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# MORPHOLOGY AND PRODUCTION OF WEST INDIAN CHERRY IRRIGATED WITH SALINE WATERS UNDER COMBINATIONS OF NITROGEN-POTASSIUM FERTILIZATION[1]

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**ABSTRACT** - Fertilization management is one of the technologies studied to reduce nutritional imbalance in plants submitted to saline stress. In this context, we analyzed the effect of the combination of nitrogen and potassium fertilization on the morphology and production of West Indian cherry irrigated with saline waters in the first year of cultivation. The experiment was carried out in the CCTA/UFCG, in 60-L lysimeters installed in the field, in a randomized block design and 5 x 4 factorial scheme, referring to five levels of irrigation water salinity (ECw), i.e., 0.3, 1.3, 2.3, 3.3, and 4.3 dS $m^{-1}$, and four combinations (C) of nitrogen-potassium fertilization, i.e., C1 = 70% N + 50% $K_2O$; C2 = 100% N + 75% $K_2O$; C3 = 130% N + 100% $K_2O$, and C4 = 160% N + 125% $K_2O$ of the recommended dose for West Indian cherry, with three replicates and one plant per plot consisting of a lysimeter. The cv. 'Flor Branca', grafted on cv. Junco, was studied. The combination of fertilization with 70% N + 50% $K_2O$ promoted higher morphology and production values and mitigated the effect of salinity on fruit diameter up to an ECw of 1.3 dS $m^{-1}$. Nitrogen-potassium fertilization in the combination of 130% N + 100% $K_2O$ impaired plant morphology and production. The ECw above 0.3 dS $m^{-1}$ decreased the stem diameter, size, and average weight of fruits of West Indian cherry in the first year of cultivation.

**Keywords**: *Malpighia emarginata* D. C. Salinity. Mineral fertilizer.

## MORFOLOGIA E PRODUÇÃO DE ACEROLEIRA IRRIGADA COM ÁGUAS SALINAS SOB COMBINAÇÕES DE ADUBAÇÃO NITROGENADA-POTÁSSICA

**RESUMO -** O manejo da adubação tem sido uma das tecnologias estudadas no propósito de diminuir o desequilíbrio nutricional nas plantas submetidas ao estresse salino. Neste sentido, objetivou-se com a pesquisa, analisar o efeito da combinação de adubação nitrogenada e potássica sobre a morfologia e produção da aceroleira irrigada com águas salinas no primeiro ano de cultivo. O experimento foi conduzido no CCTA/UFCG, em lisímetros de 60 L instalados em campo, em delineamento de blocos ao acaso e esquema fatorial 5 x 4, referentes a cinco níveis de salinidade da água de irrigação (CEa): 0,3; 1,3; 2,3; 3,3 e 4,3 dS $m^{-1}$ e quatro combinações (C) de adubação nitrogenada-potássica: C1 = 70% N + 50% $K_2O$; C2 = 100% N + 75% $K_2O$; C3 = 130% N + 100% $K_2O$ e C4 = 160% N + 125% $K_2O$ da dose recomendada para aceroleira, com três repetições e uma planta por parcela constituída de um lisímetro. Estudou-se a cv. Flor Branca enxertada sobre porta-enxerto da cv. Junco. A combinação de adubação com 70% N + 50% $K_2O$ promoveu maiores valores das variáveis morfológicas e de produção e, mitigou o efeito da salinidade sobre diâmetro de fruto até a CEa de 1,3 dS $m^{-1}$. A adubação nitrogenada-potássica a partir da combinação de 130% N + 100% $K_2O$ prejudicaram a morfologia e a produção das plantas. A CEa acima de 0,3 dS $m^{-1}$ diminuiu o diâmetro de caule, o tamanho e peso médio de frutos da aceroleira no primeiro ano de cultivo.

**Palavras-chave**: *Malpighia emarginata* D. C. Salinidade. Adubação mineral.

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# INTRODUCTION

The West Indian cherry (*Malpighia emarginata* D. C.) is a tropical fruit plant that found favorable edaphoclimatic conditions for cultivation in the Northeast and Southeast regions of Brazil. In Brazil, the estimated area cultivated with *M. emarginata* is 5,000 hectares, with the northeastern region being the largest producer, particularly the sub-middle São Francisco Valley, which accounts for approximately 20% of the planted area in the country (SOUZA et al., 2017).

Among the main factors facilitating the planting of irrigated orchards of West Indian cherry is the growing demand for products in domestic and external markets due to the high contents of vitamin C in its fruits, the early production, the possibility of several harvests in an year, and few pests and diseases (CALGARO; BRAGA, 2012).

Despite that, reduced water amounts and salinization of irrigation water have become limiting factors in the semiarid region of Northeast Brazil (HOLANDA et al., 2016), considering that 53.20% of the water sources (reservoirs, dams, and wells) have a salinity above 3.0 dS $m^{-1}$, with severe restriction for irrigation (MORAIS; MAIA; OLIVEIRA, 1998).

Excess salts in water and soil lead to osmotic effects, toxic effects, and nutritional imbalance in plants (MUNNS; TESTER, 2008), which have been observed in West Indian cherry, resulting in decreased photosynthetic efficiency, growth, and production under irrigation with water of electrical conductivity higher than 2.2 dS $m^{-1}$ (SÁ et al., 2019). Thus, it is necessary to seek strategies that allow saline water to be used in irrigation, such as fertilization managements, aiming to counterweight the nutritional imbalance caused by deficiencies of $Ca^{2+}$, $Mg^{2+}$, $K^+$, $NO_3^-$, and $H_2PO_4^-$, induced by the excess of $Na^+$ and $Cl^-$ in irrigation water (SÁ et al., 2019; LIMA et al., 2019).

Combining adequate doses of nitrogen and potassium can contribute to maintaining low $Na^+/K^+$ and $Cl^-/NO_3^-$ ratios in plant tissues, reducing the nutritional imbalance and the osmotic effect caused by salinity, thereby increasing the tolerance of plants to salt stress (GURGEL; GHEYI; OLIVEIRA, 2010; ANDRADE JÚNIOR et al., 2011).

