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GAS EXCHANGES, QUANTUM YIELD AND PHOTOSYNTHETIC PIGMENTS OF WEST INDIAN CHERRY UNDER SALT STRESS AND POTASSIUM FERTILIZATION[1]

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ABSTRACT - Water resources in the semi-arid region of Northeast Brazil commonly contain high salt concentrations, compromising the quality of water for agriculture. Thus, adopting techniques that make the use of these resources feasible in agriculture is fundamental. The present study aimed to evaluate the gas exchanges, quantum yield and photosynthetic pigments of grafted West Indian cherry subjected to salt stress and potassium fertilization under greenhouse conditions in the municipality of Campina Grande, PB, Brazil. Treatments were distributed in randomized blocks, composed of two levels of electrical conductivity – ECw (0.8 and 3.8 dS m^{-1}) of water and four doses of potassium (50, 75, 100 and 125% of the dose recommended for the crop), with three replicates. The dose relative to 100% corresponded to 19.8 g of K_2O per plant. Gas exchanges, chlorophyll *a* fluorescence and photosynthetic pigments of West Indian cherry are negatively affected by irrigation using water with electrical conductivity of 3.8 dS m^{-1}, which compromises the photosynthetic apparatus of the plant, a situation evidenced by the reduction in photosystem II quantum efficiency. Increasing potassium doses led to increments in transpiration, chlorophyll *a* maximum fluorescence and chlorophyll *b* content in West Indian cherry grown under salt stress, but do not attenuate the negative effects of irrigation with 3.8 dS m^{-1} water on its potential photochemical efficiency.

Keywords: *Malpighia emarginata.* Physiology. Potassium. Salinity.

TROCAS GASOSAS, RENDIMENTO QUÂNTICO E PIGMENTOS FOTOSSINTÉTICOS DA ACEROLEIRA SOB ESTRESSE SALINO E ADUBAÇÃO POTÁSSICA

RESUMO - Os recursos hídricos da região semiárida do Nordeste Brasileiro comumente possuem elevadas concentrações de sais, comprometendo a qualidade da água para agricultura. Desta forma, a adoção de práticas de manejo que viabilizem o uso de tais recursos na agricultura é fundamental. Neste trabalho, objetivou-se avaliar as trocas gasosas, o rendimento quântico e os pigmentos fotossintéticos da acerola enxertada submetida ao estresse salino e adubação potássica em condição de casa de vegetação no município de Campina Grande-PB. Os tratamentos foram distribuídos em blocos casualizados, sendo constituídos de dois níveis de condutividade elétrica da água - CEa (0,8 e 3,8 dS m^{-1}) e quatro doses de potássio (50, 75; 100 e 125% da dose recomendada para a cultura), com três repetições. A dose de 100% correspondeu a 19,8 g de K_2O por planta. As trocas gasosas a fluorescência da clorofila *a* e os pigmentos fotossintéticos da aceroleira são afetados negativamente pela irrigação com água de condutividade elétrica de 3,8 dS m^{-1} que compromete o aparato fotossintético da planta, situação observada através da redução da eficiência quântica do fotossistema II. As doses de potássio crescentes promovem incremento na taxa de transpiração, fluorescência máxima da clorofila *a* e no teor de clorofila *b* da aceroleira cultivada sob estresse salino, porém não atenuam os efeitos negativos da irrigação com água de 3,8 dS m^{-1} sobre a eficiência quântica potencial da acerola.

Palavras-chave: *Malphigia emarginata.* Fisiologia. Potássio. Salinidade.

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INTRODUCTION

West Indian cherry (*Malpighia emarginata*) fruits are known for their pleasant taste, high contents of vitamin C, vitamin A, B-complex vitamins, iron, calcium (SÁ et al., 2017), anthocyanins and carotenoids, compounds which have beneficial effects on human health for their known antioxidant action (MACIEL et al., 2010). The crop is adapted to the most diverse climates and can be found in several regions of the planet, but its commercial cultivation is concentrated in tropical and subtropical regions (ADRIANO et al., 2011), such as those found in the Brazilian territory.

