 days after application of the salinity levels.

The phosphorus contents in the leaves of West Indian cherry plants fertilized with 100:100% of the P/N recommendation were reduced by 0.227 g kg^{-1} per unit increase in irrigation water salinity (Figure 2A). No regression model fitted the data relative to the P/N proportions of 140:100%, 100:140%, and 140:140%, and the mean phosphorus contents were equal to 1.74, 1.65, and 1.83 g kg^{-1} (Figure 2A). Thus, it was found that the contents of these nutrients were not influenced by increased salinity in plants that received 40% more phosphorus and/or nitrogen (Figure 2A). However, plants that received only the recommended doses of P and N had reduced phosphorus contents in the leaves as water salinity increased. Considering that phosphorus has more complexities in terms of its availability, movement in soil solution, and interception and absorption by the plant, compared to nitrogen (Epstein & Bloom, 2006; Taiz et al., 2017), the osmotic and ionic restriction caused by excess salts in the root zone directly affected its absorption by West Indian cherry plants. However, with supplementary fertilization of this nutrient, the effects of salt stress on its absorption and assimilation are minimized, and there are positive effects on production.

The mean contents of phosphorus obtained in the present experiment are consistent with the average contents observed in different West Indian cherry progenies by Lima (2008), who found a variation from 1.27 to 2.03 g of phosphorus kg^{-1} of leaf dry mass, in 2.5-year-old plants.

The calcium contents of West Indian cherry plants in the treatments 100:100% P/N and M3-100:140% P/N showed a quadratic behavior as a function of the increase in irrigation water salinity, with the highest contents observed at salinity levels of 1.77 and 1.97 dS m^{-1}. In the treatments 140:140% P/N, there was a linear reduction as a function of the increase in water salinity, with unit reduction of 1.56 g kg^{-1} of leaf dry mass (Figure 2B). In the treatment 140:100% P/N, there was no significant fit and the mean value was equal to 17.23 g kg^{-1} of leaf dry mass (Figure 2B). It is worth noting that from 2.2 dS m^{-1}, calcium contents are reduced as a function of increased water salinity, coinciding with the increase in sodium contents (Figure 2C), which indicates that the sodium concentration in the medium exceeds the contents of calcium, compromising its absorption through ionic competition, which affects the ionic homeostasis of plants.

The calcium contents observed in the present study were higher than those that were found by R. L. S. Lima (2008), when evaluating the mineral nutrition of West Indian cherry progenies in different times of the year. The author observed a variation from 3.6 to 9.8 g kg^{-1} of calcium in leaf dry mass, while in the present study, calcium contents ranged from 17 to 22 g kg^{-1} of leaf dry mass. This fact can be explained by the application of calcium both via irrigation water and via phosphate fertilizer.

With the increase in the salinity of irrigation waters, the sodium contents in the leaves increased by 5.37 g kg^{-1} per unit increase in water electrical conductivity (Figure 2C). The highest sodium contents in West Indian cherry leaf tissues were observed in plants under the fertilization management M1 (100:100% P/N) (Figure 2D). In general, with the increase in phosphate and/or nitrogen fertilization, there was a reduction in sodium contents in leaf tissues compared to the control treatment (M1), but the results were more significant in plants under the fertilization management M2 (140:100% P/N), which had 17.56% less sodium in the leaf tissues (Figure 2D). The increase in phosphorus and nitrogen doses stimulates the synthesis and, consequently, greater supply of organic solutes and greater energy availability, allowing the plant to increase its selectivity in the absorption of beneficial ions and exclude toxic ions, favoring ionic homeostasis (Gupta & Huag, 2014).

Irrigation with saline water in West Indian cherry plants caused these plants to absorb high concentrations of sodium, which explains the high contents of these ions in leaf tissues (Figure 2C).

There were increments in the contents of sodium, compared to the other ions, on the order of 98.19% in the sodium/nitrogen ratio, 43.49% in the sodium/potassium ratio, 65.25% in the sodium/calcium ratio, and 58.24% in the sodium/magnesium ratio, per unit increase in irrigation water salinity (Figures 3 A, D, E and F).

