ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.27, n.7, p.539-549, 2023
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n7p539-549

Morphophysiology and production of West Indian cherry under salt stress and nitrogen-phosphorus-potassium fertilization[1]

Morfofisiologia e produção de aceroleira sob estresse salino e adubação com nitrogênio-fósforo-potássio

Leandro de P. Souza[2], Geovani S. de Lima[2*], Hans R. Gheyi[2], Reynaldo T. de Fátima[2], André A. R. da Silva[2], Reginaldo G. Nobre[3], Lauriane A. dos A. Soares[4] & Cassiano N. de Lacerda[2]

[1] Research developed at Universidade Federal de Campina Grande, Centro de Tecnologia e Recursos Naturais, Campina Grande, PB, Brazil
[2] Universidade Federal de Campina Grande/Programa de Pós-Graduação em Engenharia Agrícola, Campina Grande, PB, Brazil
[3] Universidade Federal Rural do Semi-Árido/Departamento de Ciências e Tecnologia, Caraúbas, RN, Brazil
[4] Universidade Federal de Campina Grande/Unidade Acadêmica de Ciências Agrárias, Pombal, PB, Brazil

HIGHLIGHTS:
Water salinity of 4.0 dS m⁻¹ reduced stomatal conductance, crown volume, and the number of fruits of West Indian cherry.
Fertilization with 100-100-100% recommendation of nitrogen-phosphorus-potassium (NPK) increases the CO_2 assimilation rate.
The lowest production per plant was obtained under fertilization with 100-100-120% of the NPK recommendation.

ABSTRACT: The cultivation of West Indian cherry under irrigation with saline water is subjected to harmful effects caused by salt stress. Identifying combinations of nitrogen-phosphorus-potassium fertilization can be a strategy to ensure the expansion of irrigated agriculture. In this context, the objective of this study was to evaluate the morphophysiology and production of the West Indian cherry 'Flor Branca' as a function of irrigation with waters of different electrical conductivities and fertilization with nitrogen-phosphorus-potassium combinations. The experiment was conducted in a greenhouse using the randomized block design in a 2 × 10 factorial scheme, corresponding to two values of electrical conductivity of irrigation water (0.6 and 4.0 dS m^{-1}) and ten combinations of fertilization with nitrogen (N), phosphorus (P), and potassium (K): 80-100-100, 100-100-100, 120-100-100, 140-100-100, 100-80-100, 100-120-100, 100-140-100, 100-100-80, 100-100-120, and 100-100-140% of the NPK recommendation, with three replicates. Irrigation with water of 4.0 dS m^{-1} negatively affected stomatal conductance, average crown diameter, crown volume, and the number of fruits per plant of West Indian cherry cv. Flor Branca. The combination of 100-100-100% NPK increased transpiration, CO_2 assimilation rate, and stomatal conductance at 260 days after transplantation. Although the NPK combination of 80-100-100% increased number of fruits, the highest production per plant was obtained under 100-80-100% NPK, regardless of the electrical conductivity of irrigation water.

Key words: *Malpighia emarginata* Sesse & Moc. ex DC., fertilization management, water scarcity

RESUMO: O cultivo de aceroleira sob irrigação com água salina está sujeito aos efeitos deletérios ocasionados pelo estresse salino. Dessa forma, a identificação de combinações de adubação com NPK pode ser uma estratégia para garantir a expansão da agricultura irrigada. Neste contexto, objetivou-se com o presente estudo avaliar a morfofisiologia e a produção da aceroleira cv. Flor Branca em função da irrigação com águas de diferentes condutividades elétricas e da adubação com combinações de nitrogênio-fósforo-potássio. O experimento foi desenvolvido em casa de vegetação utilizando-se o delineamento de blocos casualizados, em esquema fatorial 2 × 10, sendo dois níveis de condutividade elétrica da água de irrigação (0,6 e 4,0 dS m^{-1}) e dez combinações de adubação com nitrogênio (N), fósforo (P_2O_5) e potássio (K_2O): (80-100-100; 100-100-100; 120-100-100; 140-100-100; 100-80-100; 100-120-100; 100-140-100; 100-100-80; 100-100-120 e 100-100-140% da recomendação de N-P_2O_5-K_2O), com três repetições. A salinidade da água de irrigação de 4,0 dS m^{-1} afetou negativamente a condutância estomática, diâmetro médio da copa, volume de copa e número de frutos por plantas da aceroleira cv. Flor Branca. A combinação de 100-100-100% de NPK aumentou a transpiração, a taxa de assimilação de CO_2 e a condutância estomática, aos 260 dias após o transplantio. Embora a combinação NPK de 80-100-100% tenha aumentado o número de frutos, a maior produção por planta foi obtida sob 100-80-100% NPK, independentemente da condutividade elétrica da água de irrigação.

Palavras-chave: *Malpighia emarginata* Sesse & Moc. ex DC., manejo de adubação, escassez de água

• Ref. 268384 – Received 04 Oct, 2022
* Corresponding author - E-mail: geovani.soares@pq.cnpq.br
• Accepted 22 Feb, 2023 • Published 25 Feb, 2023
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

Introduction

West Indian cherry (*Malpighia emarginata* Sesse & Moc. ex DC) has high concentrations of vitamin C, anthocyanins, and carotenoids, compounds with beneficial effects on human health due to their recognized antioxidant action (Dias et al., 2018). Despite the socioeconomic importance of the West Indian cherry in the Brazilian Northeast, the expansion of its cultivation is limited due to the climatic conditions of this region, where the plants are frequently subjected to abiotic stress, due to the irregularity of the rains and the high temperatures, with the common occurrence of water sources with high salt content (Sá et al., 2018; Silva et al., 2020).

Thus, studies aimed at reducing the deleterious effects of salt stress on plants are extremely important for the development of irrigated fruit growing as highlighted by Sá et al. (2018), Dias et al. (2021a), and Pinheiro et al. (2022). Among the alternatives, balanced fertilization with NPK stands out. Nitrogen is a macronutrient that participates in the formation of proteins, amino acids, and chlorophylls, among other important molecules in plant metabolism (Siddiqui et al., 2019). Phosphorus contributes to the maintenance of metabolic functions of plants, such as photosynthesis, respiration, synthesis of nucleic acids, enzymatic activities, synthesis, and stability of membranes, besides contributing to the functioning of carbohydrate metabolism, signaling, and redox reactions (Zribi et al., 2018). Potassium participates in enzyme activation, regulation of stomatal movement, maintenance of cell turgor, and transport of photoassimilates via the phloem (Gul et al., 2019). Several studies conducted with West Indian cherry have shown that fertilization alone (Pinheiro et al., 2019; Lima et al., 2019a) or combined (Sá et al., 2018; Dias et al., 2021a; Silva et al., 2021) mitigates the effects of salt stress on the physiological aspects and production of plants. However, the research already carried out with this fruit plant has been limited to evaluating the effects of N and K alone or NK, NP, and KP combining two nutrients.

In this context, the objective of this study was to evaluate the morphophysiology and production of the West Indian cherry cultivar 'Flor Branca' as a function of irrigation with waters of two electrical conductivities and fertilization with nitrogen-phosphorus-potassium combinations.

Material and Methods

The experiment was carried out from March 2020 to April 2021 in an arch-type greenhouse with 150-micron low-density polyethylene covering, belonging to the Unidade Acadêmica de Engenharia Agrícola - UAEA of the Universidade Federal de Campina Grande - UFCG, in Campina Grande, Paraíba, Brazil, located by the geographic coordinates 7° 15' 18" South latitude and 35° 52' 28" West longitude with an altitude 550 m. The data of air temperature (maximum and minimum) and average relative humidity of the air inside the greenhouse are shown in Figure 1.

The experimental design was randomized block, in a 2 × 10 factorial scheme, corresponding to two values of electrical conductivity of irrigation water - ECw (0.6 and 4.0 dS m^{-1}) and ten combinations of fertilization with nitrogen (N), phosphorus (P), and potassium (K): 80-100-100, 100-100-100, 120-100-100, 140-100-100, 100-80-100, 100-120-100, 100-140-100, 100-100-80, 100-100-120, and 100-100-140% of the recommendation of Cavalcanti (2008), for the first year, with three replicates and one plant per plot, arranged at a spacing of 1.8 × 2.0 m.