An adequate N concentration in plant tissue may contribute to a greater synthesis of low-molecular-weight compounds, such as glycine betaine and proline, which act as osmoprotectants of membranes and macromolecules and might play a role in osmotic adjustment to salinity (ASHRAF et al., 2018). On the other hand, K can minimize the effects of salinity, promoting the control of cell turgor, the regulation of stomatal conductance, and the activation of enzymes (ALMEIDA; OLIVEIRA; SAIBO, 2017).

Lima et al. (2019) found that a 25% increase in potassium fertilization mitigated the deleterious effects of ECw levels of 0.8 and 3.8 dS $m^{-1}$ on stem diameter, fruit number, and fruit mass of 'BRS Jaburu' West Indian cherry. Similarly, Sá et al. (2019) observed mitigation of the effects of salt stress between ECw levels of 2.2 and 3.8 dS $m^{-1}$ on the photosynthetic activity, growth, and production of this crop with increments of 40% of N and P in comparison to the recommended dose in the first year of cultivation.

In relation to the combination of nitrogen and potassium, studies analyzing its effect on West Indian cherry plants irrigated with saline water are incipient. Thus, the present study aimed to analyze the effect of the combination of nitrogen and potassium fertilization on the morphology and production of West Indian cherry irrigated with saline waters in the first year of cultivation.

# MATERIAL AND METHODS

The experiment was conducted between April 19, 2017 and March 20, 2018, under field conditions, in the experimental area of the Center of Science and Agri-Food Technology (CCTA) of the Federal University of Campina Grande (UFCG), Pombal, Paraiba, Brazil. The experimental area is georeferenced with the geographic coordinates of 6º 48' 16" South latitude, 37º 49' 15" West longitude, at an elevation of 144 m. The meteorological data obtained by INMET (2018) are presented in Figure 1.

The treatments were arranged in a 5 × 4 factorial scheme, referring to five levels of irrigation water electrical conductivity (ECw), namely 0.3, 1.3, 2.3, 3.3, and 4.3 dS $m^{-1}$, and four combinations (C) of nitrogen (N) and potassium ($K_2O$), namely C1 = 70% N + 50% $K_2O$; C2 = 100% N + 75% $K_2O$; C3 = 130% N + 100% $K_2O$, and C4 = 160% N + 125% $K_2O$ of the recommended dose for West Indian cherry (CAVALCANTI, 2008), in randomized blocks with three replicates and one plant per plot, cultivated in a lysimeter with a capacity of 60 L.

The salinity levels were based on the study conducted by Sá et al. (2019), who found that irrigation with water salinity of up to 2.2 dS $m^{-1}$ and application of 10% leaching fraction did not compromise the growth, photosynthetic activity, and production of the West Indian cherry cv. 'BRS 336 Jaburu' in the first year, cultivated in medium-textured Entisol.

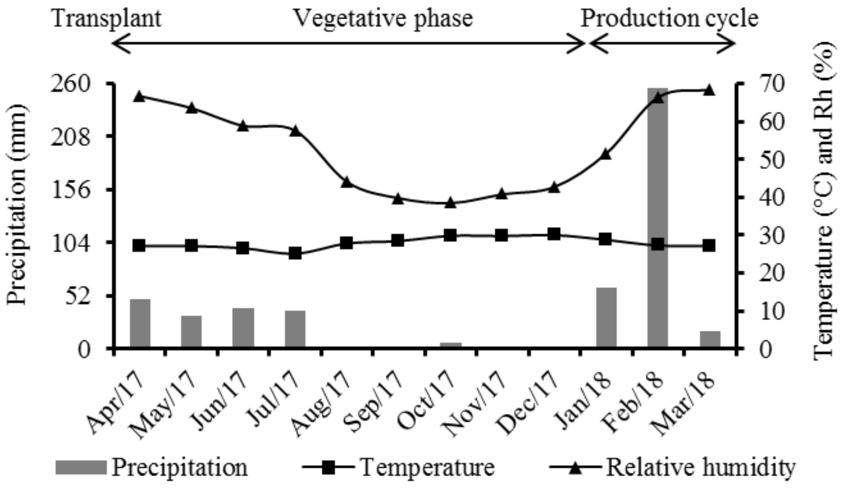



**Figure 1**. Mean data of precipitation, temperature and relative humidity (Rh) throughout the experimental period.

The saline waters of the treatments from 1.3 to 4.3 dS $m^{-1}$ were prepared by following the relationship between ECw, concentration of salts ($mmol_c$ $L^{-1}$ = 10 x ECw), and the gram equivalent of the salts NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$, added in the equivalent proportion of 7:2:1, respectively, to the water of the treatment of lowest salinity (0.3 dS $m^{-1}$), which came from a water reservoir for irrigation of crops in the region. This proportion of salts prevails in most of the sources of water used in irrigation in Northeast Brazil (SILVA JUNIOR; GHEYI; MEDEIROS, 1999).

The recommendation of fertilization for the West Indian cherry cultivar 'Flor Branca', cultivated under irrigated conditions, is 100 g of N and 80 g of $K_2O$ $plant^{-1}$ $year^{-1}$ (CAVALCANTI, 2008), equivalent to the doses of the treatments with 100% N and K. Based on this recommendation, the $K_2O$ dose was determined according to the availability of K in the soil used in the experiment, after chemical and physical analysis performed in the Irrigation and Salinity Laboratory of the Center of Technology and Natural Resources (CTRN) of UFCG (Table 1).