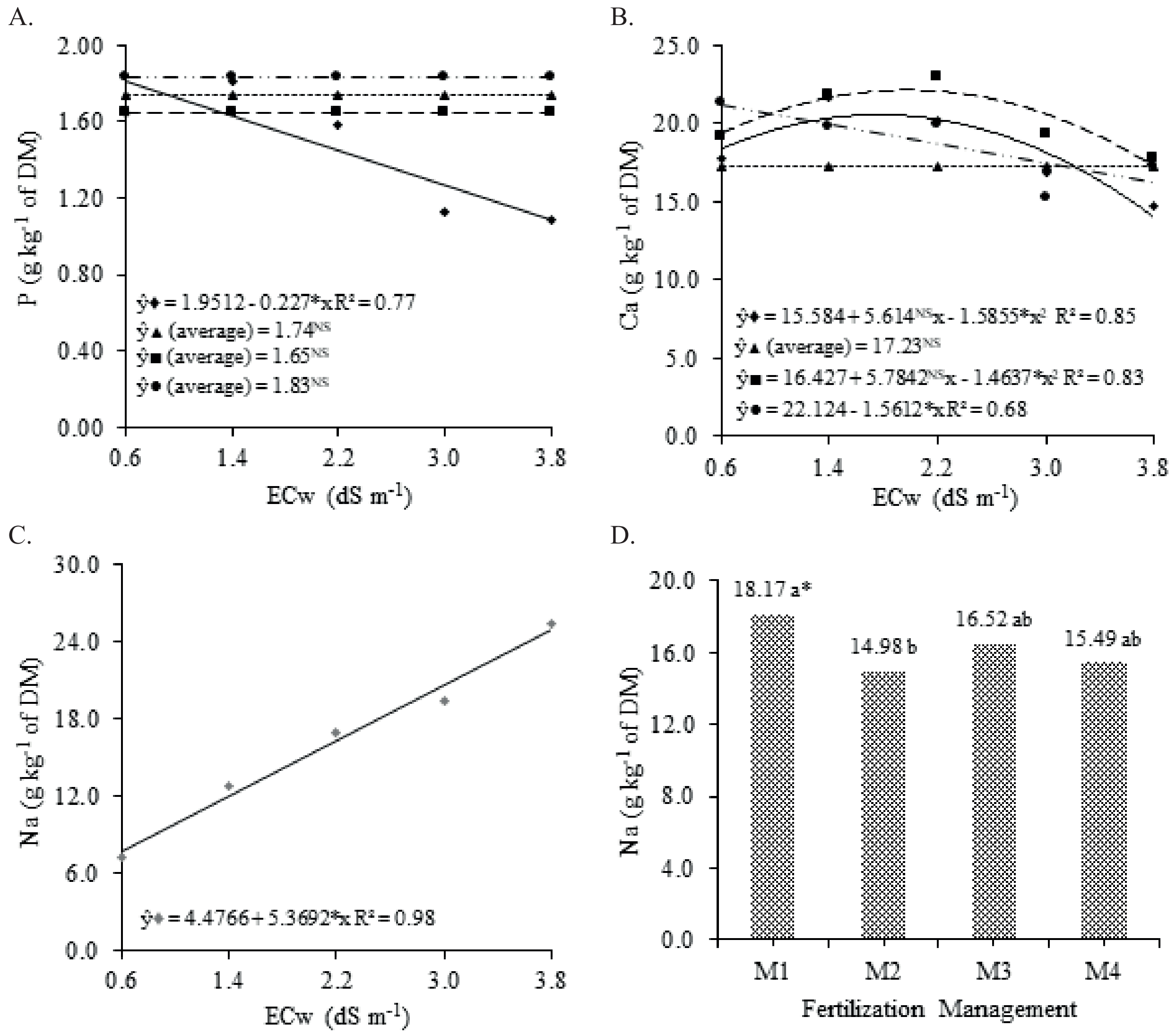
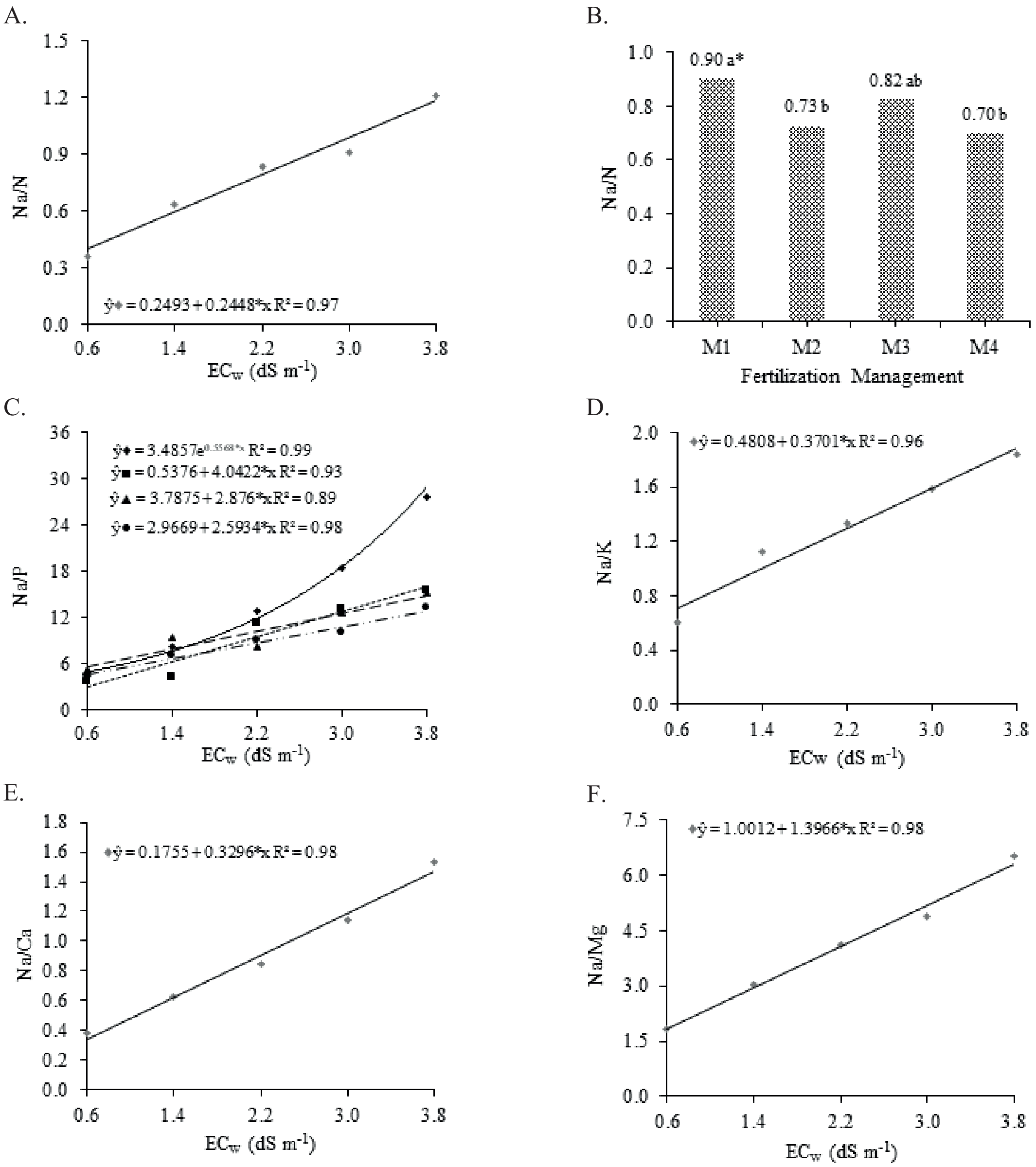