The electrical conductivities of water were based on the studies conducted by Sá et al. (2018), who classified the West Indian cherry cv. BRS 366-Jaburu as moderately sensitive to irrigation water salinity. The saline waters were prepared by dissolving NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ salts in the local-supply water (ECw = 0.24 dS m^{-1}) in the equivalent proportion of 7:2:1 (commonly observed in northeast Brazil), following the relationship between ECw and salt concentration (Richards, 1954), according to Eq. 1.

$$Q \approx 10 \times ECw \quad (1)$$

where:

Q - sum of cations (mmol$_c$ L^{-1}); and,

ECw - electrical conductivity to be adjusted after discounting the ECw of the water from the municipal supply system (dS m^{-1}).

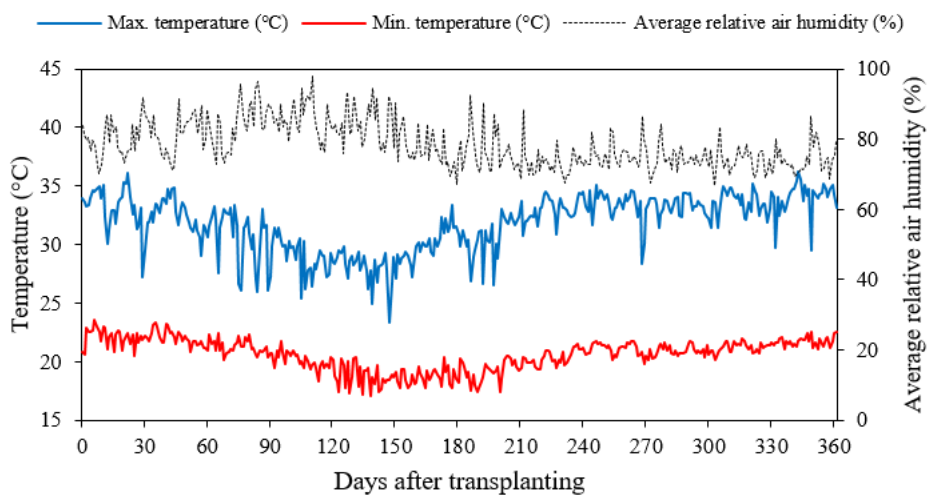


Figure 1. Daily air temperature (maximum and minimum) and average relative air humidity observed in the internal area of the greenhouse during the experimental period

The fertilization management was based on the recommendation for irrigated West Indian cherry proposed by Cavalcanti (2008), using the fertilizers ammonium sulfate (22% N), potassium chloride (60% K_2O), and monoammonium phosphate - MAP (61% P_2O_5 and 11% N) as sources of nitrogen, potassium, and phosphorus, respectively. The salt indices of ammonium sulfate, potassium chloride, and monoammonium phosphate are 69, 116, and 34, respectively (Rader Jr et al., 1943).

West Indian cherry seedlings came from a commercial nursery accredited by the National Registry of Seeds and Seedlings, located in the District of São Gonçalo, Sousa - PB, Brazil. These seedlings were grown in polyethylene bags with dimensions of 10 × 20 cm and volume of 0.5 L, grafted by the full cleft method, using rootstock and scion of the cultivars 'Junco' and 'Flor Branca', respectively.

Fertilization with N, P, and K was carried out every two weeks and with Quimifol Nutri to meet the micronutrient requirements, at the concentration of 2.5 g L^{-1} [Mg (1.1%), Zn (4.2%), B (0.85%), Fe (3.4%), Mn (3.2%), Cu (0.5%), and Mo (0.05%)], by foliar application, on the adaxial and abaxial sides, using a backpack sprayer with working pressure (maximum) of 88 psi (6 bar) and JD 12P nozzle.

The plants were transplanted to lysimeters filled with 235 kg of soil classified as Entisol (United States, 2014), which corresponds to a Neossolo Regolítico in the Brazilian soil classification system (EMBRAPA, 2018), from the municipality of Esperança, Paraíba, collected at 0-0.30 m depth (A horizon), whose chemical and physical-hydraulic characteristics were determined according to methodologies recommended by Teixeira et al. (2017) and are presented in Table 1.

Each lysimeter had two 18-mm-diameter drains spaced equidistantly at the bottom, and a 0.5-kg layer of crushed stone and geotextile (Bidim®) were placed on each drain. The drained water was collected in two 2 L PET bottles, which were positioned below the lysimeters. The volume of water drained was computed and used to estimate the crop water balance, according to Eq. 2.

$$VI = \frac{(Va - Vd)}{(1 - LF)} \qquad (2)$$

where:

VI - volume of water to be used in the irrigation event (mL);

Va - volume of water applied in the previous irrigation event (mL);

Vd - volume of water drained (mL); and,

LF - leaching fraction (0.10).

Before transplanting, the soil moisture content was increased to the value corresponding to the maximum water retention capacity using water of the lowest ECw level (0.24 dS m^{-1}). During the acclimatization period of the plants (50 days after transplanting), irrigation was carried out with water of the low salinity, and after this period, different saline water treatments were applied.

Fertilization with NPK combinations started 15 days after transplanting (DAT) and was performed fortnightly via fertigation. Irrigations with saline waters started at 52 DAT, with intervals ranging from two to three days, according to plant growth and the need to increase irrigation volume based on the drainage lysimetry principle. From the beginning of the application of treatments to 360 DAT, the total volume of water applied per plant was 1093.26 L for the low salinity level (ECw = 0.6 dS m^{-1}) and 983.96 L for the high salinity level (ECw = 4.0 dS m^{-1}).

The plants were grown with a single stem, and their apical bud was pruned at 50 cm height to stimulate the sprouting of lateral buds. Formative pruning was performed on the lateral branches that emerged, leaving three branches well located at different heights near the apex, symmetrically distributed in a spiral pattern. These, called primary branches, were the base structure of the crown and were pruned when they reached 0.25 m in length to stimulate the sprouting of secondary branches and control lateral growth for the plants to adjust to the adopted spacing.

During the experiment, the cultural practices (cleaning of the area, weeding between lysimeter rows, scarification of the soil in the containers) and phytosanitary treatments (application of insecticides and fungicides) recommended for the crop were carried out, monitoring the appearance of pests and diseases and adopting control measures when necessary (Dias et al., 2021a).

Gas exchange evaluations were performed 260 DAT, when the plants were in the pre-flowering stage, through stomatal conductance - gs (mol H_2O m^{-2} s^{-1}), transpiration- E (mmol H_2O m^{-2} s^{-1}), internal CO_2 concentration - Ci (μmol CO_2 m^{-2} s^{-1}), and CO_2 assimilation rate - A (μmol CO_2 m^{-2} s^{-1}). These data were then used to calculate the instantaneous water use efficiency - WUEins - (A/Ci) (μmol CO_2 m^{-2} s^{-1}) (μmol CO_2 m^{-2} s^{-1}) and the intrinsic water use efficiency - WUEint - (A/gs)

Table 1. Chemical and physical attributes of the soil (0-0.30 m) used in the experiment before the application of the treatments

Chemical attributes									
pH (H_2O) (1:2.5)	OM (%)	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	$Al^{3+} + H^+$	ESP (%)	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-hydraulic attributes									
Particle-size fraction (g kg^{-1})			Textural class	Moisture (kPa)		AW	Total porosity (%)	BD	PD
Sand	Silt	Clay		33.42^1	1519.5^2			(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 calcium acetate at pH 7.0; ESP - Exchangeable sodium percentage; ECse - Electrical conductivity of saturation extract; SL - Sandy loam; AW - Available water; BD - Bulk density; PD - Particle density; The indices 1 and 2 refer to field capacity and permanent wilting point (μmol CO_2 m^{-2} s^{-1}) (mol H_2O m^{-2} s^{-1}). A gas exchange analyzer (Infrared Gas Analyzer - IRGA, LCpro-SD model, from ADC BioScientific, UK) was used to measure, between 07:00 and 10:00 h, on the third fully expanded leaf counted from the apical bud of the primary branch, under natural conditions of air temperature, CO_2 concentration, and using an artificial radiation source of 1200 μmol m^{-2} s^{-1} (Fernandes et al., 2021). The time of gas exchange readings was defined according to the local temperature (varying between a minimum of 23 °C and a maximum of 30 °C) and intensity of solar radiation.

In the determination of the relative water content (RWC), leaves were removed from the intermediate third of the branches, and then five leaf discs with area of 1.54 cm^2 each were collected. Immediately after collection, the discs were weighed, avoiding moisture losses, to obtain the values of fresh mass (FM). Then, these discs were placed in beaker, immersed in 50 mL of distilled water, and stored for 24 hours. After this period, excess water was removed with paper towels to determine the turgid mass (TM) of the samples, which were taken to the oven (temperature ≈ 65 ± 3 °C, until reaching constant weight) to obtain the dry mass (DM). Relative water content was determined according to the methodology of Weatherley (1950) using Eq. 3:

$$\mathrm{RWC} = \frac{\mathrm{FM} - \mathrm{DM}}{\mathrm{TM} - \mathrm{DM}} \times 100 \tag{3}$$

where:

RWC - relative water content (%);
FM - fresh mass of discs (g);
TM - turgid mass (g); and,
DM - dry mass (g).