**Table 1**. Physical and chemical attributes of the soil used in the experiment, collected from the 0-0.20-m layer in Lot 14, Sector I, of the Irrigated Perimeter of Várzeas de Sousa-PB, Brazil.

| Textural Class | Ad | Tp | O.M | N | P assimilable | Exchangeable complex | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $H^{+}+Al^{3+}$ |
| | (kg $dm^{-3}$) | -------- (%) ------- | | | (mg $dm^{-3}$) | ---------------- ($cmol_c$ $dm^{-3}$) ---------------- | | | | |
| SL | 1.44 | 47.63 | 0.41 | 0.02 | 41.00 | 3.50 | 1.70 | 0.14 | 0.30 | 0.00 |
| Saturation extract | | | | | | | | | | |
| pHse | ECse | $Ca^{2+}$ | $Mg^{2+}$ | $K^{+}$ | $Na^{+}$ | $Cl^{-}$ | $SO_4^{2-}$ | $CO_3^{2-}$ | $HCO_3^{-}$ | SM |
| | (dS $m^{-1}$) | -------------------------- ($mmol_c$ L) ---------------------------- | | | | | | | | (%) |
| 7.11 | 1.28 | 1.39 | 3.23 | 0.38 | 5.78 | 9.00 | Absent | 0.00 | 1.40 | 20.80 |
| SAR (mmol $L^{-1}$)$^{0,5}$ | | ESP | | Salinity | | | | Soil Class | | |
| 3.80 | | 2.48 | | No saline | | | | Normal | | |

SL – Sandy loam; Ad – Apparent density; Tp – Total porosity; pHse - pH of the saturation extract; ECse - Electrical conductivity of the saturation extract of soil at 25 °C; SM - Saturated soil moisture content (mass basis); SAR - Sodium adsorption ratio; ESP - Exchangeable sodium percentage; P, $K^+$ and $Na^+$ extracted by Mehlich 1; $Ca^{2+}$ and $Mg^{2+}$ extracted by 1.0 M KCl at pH 7.0; $H^+ + Al^{3+}$ extracted by 0.5 M CaOAc at pH 7.0; O.M - Organic matter estimated by Walkley-Black wet digestion.

Dose splitting was planned for 24 applications at 15-day intervals for the first year of cultivation (365 days), and during the studied period (until 330 days after transplanting-DAT), N and $K_2O$ were applied 22 times in equal parts every 15 days, resulting in the application of 91.67 g of N and 73.33 g of $K_2O$: corresponding to 100% applied doses, using urea (45% N) and potassium chloride (60% $K_2O$) as sources of N and K, respectively. The phosphorous dose applied per plant was 20 g of $P_2O_5$, determined according to the availability of phosphorus in the soil (CAVALCANTI, 2008), achieved by applying 111.11 g of single superphosphate (18% $P_2O_5$), in a single application, and mixing the fertilizer into the soil of each lysimeter.

In the experiment, grafted West Indian cherry seedlings were used, with rootstock of cv. 'Junco' and scion of cv. 'Flor Branca', obtained from a commercial nursery accredited by the National Registry of Seeds and Seedlings, located in the São Gonçalo district, Sousa – Paraíba, cultivated in polyethylene bags with dimensions of 10 × 20 cm and a volumetric capacity of 0.5 L. When the seedlings reached a height between 0.30 and 0.40 m, at 120 days after grafting, they were transplanted to 60-L lysimeters with dimensions of 0.58 m (height), 0.42 m (upper diameter), and 0.32 m (lower diameter).

At the bottom of the lysimeters, a drainage system was installed, consisting of a drain with ½ inch diameter (12.7 mm) inserted at the end of the base and connected to a 2-L PET bottle for collection of drained water. A 3.0-cm-thick layer of crushed stone n° 1 and a 2.0-cm-thick layer of washed sand was placed at the bottom of the lysimeters. Above the sand, 56 L of soil were placed to fill the lysimeters, which were accommodated on a ceramic brick base at a height of 20 cm and spaced at 1.8 x 2.0 m, between plants and planting rows, respectively, occupying an area of 216 $m^2$.

After the seedlings were transplanted to the soil with adequate moisture content (field capacity), the lysimeters received a 4.0-cm-thick layer of mulch, composed of grass residues, to minimize water losses by evaporation. Plants were supported by 80-cm-high wooden stakes to avoid lodging during initial growth.

The application of the fertilization combinations of the treatments started at 20 DAT, carried out simultaneously as top-dressing by the conventional method, in a circle, in a radius of 20 cm in relation to the base of the plant.

Initially, until 40 DAT, plants were irrigated using water with an electrical conductivity of 0.3 dS $m^{-1}$ to promote good acclimation to field conditions. The application of the saline waters of the treatments began at 41 DAT, a period in which irrigation was manually performed daily, using water of the respective treatment and based on the principle of drainage lysimetry. The volume to be applied in each irrigation was determined by the difference between the volume applied and the volume drained in the previous irrigation, and this difference was considered equivalent to the water volume required to promote a maximum water retention capacity of the soil. A leaching fraction of 0.15 was applied every 15 days, using water of the respective treatments, and the leaching volume was determined based on the volume of water applied during this period, aiming to reduce excessive salt accumulation in the root zone.

Plants were conducted in single stem from the transplanting, and the apical bud was removed at a height of 0.50 m at 70 DAT, thus stimulating the growth of the lateral buds. From the lateral branches that emerged, only three branches were left at different heights, radially distributed in the final 0.20 m of the main stem, called primary branches. During this process, sprouts and branches that were either competing for light or poorly located, especially those pointing towards the soil, were eliminated.

Flowering began at 5 months after transplanting (150 DAT); however, because the plants were still small, with uneven flowering in the different experimental plots, flowers were manually eliminated until 230 DAT, which was therefore considered the time flowering started.