Brazil is the largest producer, consumer and exporter of this fruit in the world. In the country, West Indian cherry is cultivated in the Northeast, North, South and Southeast regions (ADRIANO et al., 2011), and the Northeast region stands out due to its soil and climatic conditions, to which the crop is better adapted. In this region, its production reaches 22,964 tons per year in an area of 7,237 ha, which represents approximately 70% of the national production, making the crop a promising option for the Northeast region, due to the prospects for the fruit market, constituting a source of income for rural producers (CAETANO, 2010).

Despite the good prospects for West Indian cherry cultivation, the Brazilian semi-arid region poses risks to its cultivation, due to the scarcity of water resources both quantitatively and qualitatively. In addition, the water sources of this region commonly contain high concentrations of salts, especially sodium (PÁDUA et al., 2017).

Using saline water in irrigation causes deleterious effects on crops, due to the reduction in water availability to plants resulting from the decrease in the osmotic potential of the soil solution, leading to stomatal closure and compromising transpiration and photosynthesis (SILVA et al., 2015). Additionally, it causes alterations in the functional state of chloroplast thylakoid membranes and modifications in the characteristics of fluorescence signals in the leaves (FREIRE et al., 2014) and inhibits the synthesis of 5-aminolevulinate acid, which is the precursor molecule of chlorophyll, causing changes in nitrogen assimilation and protein metabolism (CAVALCANTE et al., 2011).

Thus, considering that most cultivated species are sensitive to the presence of salts in water and/or in soil, it is necessary to conduct research aiming to obtain techniques capable of minimizing the deleterious effects of salt stress on plants, since the use of saline waters in agriculture is almost mandatory in the Brazilian Northeast semi-arid region (FREIRE et al., 2014).

Potassium has been studied as an attenuator of the deleterious effects of water salinity on crops, aiming to allow these resources to be used in agriculture (GURGEL; GHEYI; OLIVEIRA, 2010; PRAZERES et al., 2015). This element favors the formation and translocation of carbohydrates and efficient water use by plants, equilibrates nitrogen application (ARAÚJO et al., 2012), acts as an enzymatic activator and osmoregulation agent, controlling stomatal opening and closure, and its management may result in greater competition of this macroelement with other cations, especially Na^+ (HEIDARI; JAMSHID, 2010).

In this context, the present study aimed to evaluate the gas exchanges, quantum yield and photosynthetic pigments of grafted West Indian cherry subjected to salt stress and potassium fertilization.

MATERIAL AND METHODS

The experiment was conducted in 250-L plastic pots adapted as drainage lysimeters under greenhouse conditions, at the Center of Technology and Natural Resources of the Federal University of Campina Grande (CTRN/UFCG), located in the municipality of Campina Grande, PB, Brazil, situated at the local geographic coordinates of 7° 15’ 18” S, 35° 52’ 28” W and an altitude of 550 m.

The experimental design was randomized blocks, in 2 x 4 factorial arrangement, corresponding to two levels of irrigation water electrical conductivity – ECw (0.8 and 3.8 dS m^{-1}) and four doses of potassium – KD (50, 75, 100 and 125% of K_2O, based on the recommendation of Musser (1995)), with three replicates. The dose relative to 100% corresponded to the application of 19.8 g of K_2O per plant.

Water with electrical conductivity of 3.8 dS m^{-1} was prepared by dissolving the salts NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$, at equivalent proportions of 7:2:1, respectively. This is the average composition of the contents of these cations in the water commonly used for irrigation in the Brazilian Northeast semi-arid region (MEDEIROS, 1992). The ECw level of 0.8 dS m^{-1} was obtained by mixing rainwater (ECw = 0.02 dS m^{-1}) and water from the municipal supply system (ECw = 1.40 dS m^{-1}).