Crown diameter (D_{CROWN}) was also determined 260 DAT by the average crown diameter in the row direction (D_{ROW}) and the interrow direction ($D_{INTERROW}$). At the same period, crown volume (V_{CROWN}) and vegetative vigor index (VVI) were measured using the methodology of Portella et al. (2016), according to Eqs. 4 and 5:

$$V_{CROWN} = \left(\frac{\pi}{6}\right) \times H \times D_{ROW} \times D_{INTERROW} \tag{4}$$

where:

V_{CROWN} - crown volume (m^3);
H - plant height (m);
D_{ROW} - crown diameter in the row direction (m); and,
$D_{INTERROW}$ - crown diameter in the interrow direction (m).

$$\mathrm{VVI} = \frac{\left[H + D_{Crown} + \left(D_{Rootstock} \times 10\right)\right]}{100} \tag{5}$$

where:

VVI - vegetative vigor index;
H - plant height (m);
D_{Crown} - average crown diameter (m); and,
$D_{Rootstock}$ - rootstock stem diameter (m).

The following physical variables of the fruits were evaluated: polar diameter (PD), equatorial diameter (ED), number of fruits (NFP), and total production per plant (TPP). These variables were determined in fruits obtained from harvests, at three-day intervals, carried out during the first production cycle, from 260 to 360 DAT. Fruits with intense red color peel, which is the fruit maturity standard of the cultivar Flor Branca, were harvested. PD and ED measurements were made in a representative sample of 15 fruits harvested per plant, selected randomly from the total obtained in the harvest. Total production per plant was obtained by summing the weight of all the fruits produced, which were weighed on a precision scale (0.01 g resolution), and NFP was determined by counting.

The data obtained were analyzed through a normality test (Shapiro-Wilk test) and subsequently, analysis of variance was performed. The F test was applied for electrical conductivity and the Scott-Knott test ($p \leq 0.05$) was applied for NPK fertilization combinations using the statistical program SISVAR-ESAL.

Results and Discussion

There was no significant effect of the interaction between electrical conductivity and NPK fertilization (SL × NPK) on the studied variables of gas exchange. The NPK combinations significantly affected transpiration, CO_2 assimilation rate, stomatal conductance, instantaneous water use efficiency, and intrinsic water use efficiency, whereas the electrical conductivity of irrigation water significantly affected only the stomatal conductance of West Indian cherry plants 260 DAT (Table 2).

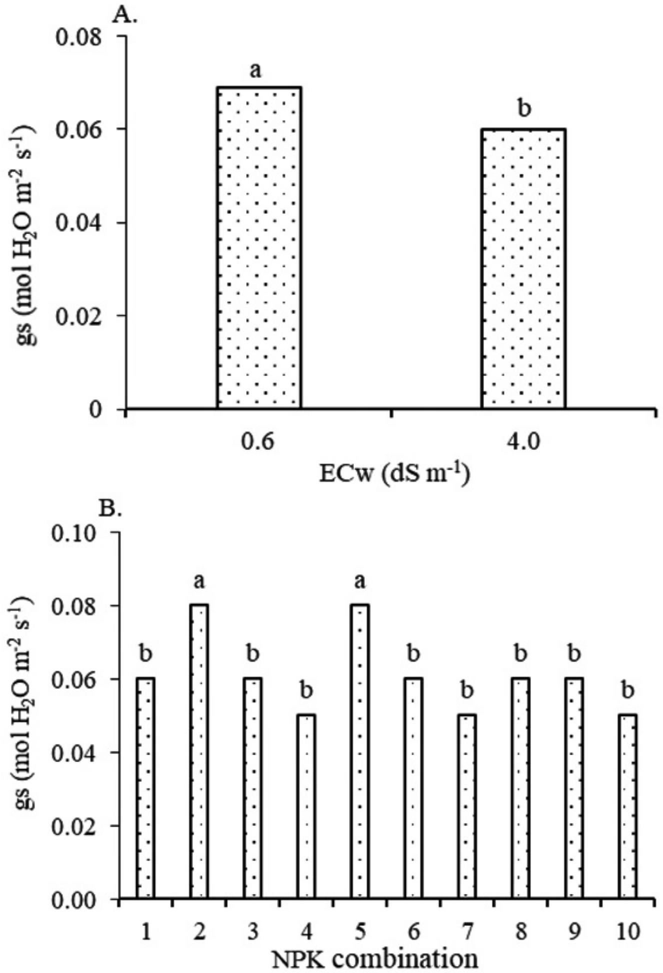
The stomatal conductance (Figure 2A) of West Indian cherry plants subjected to irrigation with the low-electrical conductivity water (0.6 dS m^{-1}) was 0.009 mol H_2O m^{-2} s^{-1}, on average 15% higher than the value observed in plants under irrigation with water of ECw = 4.0 dS m^{-1}. The decrease in stomatal conductance may be a strategy of plants to reduce water loss (Lima et al., 2020) and may be related to the variation of osmotic potential in the root zone, caused by the elevation in the electrical conductivity of irrigation water, given that when plants are subjected to these conditions, a sequence of hormone-modulated reactions is triggered as a physiological acclimatization response, which restricts stomatal opening, leading to effects on transpiration and CO_2 assimilation rate (Dias et al., 2020).

It is also observed for gs (Figure 2B) that the combination 100-100-100% NPK (C2) promoted the highest value, but there was no significant difference compared to the combination 100-80-100% (C5). The other treatments also showed no significant differences from each other, but their means were on average 29.7% (0.024 mol H_2O m^{-2} s^{-1}) lower than the mean of the treatments C2 and C5. In a study with the West Indian cherry cv. Flor Branca under irrigation with saline water (ECw ranging from 0.8 to 4.0 dS m^{-1}) and nitrogen rates, Lima et al. (2019a) found that fertilization with 125% N recommendation did not significantly influence gs 130 DAT. A similar situation was also reported by Silva et al. (2021), who observed no significant effects of the NK combinations (70-50, 100-75, 130-100, and

Table 2. Summary of the analysis of variance for stomatal conductance (gs), transpiration (E), internal CO_2 concentration (Ci), CO_2 assimilation rate (A), instantaneous water use efficiency (WUEins), and intrinsic water use efficiency (WUEint) of West Indian cherry plants, cv. Flor Branca irrigated with water of different salinity levels (SL), under combinations of fertilization with nitrogen, phosphorous, and potassium (NPK) 260 days after transplanting - DAT

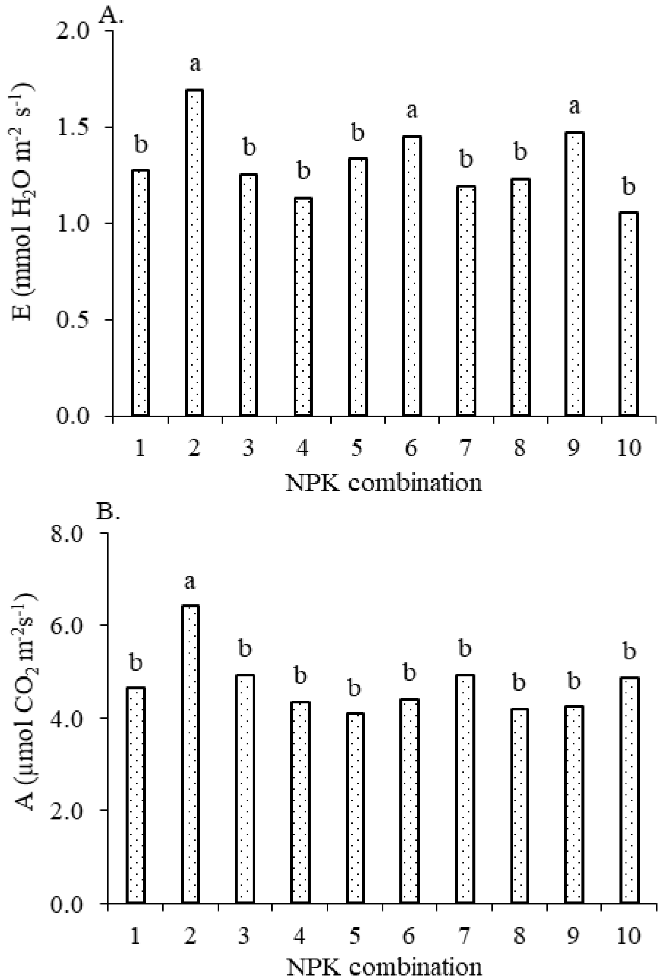
Sources of variation	DF	Mean squares					
		gs	E	Ci	A	WUEins	WUEint
Salinity levels (SL)	1	0.001*	0.00054^{ns}	294.81^{ns}	0.01^{ns}	0.09^{ns}	74.01^{ns}
Fertilization (NPK)	9	0.0004*	0.20*	1092.78^{ns}	2.75*	1.02**	280.52**
Interaction (SL × NPK)	9	0.0005^{ns}	0.14^{ns}	1930.29^{ns}	4.85^{ns}	2.44^{ns}	842.68^{ns}
Blocks	2	0.0001^{ns}	0.48^{ns}	9208.11^{ns}	1.78^{ns}	1.02^{ns}	66.67^{ns}
Residual	38	0.0001	0.07	1091.41	0.40	0.18	62.54
CV (%)		19.86	21.58	13.51	13.45	11.86	10.31