The following morphological parameters of the crop were evaluated at 300 DAT: stem diameter below the grafting point (SDbg) and above the grafting point (SDag), scion diameter (ScionD), scion volume (ScionV), and vegetative vigor index (VVI). The SDbg was measured at 2.0 cm from the soil surface and SDag at 4.0 cm above the grafting point. The ScionD was obtained through the average scion diameter observed in the direction of the planting row (DR) and interrow (DI); Scion volume (ScionV) was calculated from plant height (H), DR, and DI, using Eq. 1, and VVI was calculated using Eq. 2, according to Portella et al (2016).

$$\text{ScionV}=\left(\frac{\pi}{6}\right) \text{x H x DR x DI} \qquad \text{Eq. 1}$$

$$\text{VVI}=\frac{[\text{H+ScionD + (SDbg x 10)}]}{100} \qquad \text{Eq. 2}$$

Production variables were obtained using fruits from 23 harvests performed during the first year of cultivation, at 3-day intervals, in the period between 260 DAT (January 8, 2018) and 330 DAT (March 20, 2018). Fruits were harvested with a red-colored skin, which is the standard characteristic of maturation for fruits of the cv. 'Flor Branca' (CALGARO; BRAGA, 2012). Fruit diameter (FD), fruit length (FL), number of fruits per plant (NF), fruit mean weight (FMW), and production per plant (PROD) were evaluated.

The measurements of FD and FL were made in a representative sample of 20 fruits harvested per plant, randomly selected from the total obtained in each harvest. The FD was measured in the median region in the width direction, whereas FL was measured from the base to the apex of the fruit, using a digital caliper. The NF was determined by counting all the fruits of the harvests. Production per plant was obtained by summing the weight of all fruits produced per plant, weighed on a precision scale (0.01 g), and FMW was calculated by dividing the total weight of the fruits produced per plant by the NF harvested per plant.

The means of the variables were subjected to analysis of variance by the F test at 0.05 probability level, using regression analysis to assess the data of salinity levels and Tukey´s test ($p < 0.05$) to compare the means of the combinations of N and P doses. Data analysis processing was carried out using the statistical program SISVAR version 5.6 (FERREIRA, 2014).

# RESULTS AND DISCUSSION

The interaction between irrigation water salinity and the combination of N and K fertilization was not significant ($p > 0.05$) for the morphological variables analyzed (Table 2). However, irrigation water salinity had a significant effect on SDbg and SDag, and the NK combination significantly influenced the variables SDbg, SDag, ScionD, ScionV, and VVI. A similar effect has been observed by Alvarenga et al. (2019), who found no significant interaction between water salinity and combinations of NK fertilization, but significant single effect of water salinity and NK combinations on the stem diameter of West Indian cherry at 200 days after transplanting.

**Table 2**. Summary of analysis of variance for stem diameter below the grafting point (SDbg), above the grafting point (SDag), scion diameter (ScionD), scion volume (ScionV), and vegetative vigor index (VVI) of West Indian cherry irrigated with saline water and fertilized with combinations of nitrogen and potassium, at 300 days after transplanting.

| Source of variation | DF | Mean squares | | | | |
|---|---|---|---|---|---|---|
| | | SDbg | SDag | ScionD | ScionV | VVI |
| Salinities (S) | 4 | 35.932** | 20.620** | $0.0106^{NS}$ | $0.0149^{NS}$ | $0.0217^{NS}$ |
| NK combination (C) | 3 | 24.813** | 19.382** | 0.0315* | 0.0641** | 0.0788** |
| Interaction S × C | 12 | $6.596^{NS}$ | $2.007^{NS}$ | $0.0129^{NS}$ | $0.0107^{NS}$ | $0.0126^{NS}$ |
| Blocks | 2 | $4.251^{NS}$ | $0.031^{NS}$ | $0.0181^{NS}$ | $0.0127^{NS}$ | $0.0155^{NS}$ |
| Residual | 38 | 3.946 | 1.895 | 0.0101 | 0.0125 | 0.0127 |
| CV (%) | - | 10.92 | 9.23 | 7.53 | 16.30 | 5.08 |

$^{NS}$, * and **, respectively not significant, significant at $p < 0.05$ and $p < 0.01$; DF - Degrees of freedom; CV - Coefficient of variation.

The non-significant effect of irrigation water salinity on ScionD, ScionV, and VVI may be related to the mechanisms of acclimation to salt stress, which may have occurred during the growth of the plants in the first year of cultivation, such as the reduction in the excessive transport of salts to the apical meristems of the growing shoots and leaf exclusion (WILLADINO; CAMARA, 2010; ROY; NEGRÃO; TESTER, 2014), minimizing the effect of salt stress on scion morphology at 300 DAT. Alvarenga et al. (2019) have observed the predominance of these mechanisms in West Indian cherry plants, resulting in a non-significant effect of irrigation water salinity on the length and number of branches at 200 days after transplanting.

The increase in ECw negatively affected the stem diameters below and above the grafting point, causing reductions of 5.27 and 4.92%, respectively, per unit increase in water salinity (Figures 2A and 2B). Such reduction in stem diameter may result from the toxic effects of the ions $Na^+$ and $Cl^-$, accumulated in the stem tissue during plant growth (MUNNS; TESTER, 2008; ALVARENGA et al., 2019; LIMA et al., 2019). The excess of these ions can cause alterations in genes responsible for the transcription and synthesis of lignin, suberin, and polysaccharides of the cell wall, negatively affecting the extensibility and, consequently, the elongation rate and cell division of the affected tissues (LI et al., 2014; BYRT et al., 2018).