A drain was connected to the base of each lysimeter, using a 4-mm-diameter plastic tube to drain the leachate into a container, determine the water consumption by the plants and evaluate the electrical conductivity of the drained water. The tip of the drain inside the pot was wrapped in nonwoven geotextile (Bidim OP 30) to avoid clogging by soil.

The lysimeters were filled using a 1-kg layer of crushed stone (size 0), followed by 250 kg of Regolithic Neosol with sandy clay texture, properly pounded to break up clods, from the rural area of the municipality of Esperança, PB. Its chemical and physical–hydraulic characteristics were obtained according to the methodologies proposed by

Donagema et al. (2011): Ca^{2+} = 9.07 $cmol_c\ kg^{-1}$; Mg^{2+} = 2.78 $cmol_c\ kg^{-1}$; Na^+ = 1.64 $cmol_c\ kg^{-1}$; K^+ = 0.23 $cmol_c\ kg^{-1}$; $H^+ + Al^{3+}$ = 8.61 $cmol_c\ kg^{-1}$; Al^{3+} = 0 $cmol_c\ kg^{-1}$; CEC = 22.33 $cmol_c\ kg^{-1}$; organic matter = 2.93 dag kg^{-1}; P = 39.8 mg kg^{-1}; pH in water (1:2.5) = 5.58; electrical conductivity of the saturation extract = 2.15 dS m^{-1}; SAR = 0.67 $(mmol\ L^{-1})^{0.5}$; exchangeable sodium percentage = 7.34%; sand = 659.9 g kg^{-1}; silt = 161.2 g kg^{-1}; clay = 178.9 g kg^{-1}; moisture at 33.42 kPa = 25.91 dag kg^{-1}; moisture at 1519.5 kPa = 12.96 dag kg^{-1}.

In the experiment, the rootstocks consisted of heirloom seedlings of West Indian cherry produced at EMBRAPA Tropical Agroindustry, in Pacajus-CE. At transplanting, the seedlings were 240 days old. During the acclimation period in the greenhouse, the seedlings were irrigated with low-salinity water (0.8 dS m^{-1}). The cultivar BRS 366 Jaburu was used as the scion variety. This cultivar is known for its high yield, 57 t ha^{-1}, and vitamin C content of 2,648 mg $100g^{-1}$. The plants are approximately 1.87 m tall, with a crown diameter of 2.18 m on average. The fruits are shiny when ripe and show a mean weight of 4 to 5 g when unripe, appropriate to obtain vitamin C, and 6 to 7 g after ripening (EMBRAPA, 2012).

Before transplanting the seedlings, the soil was brought to field capacity using the respective waters of each treatment. After transplanting, irrigation was performed daily by applying in each lysimeter a water volume sufficient to maintain the soil close to field capacity, and the applied volume was determined according to the plants' water needs, estimated by the water balance: volume applied minus volume drained in the previous irrigation, plus a leaching fraction of 0.10.

Fertilization with phosphorus and nitrogen was applied as recommended by Musser (1955), using single superphosphate and urea, respectively. The phosphorus was entirely applied before planting, whereas nitrogen and potassium were split into 12 equal portions, applied monthly. To meet probable deficiencies of micronutrients, the plants were weekly sprayed on the adaxial and abaxial faces of the leaves with Ubyfol solution containing 1.5 g L^{-1} [(N (15%); P_2O_5 (15%); K_2O (15%); Ca (1%); Mg (1.4%); S (2.7%); Zn (0.5%); B (0.05%); Fe (0.5%); Mn (0.05%); Cu (0.5%); Mo (0.02%)]. On average, 5 L were used in each application for the entire experiment.