^{ns}, *, **, - Respectively not significant, significant at $p \leq 0.05$ and $p \leq 0.01$ by F test; DF - Degrees of freedom; CV - Coefficient of variation



Means followed by different letters indicate significant differences between the electrical conductivity of water by the F test ($p \leq 0.05$) (Figure A) and between combinations of NPK fertilization by the Scott-Knott test ($p \leq 0.05$) (Figure B). NPK combination indices indicate: 1 = 80-100-100, 2 = 100-100-100, 3 = 120-100-100, 4 = 140-100-100, 5 = 100-80-100, 6 = 100-120-100, 7 = 100-140-100, 8 = 100-100-80, 9 = 100-100-120, and 10 = 100-100-140% of the NPK recommendation by Cavalcanti (2008)

Figure 2. Stomatal conductance - gs of West Indian cherry as a function of electrical conductivity of irrigation water - ECw (A) and different combinations of fertilization with NPK (B) 260 days after transplanting



Means followed by different letters indicate significant differences between NPK combinations by the Scott-Knott test ($p \leq 0.05$). NPK combination indices indicate: 1 = 80-100-100, 2 = 100-100-100, 3 = 120-100-100, 4 = 140-100-100. 5 = 100-80-100, 6 = 100-120-100, 7 = 100-140-100, 8 = 100-100-80, 9 = 100-100-120, and 10 = 100-100-140% of the NPK recommendation by Cavalcanti (2008)

Figure 3. Transpiration - E (A) and CO_2 assimilation rate - A (B) of West Indian cherry plants grown under different NPK combinations 260 days after transplanting

160-125% of N and K_2O, recommendation) on the gs of West Indian cherry plants cv. Flor Branca, at 540 DAT.

The transpiration of West Indian cherry plants cv. Flor Branca (Figure 3A) fertilized with 100-100-100% (C2), 100-120-100% (C6), and 100-100-120% (C9) of NPK recommendation was statistically higher, on average 27.29% (0.329 mmol H_2O m^{-2} s^{-1}) than the value of those which received the other combinations. In general, the NPK combinations C2 (100-100-100%), C6 (100-120-100%), and C9 (100-100-120%) promoted an increase in leaf transpiration (Figure 3A), reinforcing the importance of these nutrients in appropriate combinations for physiological activities, as reported by Silva et al. (2021).

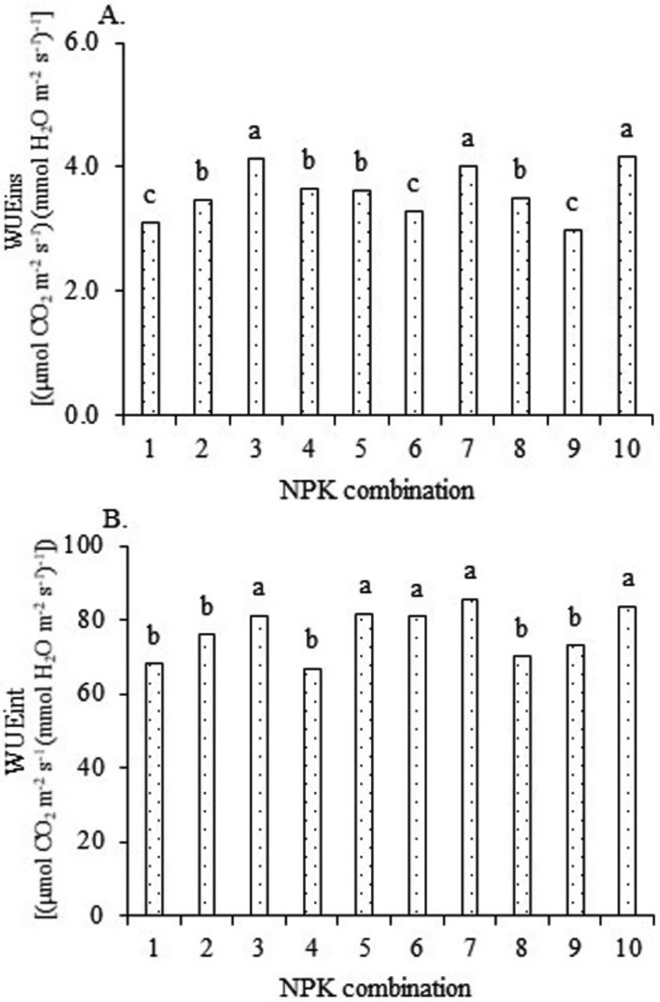
On the other hand, the combinations 140-100-100 (C4), 100-140-100 (C7), and 100-100-140% (C10), in which the doses of N, P, and K were higher, may cause nutritional imbalance relative to the distribution of the other nutrients. In addition, the salt index of the fertilizers used also contributes to the increase in salinity in the root zone. Under these circumstances, the concentrations of NPK, mainly K, may have reduced the availability of other nutrients (Mg^{2+} and Ca^{2+}) in West Indian cherry plants through the processes of dilution, inhibition, or even competition between the elements (Inthichack et al., 2012; Silva et al., 2020), affecting their stomatal conductance.

The highest CO_2 assimilation rate (Figure 3B) was obtained in plants fertilized with the combination 100-100-100% N-P-K (C2), on average 31.40% higher than the values found under the other combinations, which showed no significant difference among them for this trait. Thus, fertilization with NPK at the dose recommended by Cavalcanti (2008) for the cultivation of West Indian cherry under greenhouse conditions is sufficient to maintain the adequate metabolic and physiological activity of plants, for the production of nitrogen compounds, such as enzymes and organelles, to the maintenance of transpiration flow for the energy expenditure of ATP breakage and formation.

These results differ from those reported by Silva et al. (2021), who observed the highest values of CO_2 assimilation in West Indian cherry fertilized with 70% N and 50% K of the recommended doses (100 g of N and 80 g of K_2O per plant) 200 DAT. Silva et al. (2020), working with the cv. Flor Branca, analyzed the physiology of West Indian cherry 230 DAT and observed no difference with the variation of N and K doses from 70 to 130% and from 50 to 100% of the recommended doses (100 g of N and 80 g of K_2O per plant), respectively.

The instantaneous water use efficiency showed a significant difference as a function of the NPK combinations (Figure 4A), and the highest WUE was obtained in plants that received the NPK combination of 100-100-140% (C10), with no significant difference compared to 120-100-100% (C3) and 100-140-100% (C7) (Figure 4A), but significantly differs from the other combinations studied. On the other hand, the NPK combinations C2, C4, C5, and C8 showed no difference from one another, and similar behavior can be observed in plants that received the NPK combinations 80-100-100% (C1), 100-120-100% (C6), and 100-100-120% (C9). When comparing plants subjected to the combination 100-100-120% (C9), which had the lowest WUEins, to those under 100-100-140% (C10) of NPK, which had the highest WUEins, there was a reduction of 28.8%.

For intrinsic water use efficiency, the highest values for NPK fertilization combinations (Figure 4B) were obtained in plants that received the NPK combinations C3, C5, C6, C7, and C10, whose mean was 11.81 (μmol CO_2 m^{-2} s^{-1})(mmol H_2O m^{-2} s^{-1})$^{-1}$ higher than that of plants subjected to the NPK combinations C1, C2, C4, C8, and C9. WUEint expresses the relationship between CO_2 assimilation rate and stomatal conductance and indicates the amount of carbon dioxide fixed by the plant for each unit of water lost in this process (Lima et al., 2019a). It is important to highlight that the absorption of carbon dioxide through the stomata also results in water loss, and the plant, aiming at reducing this loss, restricts CO_2 entry (Dantas et al., 2022). The limitations that occurred in the stomatal conductance through the partial closure of the stomata (Figure 2B) and in the CO_2 assimilation rate (Figure 3B) of the West Indian cherry plants affected the WUEint. This situation may be related to the fertilizers used considering that ammonium sulfate, potassium chloride, and monoammonium phosphate have salt indices of 69, 116, and 34, respectively (Rader Jr et al., 1943).