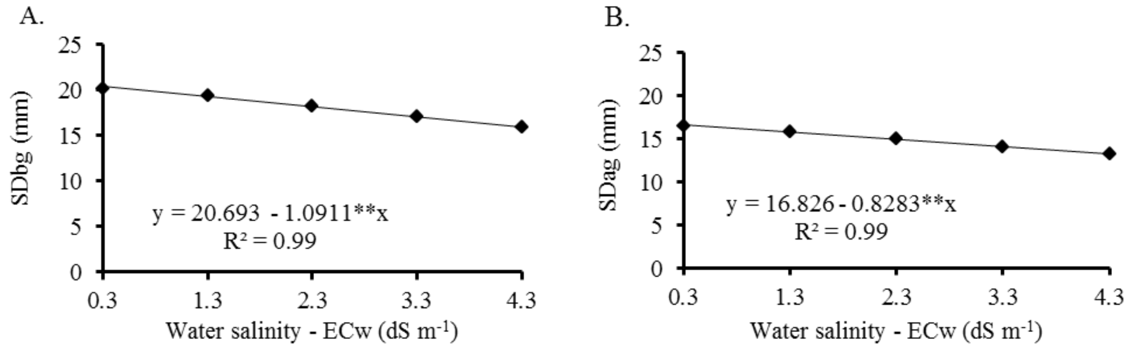
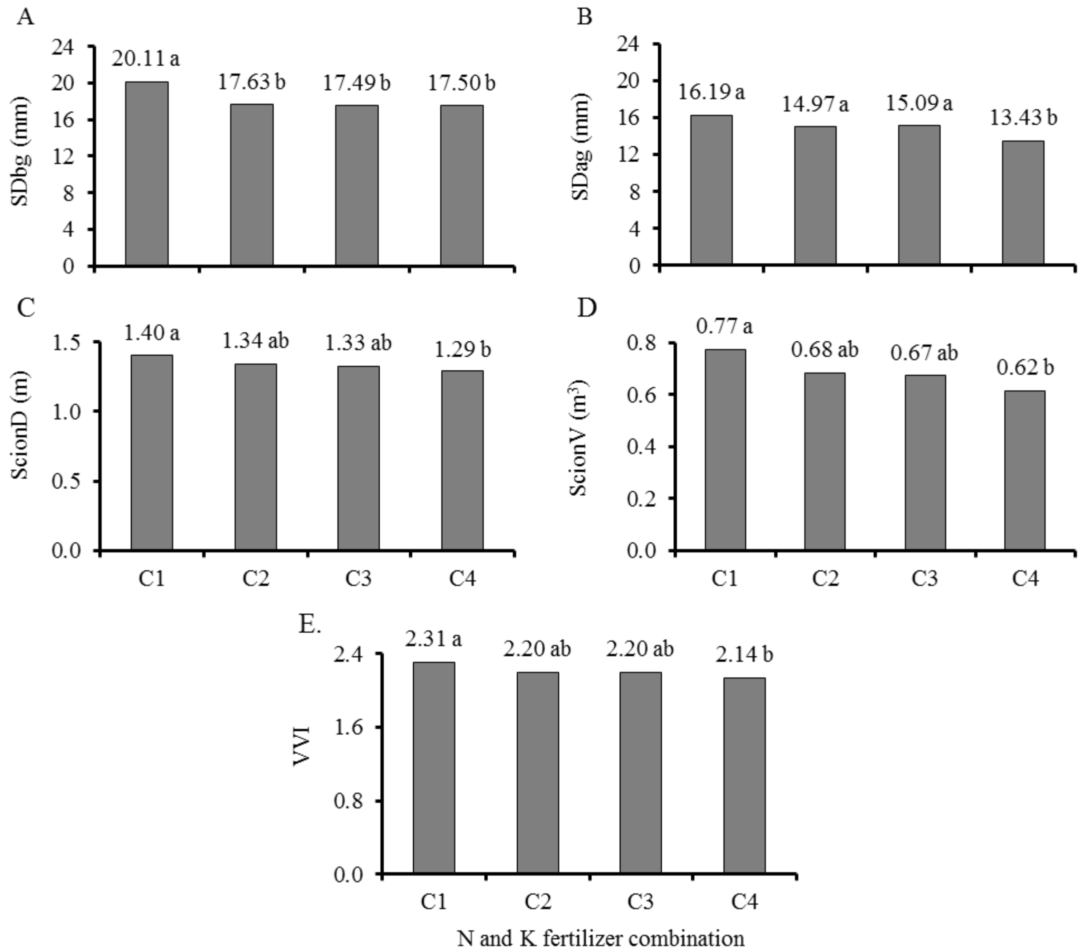



**Figure 2**. Stem diameter below the grafting point - SDbg (A) and above the grafting point - SDag (B) in West Indian cherry plants as a function of irrigation water salinity – ECw, at 300 days after transplanting.

Fertilization with the combination C1 (70% N + 50% $K_2O$) favored the growth of SDbg (Figure 3A), whereas a higher value of SDag was obtained in plants fertilized with up to the combination C3, when there was no significant difference (Figure 3B). In relation to ScionD, ScionV, and VVI (Figures 3C, 3D, and 3E), the combination C1 promoted the highest values of the variables, followed by C2 (100% N + 75% $K_2O$) and C3 (125% N + 100% $K_2O$), in which the means did not differ statistically, whereas plants fertilized with the combination C4 (160% N + 125% $K_2O$) were most negatively affected, obtaining the lowest values of SDbg, ScionD, ScionV, and VVI.




C1 - 70%N + 50%$K_2O$; C2 - 100%N + 75%$K_2O$; C3 - 130%N + 100%$K_2O$ and C4 - 160%N + 125%$K_2O$

Means with different letters indicate that the treatments differ by Tukey test at $p < 0.05$.

**Figure 3**. Stem diameter below the grafting point – SDbg (A), above the grafting point – SDag (B), scion diameter – ScionD (C), scion volume – ScionV (D), and vegetative vigor index – VVI (E) in West Indian cherry plants fertilized with combinations of nitrogen and potassium fertilization, at 300 days after transplanting.

The N and K fertilization doses of the combination C1 were sufficient to promote greater nutritional balance, increasing morphological variables, since these nutrients, at adequate concentrations, are fundamental for better performance of physiological and biochemical activities, with positive effects on plant growth (TAIZ et al., 2017). In plants fertilized with the other combinations, especially in C4, in which N and K doses were higher, nutritional imbalance may have occurred (TAIZ et al., 2017; ALVARENGA et al., 2019).