The cultural practices consisted of manual weeding every week, superficial soil scarification before each irrigation event and plant tutoring to avoid lodging. In addition, insecticides of the Neonicotinoid chemical group, fungicide of the Triazole chemical group and acaricide from the Abamectin chemical group were preventively applied at doses of 4.0, 5.0 and 3.5 g L^{-1}, respectively.

At 400 days after transplanting, the period of transition between flowering and fruiting, the stomatal conductance - *gs* (mol $H_2O\ m^{-2}\ s^{-1}$), CO_2 assimilation rate - *A* (μmol $m^{-2}\ s^{-1}$), transpiration - *E* (mmol of $H_2O\ m^{-2}\ s^{-1}$) and internal CO_2 concentration – *Ci* (μmol mol^{-1}) were determined using a portable infrared gas analyzer (IRGA), model LCPro+ Portable Photosynthesis System®. After collection, these data were used to quantify the instantaneous water use efficiency - WUEi (*A*/*E*) [(μmol $m^{-2}\ s^{-1}$) (mmol $H_2O\ m^{-2}\ s^{-1})^{-1}$] and instantaneous carboxylation efficiency - CEi (*A*/*Ci*) [(μmol $m^{-2}\ s^{-1}$) (μmol $mol^{-1})^{-1}$]. In the same period, the initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv) and potential quantum efficiency (Fv/Fm) were measured in leaves pre-adapted to the dark using clips for 30 minutes, between 7:00 and 8:00 A.M., using a modulated fluorometer Plant Efficiency Analyser – PEA II®.

The contents of chlorophyll *a*, chlorophyll *b* and carotenoids were determined according to the methodology of Arnon (1949), using 5 discs from the lamina of the third mature leaf from the apex, which were collected, immersed in 80% acetone and stored in the dark for 48 hours. The obtained extracts were subjected to readings in a spectrophotometer at the wavelengths of 470, 646 and 663 nm. The values observed in the readings were subjected to the following equations: Chlorophyll *a* (*Chl a*) = 12.21 ABS663 – 2.81 ABS646; Chlorophyll *b* (*Chl b*) = 20.13 A646 – 5.03 ABS663; total carotenoids (Car) = (1000 ABS470 – 1.82 *Chl a* – 85.02 *Chl b*) /198, to determine the contents of chlorophyll *a*, chlorophyll *b* and carotenoids, expressed in mg g^{-1} of fresh matter (FM).

The data were subjected to analysis of variance by the F test and, when significant, a means comparison test (Tukey test at 0.05 probability level) was carried out for the water salinity levels (SL), and regression analysis was conducted for the potassium doses (KD). When there was significant interaction between factors, the SL factor was further analyzed considering each KD using the statistical program SISVAR-ESAL (FERREIRA, 2014).

RESULTS AND DISCUSSION

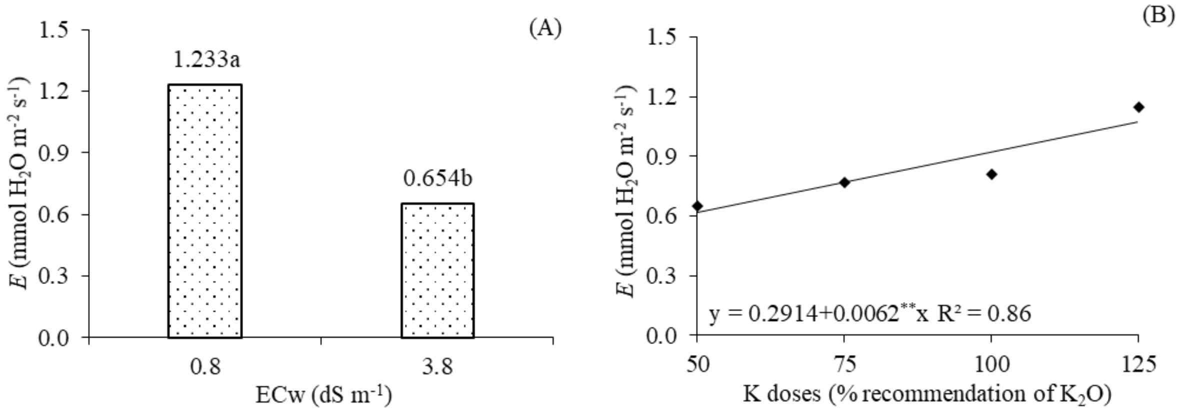
According to Table 1, the water salinity significantly influenced the stomatal conductance (*gs*), transpiration (*E*), CO_2 assimilation rate (*A*), internal CO_2 concentration (*Ci*) and instantaneous carboxylation efficiency (CEi). The potassium doses had a significant effect only on leaf transpiration in the West Indian cherry. The interaction between the water salinity levels and K doses had no significant influence on any of the variables evaluated at 400 days after transplanting.