Means followed by different letters indicate significant difference between NPK combinations by the Scott-Knott test ($p \leq 0.05$). NPK combination indices indicate: 1 = 80-100-100, 2 = 100-100-100, 3 = 120-100-100, 4 = 140-100-100. 5 = 100-80-100. 6 = 100-120-100, 7 = 100-140-100, 8 = 100-100-80, 9 = 100-100-120, and 10 = 100-100-140% of the NPK recommendation by Cavalcanti (2008)

Figure 4. Instantaneous water use efficiency - WUEins (A) and intrinsic water use efficiency - WUEint (B) of West Indian cherry plants grown under different NPK combinations 260 days after transplanting

There were significant effects ($p \leq 0.01$) of the water salinity on crown volume and average crown diameter and of NPK combinations on relative water content, crown volume, and average crown diameter (Table 3). There was no significant effect of the interaction between the electrical conductivity of water and NPK combinations on the studied variables 260 DAT. Pinheiro et al. (2019), when evaluating the water relations of West Indian cherry under irrigation with saline water (ECw of 0.8 and 3.8 dS m^{-1}) and potassium fertilization, also found that water salinity did not significantly influence the relative water content.

The NPK combinations C2, C3, C5, and C9 led to the highest values of RWC (> 74.7%) and showed no significant differences from one another (Figure 5). When comparing the NPK combination 120-100-100% (C3), which led to the highest value for RWC (77.99%), to the NPK combination 140-100-

Table 3. Summary of the analysis of variance for relative water content (RWC), crown volume (V_{CROWN}), vegetative vigor index (VVI), and average crown diameter (D_{CROWN}) of West Indian cherry plants irrigated with water of different electrical conductivities, under combinations of fertilization with nitrogen, phosphorus, and potassium (NPK) 260 days after transplanting - DAT

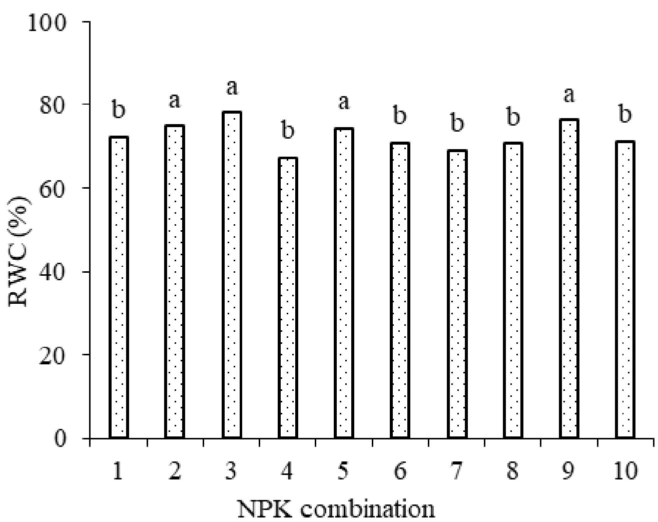
Source of variation	DF	Mean squares			
		RWC	V_{CROWN}	VVI	D_{CROWN}
Salinity levels (SL)	1	18.09^{ns}	1.86**	0.00001^{ns}	0.08**
Fertilization (NPK)	9	57.82**	0.37**	0.00002^{ns}	0.02**
Interaction (SL × NPK)	9	59.67^{ns}	0.50^{ns}	0.00003^{ns}	0.03^{ns}
Blocks	2	9.67^{ns}	0.004^{ns}	0.00001^{ns}	0.01^{ns}
Residual	38	22.46	0.07	0.00002	0.008
CV (%)		6.57	11.33	13.44	5.68

^{ns}, *, **, - Respectively not significant, significant at $p \leq 0.05$ and $p \leq 0.01$ by F test; DF - Degrees of freedom; CV - Coefficient of variation

100% (C4), with the lowest value (67.24%), the superiority was 15.98% (Figure 5). Plants of the treatments 100-100-100% (C2), 120-100-100% (C3), 100-80-100% (C5), and 100-100-120% (C9) of NPK exhibited higher RWC potential. The increase in RWC reflects the higher water absorption by plants, due to osmotic adjustment induced by the synthesis of compatible osmolytes. This synthesis, comprising soluble amino acids and sugars, is elevated by the increase of N, which is part of their composition, and K, which promotes a reduction in the imbalance between transpiration and water absorption by plants, favoring ionic homeostasis (Santana et al., 2011; Lima et al., 2019b).

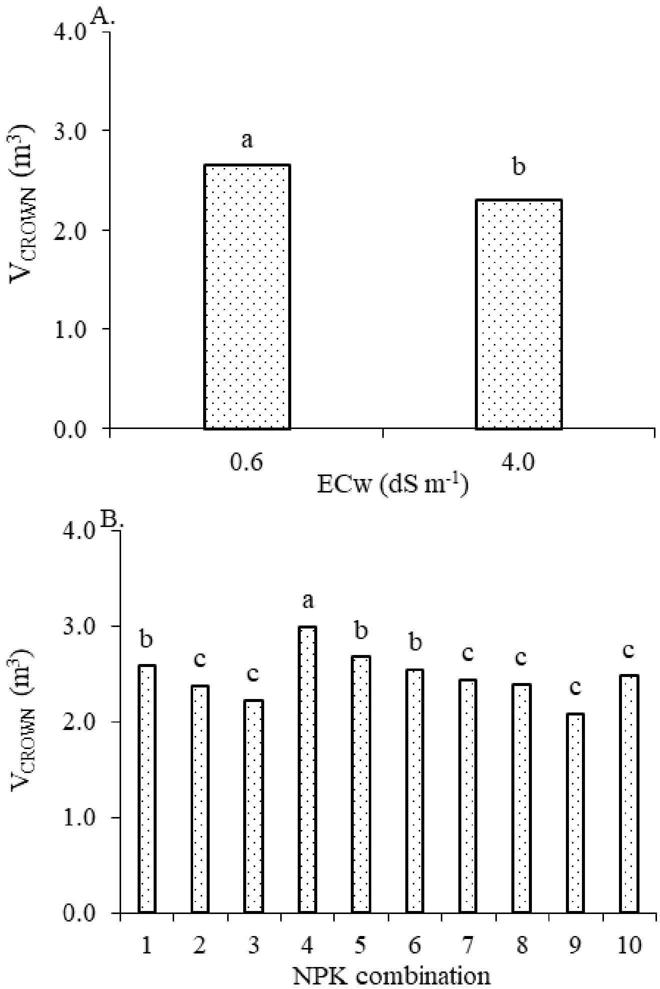
The variables crown volume (V_{CROWN}), vegetative vigor index (VVI), and average crown diameter (D_{CROWN}) are directly related to the time of formation of the crown of plants. It is noteworthy that in this study, the period from 45 to 70 DAT comprised the time for the formation of the crown of the West Indian cherry plants. When the plants reached 50 cm, the apical bud was pruned to stimulate lateral shoots. The side branches were pruned when they reached 25 cm, leaving three branches located at different heights distributed symmetrically in a spiral. For crown volume (Figure 6A), West Indian cherry plants cv. Flor Branca irrigated using water with ECw of 4.0 dS m^{-1} had a reduction of 13.2% (0.35 m^3) compared to those that received irrigation with a low level of water salinity (0.6 dS m^{-1}). Similar behavior can be observed for D_{CROWN} (Figure 7A), as plants irrigated with ECw of 0.6 dS m^{-1} showed higher value compared to those irrigated with ECw of 4.0 dS m^{-1}, with superiority of 4.43% (0.07 m^3). Plant responses to salinity are often accompanied by morphological, anatomical, and osmotic adjustment changes, such as stomatal closure, directly affecting the number of leaves and consequently reducing leaf area as it is a strategy to reduce the transpiration area and therefore inhibit water losses to the atmosphere (Lima et al., 2015).