Under these conditions, the highest doses of $K^+$ may have reduced the concentrations of $Ca^{2+}$ in the plants by either dilution or competitive inhibition between these ions (INTHICHACK; NISHIMURA; FUKUMOTO, 2012), because Ca acts on the integrity of the plasma membrane and composes the binding sites of pectin molecules from the cell wall, where, at low concentrations, it affects the resistance, conformation, extensibility, and cell elongation and division rates, with negative effects on growth (PROSEUS; BOYER, 2012). Likewise, fertilization with the combinations containing the highest doses of N and K contributed to an increased osmotic effect on the plants, reducing growth and cell division. This is justified by the increment of soil salinization with increased doses of urea and KCl, which have high salt indices (ALVARENGA et al., 2019), corresponding to 75 and 105%, respectively (BORGES; SILVA, 2011).

By analyzing the production variables of West Indian cherry (Table 3), we noted significant interaction ($p < 0.01$) between irrigation water salinity and the combinations of NK fertilization, albeit only for fruit diameter. Water salinity had a significant effect on fruit length and mean weight. By contrast, the combinations of NK fertilization promoted a significant single effect on all production variables analyzed. In a previous study, a significant interaction between irrigation water salinity and K doses was observed in West Indian cherry between 180 and 515 days after transplanting, with mitigation of the deleterious effects of salt stress on the total number of fruits and the total fresh weight of fruits by the use of K fertilization (LIMA et al., 2019).

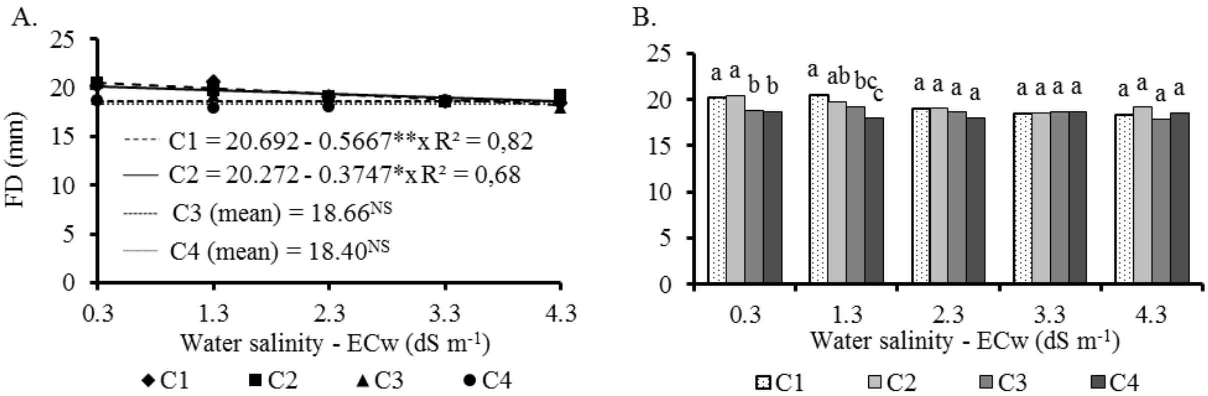
**Table 3**. Summary of analysis of variance for fruit diameter (FD), fruit length (FL), fruit mean weight (FMW), number of fruits per plant (NF), and production per plant (PROD) of West Indian cherry irrigated with saline water under combinations of nitrogen and potassium fertilization in the first year of production, from harvests performed between 260 and 330 days after transplanting.

| Source of variation | Mean squares | | | | | |
|---|---|---|---|---|---|---|
| | DF | FD | FL | FMW | NF | PROD |
| Salinity (S) | 4 | 2.713** | 1.371** | 1.399** | 27954.27$^{NS}$ | 0.127$^{NS}$ |
| NK combination (C) | 3 | 3.955** | 1.968** | 0.675** | 91228.55** | 1.847** |
| Interaction S × C | 12 | 0.946** | 0.421$^{NS}$ | 0.244$^{NS}$ | 16434.86$^{NS}$ | 0.211$^{NS}$ |
| Blocks | 2 | 0.625$^{NS}$ | 1.290$^{NS}$ | 0.212$^{NS}$ | 12798.45$^{NS}$ | 0.036$^{NS}$ |
| Residual | 38 | 0.341 | 0.255 | 0.164 | 16127.32 | 0.124 |
| CV (%) | 4 | 3.08 | 3.04 | 12.28 | 31.17 | 26.82 |

$^{NS}$, and **, respectively not significant, and significant at $p < 0.01$; DF - Degrees of freedom; CV - Coefficient of variation.

In the interactive effect analysis of irrigation water salinity levels with respect to the fertilizer combinations (Figure 4A), FD decreased linearly with increasing salinity in plants fertilized with the combinations C1 (70% N + 50% $K_2O$) and C2 (100% N + 75% $K_2O$), whose reductions were equal to 2.74 and 1.84%, respectively, per unit increase in ECw. In plants fertilized with the combinations C3 (130% N + 100% $K_2O$) and C4 (160% N + 125% $K_2O$), fruit diameter was not significantly affected when plants were irrigated using water with salinity of up to 4.3 dS $m^{-1}$, with mean values of 18.66 and 18.40 mm, respectively.

With the use of lower doses of N and K, the osmotic and toxic stresses of $Na^+$ and $Cl^-$ ions may have prevailed, thus reducing FD as salinity increased, whereas the highest doses of N and K, provided through combinations C3 and C4, may have contributed in increasing the $NO_3^-/Cl^-$ and $K^+/Na^+$ ratios in the tissues of plants subjected to higher levels of salinity, reducing the nutritional imbalance of N and K and the osmotic effect with increased salinity (see also GURGEL; GHEYI; OLIVEIRA, 2010; ANDRADE JÚNIOR et al., 2012), hence resulting in a non-significant effect on fruit diameter. This fact may be related to the greater synthesis and accumulation of low-molecular-weight compounds in the fruits, promoted by N (ASHRAF et al., 2018), and K may have aided in the control of cell turgor in the fruits, facilitating osmotic adjustment in these organs, with effects on diameter growth (ALMEIDA; OLIVEIRA; SAIBO, 2017).