Table 1. Summary of F test for stomatal conductance (*gs*), transpiration (*E*), CO_2 assimilation rate (*A*), internal CO_2 concentration (*Ci*), instantaneous carboxylation efficiency (CEi) and instantaneous water use efficiency (WUEi) of grafted West Indian cherry plants grown under water salinity and potassium doses, at 400 days after transplanting.

Source of variation	Test F					
	E	*gs*	*A*	*Ci*	CEi	WUEi
Saline levels (SL)	**	**	**	*	**	ns
K dose (KD)	*	ns	ns	ns	ns	ns
Interaction (SL x KD)	ns	ns	ns	ns	ns	ns
Blocks	ns	ns	ns	ns	ns	ns
CV (%)	17.28	13.59	19.01	23.59	15.37	13.29

ns,**, *, respectively not significant, significant at $p < 0.01$ and $p < 0.05$ probability levels.

The leaf transpiration rate of the West Indian cherry plants was significantly reduced by the increase in irrigation water salinity. According to the means comparison test (Figure 1A), *E* was 46.95% lower in plants irrigated using water of the highest salinity (3.8 dS m^{-1}) compared to those subjected to the lowest ECw (0.8 dS m^{-1}). Hussain et al. (2012) subjected citrus to salt stress and reported that a reduction in *gs* leads to a reduction in CO_2 diffusion. The same trend observed in the present study was also found by Sousa et al. (2016), in citrus plants grown with waters of different salinity levels (0.6, 1.2, 1.8, 2.4 and 3.0 dS m^{-1}). According to these authors, there is a relationship between transpiration and stomatal conductance, so that a reduction in *gs* leads to a reduction in *E*. Gonçalves et al. (2010) also observed the existence of this relationship and concluded that the water vapor flow to the atmosphere decreases as the stomata close. Therefore, a reduction in stomatal conductance causes a decrease in leaf transpiration.



Means followed by the same letter do not differ by Tukey test (p<0.05).