For the combination of NPK, a significant difference was observed (Figure 6B) between combination 4 (140-100-100%) and the others in terms of V_{CROWN}. In addition, plants that received 80-100-100% (C1), 100-80-100% (C5), and 100-120-



Means followed by different letters indicate significant differences between NPK combinations by the Scott-Knott test ($p \leq 0.05$). NPK combination indices indicate: 1 = 80-100-100, 2 = 100-100-100, 3 = 120-100-100, 4 = 140-100-100, 5 = 100-80-100, 6 = 100-120-100, 7 = 100-140-100, 8 = 100-100-80, 9 = 100-100-120, and 10 = 100-100-140% of the NPK recommendation by Cavalcanti (2008)

Figure 5. Relative water content - RWC of West Indian cherry plants grown under different NPK combinations 260 days after transplanting



Means followed by different letters indicate significant differences between electrical conductivity of water by the F test ($p \leq 0.05$) (Figure A) and between combinations of NPK fertilization by the Scott-Knott test ($p \leq 0.05$) (Figure B). NPK combination indices indicate: 1 = 80-100-100, 2 = 100-100-100, 3 = 120-100-100, 4 = 140-100-100, 5 = 100-80-100, 6 = 100-120-100, 7 = 100-140-100, 8 = 100-100-80, 9 = 100-100-120, and 10 = 100-100-140% of the NPK recommendation by Cavalcanti (2008)

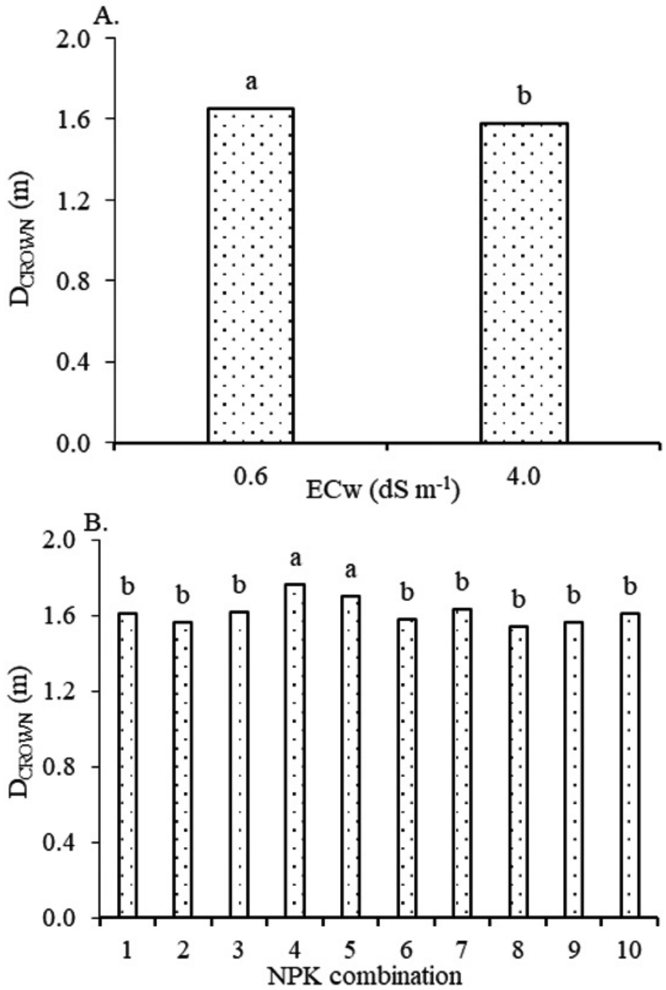
Figure 6. Crown volume (V_{CROWN}) of West Indian cherry as a function of electrical conductivity of irrigation water - ECw (A) and different combinations of fertilization with NPK (B) 260 days after transplanting

100% (C6) of NPK showed no differences from one another but were superior to those under the combinations C2, C3, C7, C8, C9, and C10, which showed the lowest values and did not differ among them. When comparing plants fertilized with the NPK combination 140-100-100% (C4) to those that received C1, C5, and C6, there was an average increment of 0.39 m^3 (13.15%). On the other hand, plants grown with 140-100-100% (C4) of NPK showed an average increase in V_{CROWN} of 0.66 m^3 (22.18%) compared to those under the combinations C2, C3, C7, C8, C9, and C10.

West Indian cherry plants cv. Flor Branca subjected to the NPK combinations C4 and C5 did not differ between them, although the combination C4 (140-100-100%) led to the highest value of D_{CROWN} (Figure 7B). The combinations C4 and C5 were significantly superior compared to the other NPK combinations, and combination 4 had a D_{CROWN} value 0.22 m higher than that promoted by combination C8 (100-100-80%), which stood out with the lowest D_{CROWN}. The highest D_{CROWN} values under C4 and C5 (Figure 7B) reinforce the importance of ionic homeostasis in plant growth, given the functions of these elements. Despite the absence of a significant difference between C4 and C5, plants that received C4 stood out with a higher mean value of D_{CROWN}, which is possibly related to the greater meristematic activity promoted by the increase in available N, which tends to accelerate the process of cell division and expansion (Luo et al., 2020).

There was a significant simple (isolated) effect of NPK fertilization combinations on the total fruit production and the number of fruits (Table 4); there was no significant effect of the interaction between the electrical conductivity of water and combinations of NPK. Electrical conductivity of water significantly affected only the number of fruits per plant. Polar and equatorial diameters were not affected by any source of variation.

For NPK combinations, Figure 8 shows that combination C1 (80-100-100%) and C5 (100-80-100%) promoted the higher values of TPP, and the other combinations comparatively caused harmful effects on this variable. The NPK combinations 100-100-100% (C2) and 100-100-120% (C9) led to lower values



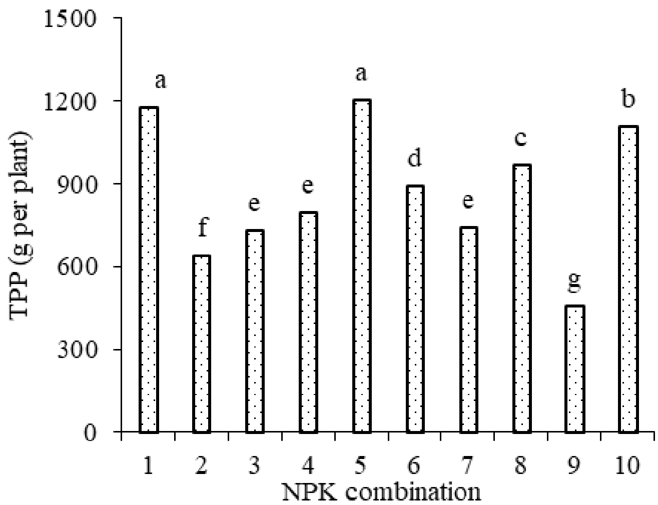
Means followed by different letters indicate significant differences between electrical conductivity of water by the F test (p ≤ 0.05) (Figure A) and between combinations of NPK fertilization by the Scott-Knott test (p ≤ 0.05) (Figure B). NPK combination indices indicate: 1 = 80-100-100, 2 = 100-100-100, 3 = 120-100-100, 4 = 140-100-100, 5 = 100-80-100, 6 = 100-120-100, 7 = 100-140-100, 8 = 100-100-80, 9 = 100-100-120, and 10 = 100-100-140% of the NPK recommendation by Cavalcanti (2008)

Figure 7. Average crown diameter (D_{CROWN}) of West Indian cherry plants as a function of electrical conductivity of irrigation water - ECw (A) and different combinations of fertilization with NPK (B) 260 days after transplanting

Table 4. Summary of the analysis of variance for total production per plant (TPP), number of fruits per plant (NFP), polar diameter (PD), and equatorial diameter (ED) of West Indian cherry irrigated with water of different electrical conductivity under combinations of fertilization with nitrogen, phosphorus, and potassium (NPK) in the period between 260 and 360 DAT

Source of variation	DF	Mean squares			
		TPP	NFP	PD	ED
Salinity levels (SL)	1	7360.44^{ns}	11124.81**	1.53^{ns}	1.49^{ns}
Fertilization (NPK)	9	362656.52**	19201.27**	1.95^{ns}	1.96^{ns}
Interaction (SL × NPK)	9	864444.64^{ns}	46124.15^{ns}	1.92^{ns}	1.97^{ns}
Blocks	2	81.28^{ns}	57.05^{ns}	3.59^{ns}	3.81^{ns}
Residual	38	4892.19	156.89	1.04	1.52
CV (%)		16.44	6.50	5.17	5.62

^{ns}, *, **, - Respectively not significant, significant at p ≤ 0.05 and p ≤ 0.01 by F test; DF - Degrees of freedom; CV - Coefficient of variation