C1 - 70%N + 50%$K_2O$; C2 - 100%N + 75%$K_2O$; C3 - 130%N +100%$K_2O$ and C4 - 160%N + 125%$K_2O$
Means with different letters indicate that the treatments differ by Tukey test at $p < 0.05$.

**Figure 4**. Single-effect analysis of irrigation water salinity levels with respect to the NK fertilization combinations (A) and of the NK fertilization combinations with respect to the salinity levels (B) for fruit diameter – FD of West Indian cherry irrigated with saline water, in the first year of cultivation, from harvests performed between 260 and 320 days after transplanting.

In the interactive effect analysis of the combinations of NK fertilization with respect to the water salinity levels (Figure 4B), the combinations C1 and C2 led to greater fruit diameter (20.23 and 20.47 mm) when plants were irrigated with the lowest levels of irrigation water salinity (ECw of 0.3 and 1.3 dS $m^{-1}$), whereas a reduction was observed with the use of the combinations C3 and C4. This shows that, at the lowest levels of electrical conductivity of water (0.3 and 1.3 dS $m^{-1}$), the fertilization combinations C1 and C2 may have promoted greater nutritional balance and reduction of salt stress by the irrigation with ECw of 1.3 dS $m^{-1}$, especially in C1 treatment, leading to greater growth of fruits in diameter, whereas the use of higher doses in the combinations C3 and C4 may have caused nutritional disturbances and increased the salt stress in the root zone of plants irrigated with ECw levels of 0.3 and 1.3 dS $m^{-1}$, resulting in a reduced fruit diameter.

However, FD did not change with the use of the different combinations of NK fertilization when plants were irrigated with ECw levels of 2.3, 3.3, and 4.3 dS $m^{-1}$, with means of 18.70, 18.65, and 18.51 mm at the respective saline levels, evidencing that the application of higher doses of N and K through the fertilization combinations C3 and C4 cannot be considered efficient for mitigating salt stress at these salinity levels.

The increase in water salinity caused a linear reduction in the length and mean weight of fruits, equal to 1.08 and 3.95%, respectively, per unit increase in ECw (Figures 5A and 5B). The reduction in the length and mean weight of West Indian cherry fruits as ECw increased is related to the osmotic effect of the salts, which affected these reproductive variables, which grew rapidly in a short period of time; i.e., the period from fruit setting to the harvest point lasted on average 25 days (CALGARO; BRAGA, 2012). In addition, the osmotic effect may cause stomatal closure, mediated by hormones such as abscisic acid, in response to salt stress, reducing the entry of $CO_2$ into the leaves and thereby decreasing the photosynthetic rate (SILVA et al., 2018), resulting in a reduction in the production of photoassimilates that would be transferred and accumulated in the fruits, leading to fruits of lower weight and size (SÁ et al., 2019).

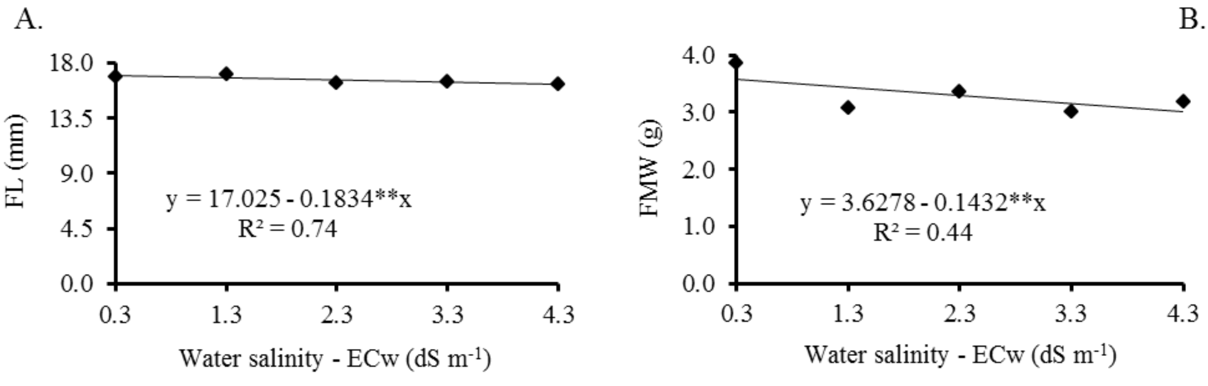
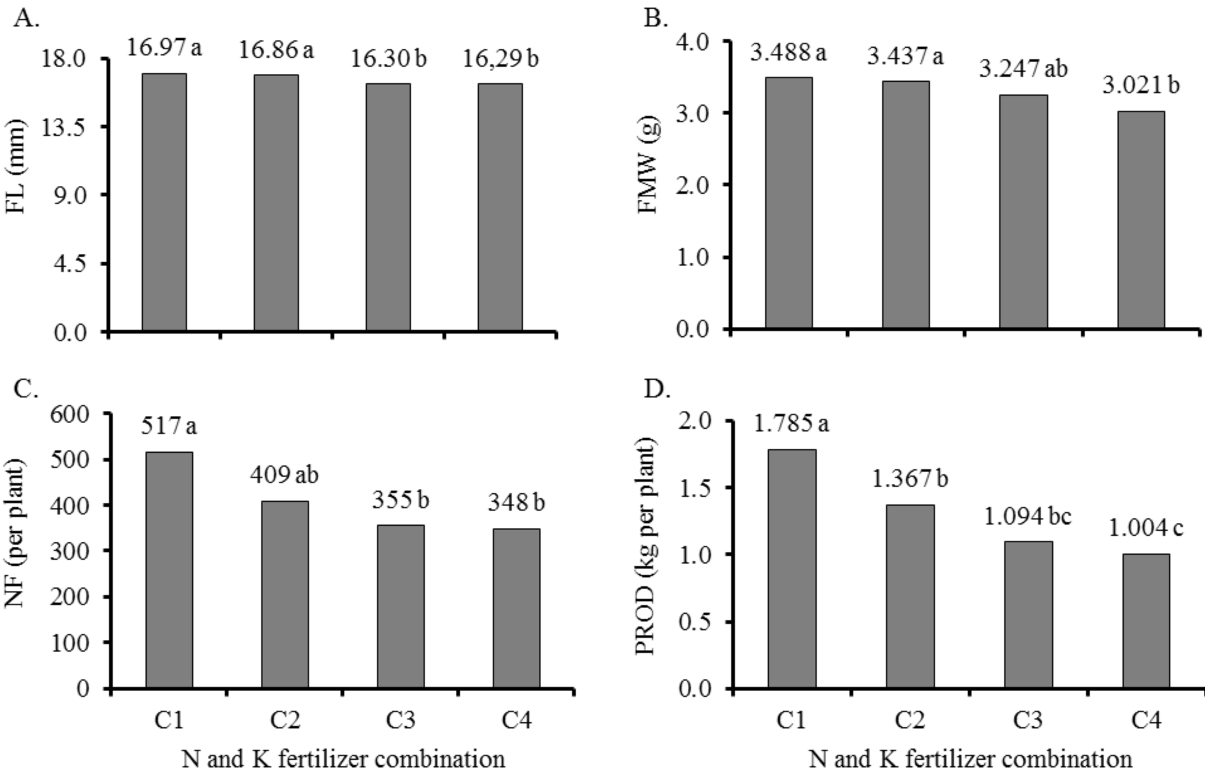