Figure 2. Contents of phosphorus-P (A), calcium-Ca (B) and sodium-Na (C and D) in the leaves of West Indian cherry plants irrigated with saline water and fertilized with phosphorus and nitrogen proportions at 285 days after application of the salinity levels.

Regarding the sodium/nitrogen ratio, it was found that plants under the M1 management had the highest values compared to the others, which may be related to the alteration in their ionic homeostasis, due to the effects of salt stress (Figure 3B). This behavior is also observed in the sodium/phosphorus ratio, and plants under the M1 management showed a different trend from that of the other treatments, indicating an excessive increase in sodium content and/or a marked reduction in phosphorus content from the level of 2.2 dS m^{-1} (Figure 3C).

Salt stress reduces the development and yield of vegetables, initially by osmotic effects, causing water deficits and, subsequently, by ionic effects, hampering the balance of absorption of essential nutrients (Munns & Tester, 2008; Habibi & Amiri, 2013; Bezerra et al., 2018). These interactions affect the availability, absorption and transport of nutrients, besides being highly complex, regardless of salinity conditions (Gupta & Huag, 2014). However, salinity adds an even greater level of complexity, affecting the activity of ions in solution and the processes of absorption, transport, assimilation and distribution (Neves et al., 2009; Silva et al., 2011).