Means followed by different letters indicate significant differences between NPK combinations by the Scott-Knott test (p ≤ 0.05). NPK combination indices indicate: 1 = 80-100-100, 2 = 100-100-100, 3 = 120-100-100, 4 = 140-100-100, 5 = 100-80-100, 6 = 100-120-100, 7 = 100-140-100, 8 = 100-100-80, 9 = 100-100-120, and 10 = 100-100-140% of the NPK recommendation by Cavalcanti (2008)

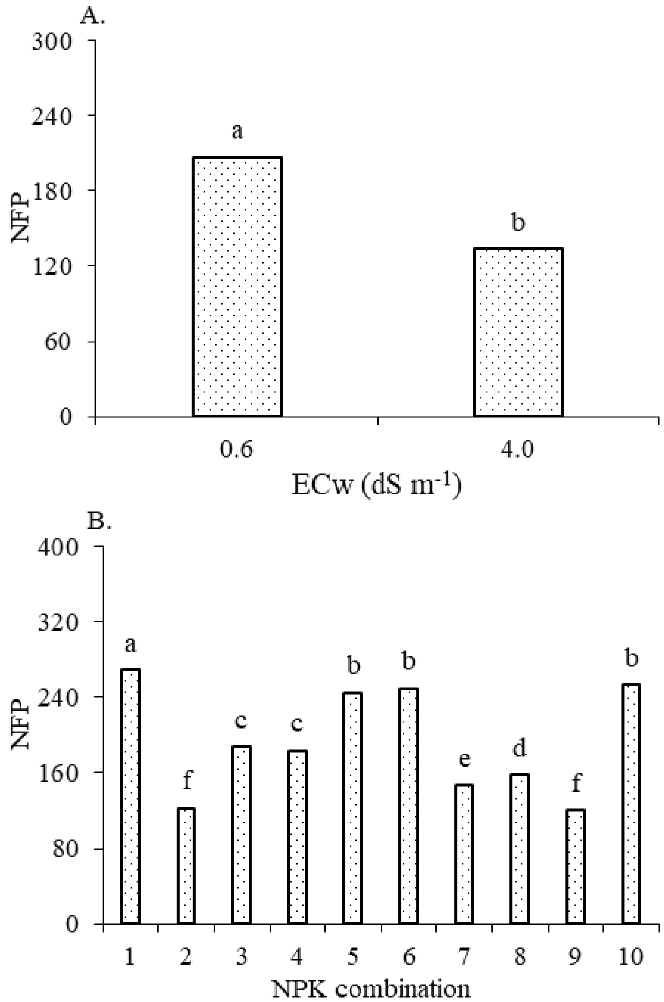
Figure 8. Total production per plant - TPP of West Indian cherry under different combinations of fertilization with NPK, in the period between 260 and 360 days after transplanting - DAT

of TPP, resulting on average reductions of 646.09 g per plant compared to combinations C1 and C5. When comparing the results obtained in this study with those reported by Dias et al. (2021a), in a study evaluating the effects of combined potassium-phosphorus fertilization on West Indian cherry, found that the weight of fruits per plant showed a significant increase (85%) under the K_2O/P_2O_5 combination of 90/54 g per plant and ECw of 1.4 dS m^{-1}. It is important to mention that the study by Dias et al. (2021a) refers to the second year of production of the West Indian cherry, and the source of nitrogen, phosphorus, and potassium used were urea, monoammonium phosphate, and potassium chloride.

The electrical conductivity of water significantly affected only the number of fruits per plant (Figure 9A); plants under ECw of 0.6 dS m^{-1} showed a higher NFP (54.7%) than the value found in plants subjected to ECw of 4.0 dS m^{-1}. The decrease in the number of fruits may be related to the reduction in the matric and osmotic potential of the soil. The osmotic pressure in the soil solution can increase to values at which plants do not have sufficient suction forces to overcome the soil potential, and the consequence of such an increase in soil solution salinity is the reduction in water availability and absorption, inhibiting cell division and elongation, resulting in the reduction of growth and production (Lima et al., 2020). Lima et al. (2019c), when evaluating the production of grafted West Indian cherry cv. BRS 366 Jaburu under irrigation with saline water (ECw of 0.8 and 3.8 dS m^{-1}) and potassium fertilization found that irrigation water salinity of 3.8 dS m^{-1} and a potassium dose greater than 91% of the recommendation markedly reduced the total number of fruits per plant, indicating the intensification of the deleterious effects caused by the high concentration of salts in the irrigation water and by the salt index of the fertilizer used in the study.

For NFP (Figure 9B), the NPK combination 80-100-100% (C1) promoted the highest values. On the other hand, plants subjected to combination C9 (100-100-120%) obtained the lowest total production per plant, significantly differing from those under the other fertilization combinations. Similar behavior is also observed for NPK combinations C3 and C4. It is worth noting that the production data refer to the first cultivation cycle, i.e., a short period after formative pruning operations were carried out during this phase. When comparing the results obtained in this study with those reported by Dias et al. (2021b), with West Indian cherry, it was observed that the plants fertilized with 140/140% of the recommendation K/P (200 g K_2O and 120 g P_2O_5 per plant) had an average number of fruits greater than 1200 fruits in the harvest carried out in the second year of cultivation. The inferiority in fruit production in the present study may be related to the studied cultivar ('Flor Branca'), the tested fertilization combinations, and the production cycle.

Considering that the results obtained in this study were only from the first year of cultivation, it is important to conduct new studies to determine a combination of NPK capable of mitigating the effects of salt stress, especially on the production components of West Indian cherry under greenhouse conditions.



Means followed by different letters indicate significant differences between electrical conductivity of water by the F test ($p \le 0.05$) (Figure A) and between combinations of NPK fertilization by the Scott-Knott test ($p \le 0.05$) (Figure B). NPK combination indices indicate: 1 = 80-100-100, 2 = 100-100-100, 3 = 120-100-100, 4 = 140-100-100, 5 = 100-80-100, 6 = 100-120-100, 7 = 100-140-100, 8 = 100-100-80, 9 = 100-100-120, and 10 = 100-100-140% of the NPK recommendation by Cavalcanti (2008)

Figure 9. Number of fruits per plant - NFP of West Indian cherry as a function of electrical conductivity of irrigation water - ECw (A) and different combinations of fertilization with NPK (B), in the period between 260 and 360 days after transplantation - DAT

Conclusions

1. Stomatal conductance, average crown diameter, crown volume, and the number of fruits per plant of West Indian cherry cv. Flor Branca are reduced by the electrical conductivity of 4.0 dS m^{-1}.

2. The combination of 100-100-100% of the NPK recommendation increases leaf transpiration, CO_2 assimilation rate, and stomatal conductance of West Indian cherry cv. Flor Branca.

3. The NPK combination 80-100-100% of the NPK recommendation increased the number of fruits; the NPK combinations 80-100-100 and 100-80-100% led to higher total production per plant, regardless of the electrical conductivity of irrigation water.

4. The interaction between the electrical conductivity of irrigation water and combinations of fertilization with NPK did not influence any of the measured traits of West Indian cherry cv. Flor Branca.

Acknowledgments

To the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for granting a Junior Postdoctoral Fellowship (Proc. CNPq 151309/2019-1) to the first author.

Literature Cited

Cavalcanti, F. J. Recomendações de adubação para o Estado de Pernambuco: 2. aproximação. 3.ed. Recife: IPA, 2008. 212p.

Dantas, M. V.; Lima, G. S.; Gheyi, H. R.; Pinheiro, F. W. A.; Silva, P. C. C.; Soares, L. A. dos A. Gas exchange and hydroponic production of zucchini under salt stress and H_2O_2 application. Revista Caatinga, v.35, p.436-449, 2022. https://doi.org/10.1590/1983-21252022v35n219rc

Dias, A. S.; Lima, G. S. de; Gheyi, H. R.; Elias, J. J.; Silva, S. S. da; Pinheiro, F. W. A. West Indian cherry production under irrigation with saline water and potassium-phosphorus fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.472-479, 2021b. http://dx.doi.org/10.1590/1807-1929/agriambi.v25n7p472-479

Dias, A. S.; Lima, G. S. de; Gheyi, H. R.; Melo, A. S. de; Silva, P. C. C.; Soares, L. A. dos A.; Paiva, F. J. da S.; Silva, S. S. da. Effect of combined potassium-phosphorus fertilization on gas exchange, antioxidant activity and fruit production of West Indian cherry under salt stress. Arid Land Research and Management, v.35, p.1-18, 2021a. https://doi.org/10.1080/15324982.2021.1959464

Dias, A. S.; Lima, G. S. de; Gheyi, H. R.; Soares, L. A. dos A.; Fernandes, P. D. Growth and gas exchanges of cotton under water salinity and nitrogen-potassium combination. Revista Caatinga, v.33, p.470-479, 2020. http://dx.doi.org/10.1590/1983-21252020v33n219rc

Dias, A. S.; Lima, G. S. de; Sá, F. V. da S.; Gheyi, H. R.; Soares, L. A. dos A.; Fernandes, P. D. Gas exchanges and photochemical efficiency of West Indian cherry cultivated with saline water and potassium fertilization. Revista Brasileira Engenharia Agrícola e Ambiental, v.22, p.628-633, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n9p628-633

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Sistema brasileiro de classificação de solos. 5.ed. Rio de Janeiro: Embrapa, 2018.