**Figure 5**. Fruit length - FL (A) and fruit mean weight – FMW (B) of West Indian cherry as a function of irrigation water salinity - ECw, in the first year of cultivation, from harvests performed between 260 and 330 days after transplanting.

Although the mean weight of fruits was reduced by the increase in water salinity (Figure 5B), which is one of the main variables which affects the production per plant (SÁ et al., 2019), however, in the present study, the production was not compromised by the reduction in fruit mean weight (Table 3), probably as a consequence of the number of fruits, which was not reduced by the increase in irrigation water salinity, as this is another parameter which is also directly related to the production per plant (SÁ et al., 2019).

The non-significant effect of irrigation water salinity on fruit number is related to the adoption of a natural mechanism of perpetuation of the species, with maintenance of fruits as salinity increased, but with reduced size and weight (Figures 5A and 5B). Silva et al. (2013), investigating in eggplant crop under protected cultivation, observed that an increase in soil salinity up to ECse of 6.0 dS $m^{-1}$ did not negatively affect the NF per plant, despite linearly reducing fruit weight.

When analyzing the combinations of NK fertilization (Figures 6A and 6B), we observed that C1 and C2 led to the highest values of FL and FMW, whereas NF (Figure 6C) and PROD (Figure 6D) reached highest values in plants fertilized with the combination C1, and the other combinations had negative effects on these variables. These results show that FMW was one of the variables that affected PROD; however, we observed (Figures 6C and 6D) that the production per plant followed a tendency similar to that of the number of fruits as a function of the combinations of NK fertilization, as also observed for the salinity factor (Table 3).




C1 - 70% N + 50% $K_2O$; C2 - 100% N + 75% $K_2O$; C3 - 130% N + 100% $K_2O$ and C4 - 160% N + 125% $K_2O$
Means with different letters indicate that the treatments differ by Tukey test at $p < 0.05$.

**Figure 6**. Fruit length – FL (A), fruit mean weight – FMW (B), number of fruits per plant – NF (C), and production per plant - PROD (D) of West Indian cherry fertilized with different combinations of nitrogen and potassium doses, in the first year of cultivation, from harvests performed between 260 and 330 days after transplanting – DAT.

The combinations containing the lowest doses of N and K, particularly C1, promoted greater nutritional balance, resulting in better conditions for development with respect to physiological and biochemical activities (see also TAIZ et al., 2017), positively influencing the length, weight, number of fruits, and, consequently, the production per plant. Nitrogen at adequate doses is essential for good activity of enzymes involved in metabolic pathways as well as for the synthesis of amino acids, amides, proteins, coenzymes, precursors of plant hormones, and chlorophylls (TAIZ et al., 2017), whereas K is involved in osmotic regulation and activation of several enzymes involved in respiration and photosynthesis, factors that are directly related to crop growth and production (MARSCHNER, 2011).

However, high doses of these nutrients applied through fertilization may have caused nutritional imbalance, reducing the growth and production of West Indian cherry plants (Figures 3 and 6), since high doses of urea, used as a source of N, can reduce soil pH through the activity of urease, which releases $H^+$, thus affecting the availability of nutrients such as P, S, and B (MARSCHNER, 2011), as well as reducing K contents in plant tissues due to the competitive effect between $NH_4^+$ and $K^+$ (BATISTA; MONTEIRO, 2010). Moreover, high concentrations of $K^+$ tend to reduce the absorption of $Ca^{2+}$ and $Mg^{2+}$ by plants, intensifying the nutritional imbalance (INTHICHACK; NISHIMURA; FUKUMOTO, 2012).

## CONCLUSIONS

The combination of nitrogen and potassium fertilization with 70% N + 50% $K_2O$, based on the recommended dose, promoted higher growth of the morphological and production variables in West Indian cherry and mitigated the effect of salinity on fruit diameter in plants irrigated using water with ECw of 1.3 dS $m^{-1}$ in the first year of cultivation.

Nitrogen and potassium fertilization above the combination of 130% N + 100% $K_2O$ intensified nutritional imbalance and salt stress in West Indian cherry plants, compromising morphological and production variables.

Irrigation water electrical conductivity above 0.3 dS $m^{-1}$ reduced stem diameter, fruit size, and fruit mean weight, but did not compromise scion morphology, number of fruits, and production per plant up to the ECw level of 4.3 dS $m^{-1}$, with the application of a leaching fraction of 0.15.

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