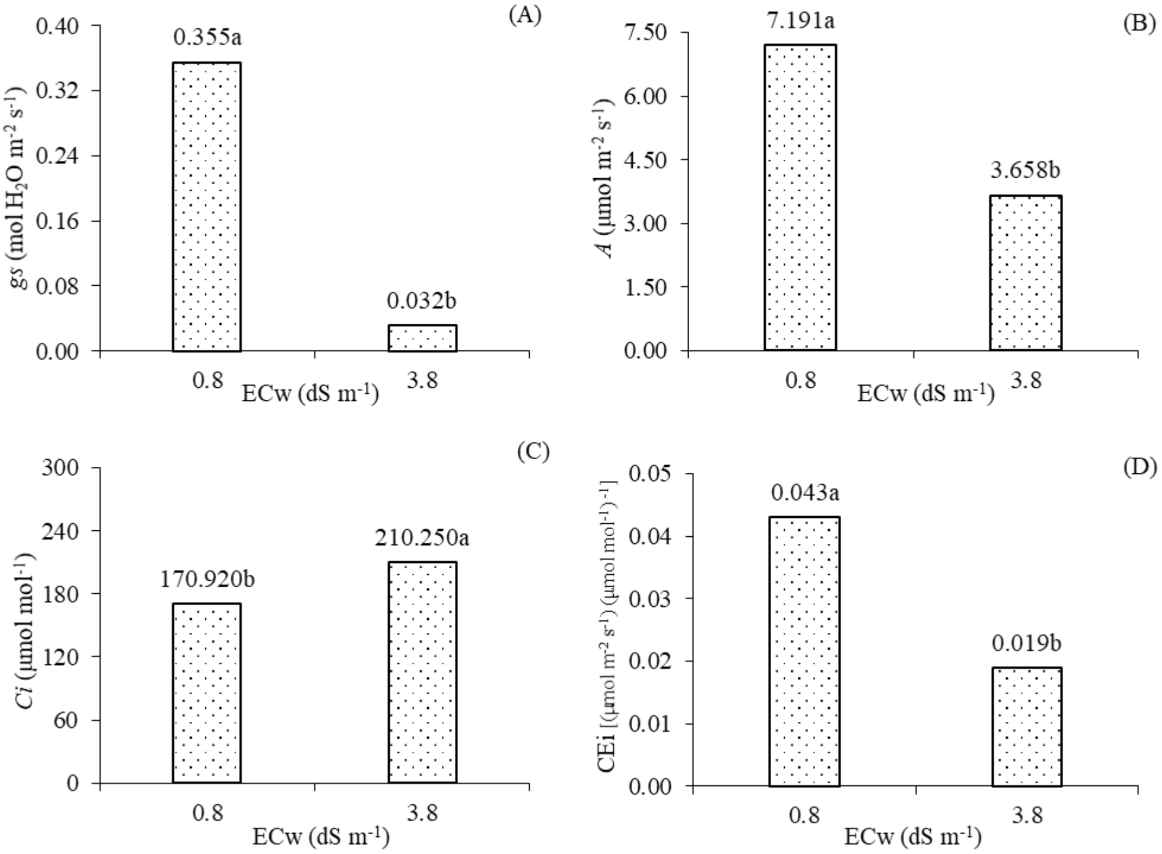
Figure 1. Transpiration – *E* of grafted West Indian cherry as a function of irrigation water salinity – ECw (A) and potassium doses (B), at 400 days after transplantation.

An increment in the potassium fertilization caused a linear increase in the transpiration rate of the West Indian cherry plants and, according to the regression equation (Figure 1B), plants subjected to 125% of the recommendation by Musser obtained *E* of 1.07 mmol H_2O m^{-2} s^{-1}, which is equivalent to a 77.32% increase compared to those which received only 50% of the K_2O recommendation. The increase of leaf transpiration in the West Indian cherry plants reflects the importance of K in stomatal regulation and photosynthesis, since the CO_2 assimilation rate depends on the entry of this gas into the plant. Melo et al. (2014) state that K accumulation in plants favors an osmotic gradient that facilitates water movement, regulating stomatal opening and closure, playing a fundamental role in cell turgidity, transport of carbohydrates and transpiration.

Mendes et al. (2013) subjected eucalyptus plants to water restriction, similar to what occurs in plants under salt stress, and observed that plants which received K fertilization showed better physiological performance than unfertilized ones, with a better stomatal control and consequently higher values of *A* and *E*, and that *E* increased from

2.70 to 2.82 in plants under K supply. These authors also claimed that K application can minimize the negative effects of water deficit.

The means comparison test (Figure 2A) shows that the West Indian cherry plants irrigated using high-salinity water (3.8 dS m^{-1}) had a drastic reduction in stomatal conductance compared to those irrigated using water of the lowest salinity level (0.8 dS m^{-1}). By comparing the results, it was possible to note that *gs* in plants subjected to 3.8 dS m^{-1} was estimated to be 90.98% lower than that observed in plants irrigated with 0.8 dS m^{-1} water. Reduction of *gs* in the West Indian cherry is one of the first responses to salt stress. This occurs as a defense mechanism to reduce water loss through the leaves to the atmosphere because water absorption by roots becomes more difficult in saline soil (SOUSA et al., 2016).