Fernandes, E. A.; Soares, L. A. dos A.; Lima, G. S. de; Silva Neta, A. M. de S.; Roque, I. A.; Silva, F. A. da; Fernandes, P. D.; Lacerda, C. N. de. Cell damage, gas exchange, and growth of *Annona squamosa* L. under saline water irrigation and potassium fertilization. Semina: Ciências Agrárias, v.42, p.999-1018, 2021. https://doi.org/10.5433/1679-0359.2021v42n3p999

Gul, M.; Wakeel, A.; Steffens, D.; Lindberg, S. Potassium-induced decrease in cytosolic Na^+ alleviates deleterious effects of salt stress on wheat (*Triticum aestivum* L.). Plant Biology, v.21, p.825-831, 2019. https://doi.org/10.1111/plb.12999

Inthichack, P.; Nishimura, Y.; Fukumoto, Y. Effect of potassium sources and rates on plant growth, mineral absorption and the incidence of tip burn in cabbage, celery, and lettuce. Horticulture, Environment and Biotechnology, v.53, p.135-142, 2012. https://doi.org/10.1007/s13580-012-0126-z

Lima, G. S de; Andrade, E. M. G.; Ketounou, T. R.; Lima, V. L. A. de; Gheyi, H. R.; Silva, S. S. da; Soares, L. A. dos A. Photosynthesis, photochemical efficiency and growth of West Indian cherry cultivated with saline waters and nitrogen fertilization. Bioscience Journal, v.35, p.67-78, 2019a. https://doi.org/10.14393/BJ-v35n1a2019-41156

Lima, G. S. de; Fernandes, C. G. J.; Soares, L. A. dos A.; Gheyi, H. R.; Fernandes, P. D. Gas exchange, chloroplast pigments and growth of passion fruit cultivated with saline water and potassium fertilization. Revista Caatinga, v.33, p.184-194, 2020. http://dx.doi.org/10.1590/1983-21252020v33n120rc

Lima, G. S. de; Gheyi, H. R.; Nobre, R. G.; Soares, L. A. dos A.; Santos, J. B. dos. Cell damage, water status and gas exchanges in castor bean as affected by cationic composition of water. Revista Caatinga, v.32, p.482-492, 2019b. http://dx.doi.org/10.1590/1983-21252019v32n221rc

Lima, G. S. de; Pinheiro, F. W. A.; Dias, A. S.; Gheyi, H. R.; Soares, L. A. dos A.; Silva, S. S. da. Growth and production components of West Indian cherry cultivated with saline waters and potassium fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.250-256, 2019c. http://dx.doi.org/10.1590/1807-1929/agriambi.v23n4p250-256

Lima, L. A.; Oliveira, F. de A. de; Alves, R. de C.; Linhares, P. S. F.; Medeiros, A. M. A. de; Bezerra, F. M. S. Tolerância da berinjela à salinidade da água de irrigação. Revista Agro@mbiente On-line, v.9, p.27-34, 2015. http://dx.doi.org/10.5327/Z1982-8470201500012202

Luo, L.; Zhang, Y.; Xu, G. How does nitrogen shape plant architecture? Journal of Experimental Botany, v.71, p.4415-4427, 2020. http://dx.doi.org/10.1093/jxb/eraa187

Pinheiro, F. W. A.; Lima, G. S. de; Gheyi, H. R.; Dias, A. S.; Moreira, R. C. L.; Nobre, R. G.; Soares, L. A. dos A. Saline water and potassium fertilization in cultivation of grafted West Indian cherry 'BRS 366 Jaburu'. Bioscience Journal, v.35, p.187-198, 2019. http://dx.doi.org/10.14393/BJ-v35n1a2019-41726

Pinheiro, F. W. A.; Lima, G. S. de; Gheyi, H. R.; Soares, L. A. dos A.; Oliveira, S. G. de; Silva, F. A. da. Gas exchange and yellow passion fruit production under irrigation strategies using brackish water and potassium. Revista Ciência Agronômica, v.53, p.1-11, 2022. http://dx.doi.org/10.5935/1806-6690.20220009

Portella, C. R.; Marinho, C. S.; Amaral, B. D.; Carvalho, W. S. G.; Campos, G. S.; Silva, M. P. S. da; Sousa, M. C. de. Desempenho de cultivares de citros enxertadas sobre o trifoliateiro Flying Dragon e limoeiro, Cravo em fase de formação do pomar. Bragantia, v.75, p.70-75, 2016. https://doi.org/10.1590/1678-4499.267

Rader Jr, L. F.; White, L. M.; Whittaker, C. W. The salt index: a measure of the effect of fertilizers on the concentration of the soil solution. Soil Science, v.55, p.201-218. 1943. https://doi.org/10.1097/00010694-194303000-00001

Richards, L. A. Diagnosis and improvement of saline and alkali soils. Washington: U.S. Department of Agriculture, 1954. 160p. USDA Handbook 60

Sá, F. V. da S.; Gheyi, H. R.; Lima, G. S. de; Paiva, E. P. de; Moreira, R. C. L.; Silva, L. de A. Water salinity, nitrogen and phosphorus on photochemical efficiency and growth of West Indian cherry. Revista Brasileira de Engenharia Agrícola e Ambiental, v.22, p.158-163, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n3p158-163

Santana, M. J. de; Carvalho, J. A.; Silva, E. L. da; Miguel, D. da S. Efeito da irrigação com água salina em um solo cultivado com o feijoeiro (*Phaseolus vulgaris* L.). Ciência e Agrotecnologia, v.27, p.443-450, 2011. https://doi.org/10.1590/S1413-70542003000200027

Siddiqui, M. H.; Alamri, S.; Al-Khaishany, M. Y.; Khan, M. N.; Al-Amri, A.; Ali, H. M.; Alsahli, A. A. Exogenous melatonin counteracts NaCl-induced damage by regulating the antioxidant system, proline and carbohydrates metabolism in tomato seedlings. International Journal of Molecular Sciences, v.20, p.1-23, 2019. https://doi.org/10.3390/ijms20020353

Silva, E. M. da; Gheyi, H. R.; Nobre, R. G.; Lima, G. S. de; Soares, L. A. dos A.; Bonifácio, B. F. Saline waters and nitrogen/potassium fertilization combinations on physiological aspects and production of West Indian cherry. Revista Ambiente & Água, v.16, p.1-14, 2021. https://doi.org/10.4136/ambi-agua.2780

Silva, E. M. da; Nobre, R. G.; Gheyi, H. R.; Lima, G. S. de; Barbosa, J. L.; Pimenta, T. A.; Fátima, R. T.; Elias, J. J. Growth and gas exchange of West Indian cherry irrigated with saline waters under combinations of nitrogen-potassium fertilization. Revista Brasileira de Ciências Agrárias, v.15, p.1-9, 2020. https://doi.org/10.5039/agraria.v15i1a6333

Teixeira, P. C.; Donagemma, G. K.; Fontana, A.; Teixeira, W. G. (org.) Manual de métodos de análise de solo. 3.ed. Brasília: Embrapa, 2017. 573p.

United States. Soil Survey Staff. Keys to soil taxonomy. 12.ed. Lincoln: USDA NRCS. 2014. Available on: <http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/>. Accessed on: Jan. 2023.

Weatherley, P E. Studies in the water relations of the cotton plant. I. The field measurement of water deficits in leaves. New Phytologist, v.49, p.81-97, 1950. https://doi.org/10.1111/j.1469-8137.1950.tb05146.x

Zribi, O. T.; Slama, I.; Trabelsi, N.; Hamdi, A.; Smaoui, A.; Abdelly, C. Combined effects of salinity and phosphorus availability on growth, gas exchange, and nutrient status of *Catapodium rigidum*. Arid Land Research and Management, v.32, p.277-290, 2018. https://doi.org/10.1080/15324982.2018.1427640