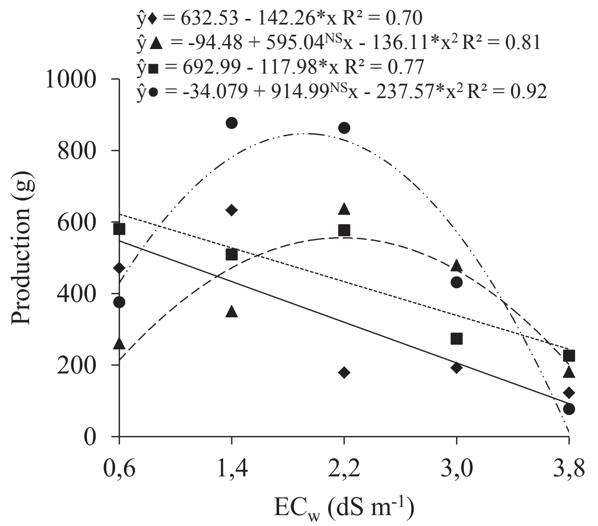


♦M1-100:100% P/N; ▲M2-140:100% P/N; ■M3-100:140% P/N and ●M4-140:140% P/N
* and NS = Significant at 0.05 probability level and not significant, respectively. Equal letters do not differ from Tukey's test at 5% probability.

Figure 3. Ratios between sodium and nitrogen, Na/N (A and B), sodium and phosphorus, Na/P (C), sodium and potassium, Na/K (D), sodium and calcium, Na/Ca (E) and sodium and magnesium, Na/Mg (F) in the leaves of West Indian cherry plants irrigated with saline water and fertilized with phosphorus and nitrogen proportions at 285 days after application of salinity levels.

Although it has no essential function to the metabolism of C3 plants, sodium is absorbed in large quantities when plants are irrigated with high-salinity water, due to the concentration of this ion in the root zone, and because it has an ionic radius similar to that of potassium, thus it passes freely through the ionic channels present in root cells. Such easy penetration into plant cells allows the concentration of this element to be raised in plant tissues to very high levels, which influences the absorption of other nutrients (Figure 3A, B, C, D, E, and F). Therefore, plants need to adopt mechanisms of tolerance to excess salts, such as compartmentalization in vacuoles and exclusion of these ions, which triggers an expenditure of energy that negatively affects their growth and, consequently, production.

In terms of production, the interaction between salinity levels and fertilization managements had an effect on fruit biomass (Table 2). In plants fertilized with the recommended levels of phosphate and nitrogen (M1 = 100:100% P/N) and in plants that received only increments of nitrogen (M3 = 100:140% P/N), fruit production decreased linearly by 22.49 and 17.02% per unit increase in the salinity of irrigation water, respectively (Figure 4).



♦M1-100:100% P/N; ▲M2-140:100% P/N; ■M3-100:140% P/N and ●M4-140:140% P/N

* and ^{NS} = Significant at 0.05 probability level and not significant, respectively.

Figure 4. Production per West Indian cherry plant irrigated with saline water and fertilized with phosphorus and nitrogen proportions at 365 days after application of the salinity levels.

Although both fertilization managements caused linear reductions, plants under the M1 management showed lower means than those under M3, besides having higher unit reductions (Figure 4). The reduction observed in the production of West Indian cherry plants cultivated under the M1 management corroborates the decrease of phosphorus contents in their leaves and the higher sodium contents observed in this treatment, indicating greater sensitivity of these plants to salt stress (Figures 2 and 3D).

In West Indian cherry plants that received an increase in phosphate fertilization (140:100% P/N) and joint increase of phosphorus and nitrogen (140:140% P/N), a quadratic behavior was observed in the production, with the highest means obtained at the estimated salinity levels of 2.19 and 1.93

dS m^{-1}, respectively (Figure 4). Plants under the managements 140:100% P/N and 140:140% P/N showed the highest phosphorus contents in the leaves, as well as the lowest sodium contents and lowest sodium/nitrogen ratios, which indicates that these plants were less affected by the effects of salt stress, resulting in higher production (Figures 2A and D and 3B).

The production of plants under M2 and M4 managements irrigated with saline water of up to 3.0 dS m^{-1} was satisfactory when compared to those irrigated with 0.6 dS m^{-1} water. It is important to highlight that, with the joint increase in N and P doses, the production was higher than in treatments that received a single increment of N and P. Therefore, there is likely synergistic action between phosphorus and nitrogen on the production of West Indian cherry, and the increase in phosphate fertilization enhances, in a more pronounced manner, the effects of nitrogen fertilization on West Indian cherry plants under salt stress.

Conclusions

Irrigation with saline water increases the sodium contents in leaf tissues to levels that are harmful to West Indian cherry growth, nutrition, and production.

Fertilization with 140% phosphorus and nitrogen reduces effects of salt stress, and promotes higher production in West Indian cherry plants irrigated with water up to 3.0 dS m^{-1}.

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