Means followed by the same letter do not differ by Tukey test ($p<0.05$).

Figure 2. Stomatal conductance - *gs* (A), CO_2 assimilation rate - *A* (B), internal CO_2 concentration – *Ci* (C) and instantaneous carboxylation efficiency - CEi (D) of grafted West Indian cherry, as a function of irrigation water salinity – ECw, at 400 days after transplanting.

In agreement with the results obtained here, Hussain et al. (2012) also observed a reduction of *gs* in different citrus genotypes when subjected to irrigation using water containing 75 mM of NaCl. These authors state that the primary effect of salinity on citrus, as observed in the present study, is the reduction in stomatal conductance.

According to the means comparison test, irrigation using water with an electrical conductivity of 3.8 dS m^{-1} negatively affected the photosynthetic process in the West Indian cherry plants (Figure 2B), whose CO_2 assimilation rate decreased by 3.53 µmol m^{-2} s^{-1} in comparison to those subjected to the lowest salinity level, a reduction corresponding to 49.13%. The decrease in stomatal conductance with the consequent reduction in CO_2 diffusion negatively affects net photosynthesis (SYVERTSEN; GARCÍA -SÁNCHEZ, 2014), due to the stomatal effects which limit the photosynthetic process (PRAZERES et al., 2015; SOUSA et al., 2016).

Studies evaluating the effect of salt stress on the photosynthesis of cowpea (PRAZERES et al., 2015) and citrus (SOUSA et al., 2016) have found similar trends to those observed in the present study, i.e., a reduction in the CO_2 assimilation rate as a result of increased irrigation water salinity. These authors commented that such effect is due to the reductions of *gs* and *E*, corroborating the idea that transpiration directly influences the CO_2 assimilation rate.

Figure 2C shows an increase of 39.33 µmol mol^{-1} in the *Ci* of plants irrigated with 3.8 dS m^{-1}

water, compared to those under irrigation with a salinity level of 0.8 dS m^{-1}. The increase of *Ci* in plants under salt stress is due to stomatal closure, which leads to a reduction of the mesophyll's capacity to assimilate carbon, which is not being fixed when it reaches the mesophyll cells (TAIZ; ZEIGER, 2013). This situation indicates a possible deterioration in the photosynthetic structure, since the damage caused to the structures responsible for CO_2 fixation is not only due to stomatal factors, for example, an accumulation of salts in the leaves (HUSSAIN et al., 2012). These authors emphasize that the accumulation of salts in the leaves negatively affects processes that are essential for plants such as *A*, *gs* and Fv/Fm.

In relation to the instantaneous carboxylation efficiency, this study makes it possible to ascertain whether non-stomatal factors have an influence on photosynthesis. According to Silva et al. (2015), this variable depends on the CO_2 availability in the leaf mesophyll, the amount of light, temperature and enzymatic activity. Thus, the CEi of the West Indian cherry plants was also negatively influenced by the use of water with high EC. Plants irrigated using water of the lowest EC (0.8 dS m^{-1}) showed a CEi of 0.043 [(μmol m^{-2} s^{-1}) (μmol mol^{1}) $^{-1}$], whereas those subjected to 3.8 dS m^{-1} obtained a CEi of 0.019 [(μmol m^{-2} s^{-1}) (μmol mol^{1}) $^{-1}$], i.e., plants under the highest ECw level showed a reduction of 55.81% in their capacity to fix CO_2 in comparison to those subjected to the lowest level of water salinity (Figure 2D). This result means that the CO_2 in the West Indian cherry plants grown using water with a high salt concentration is being totally fixed when it reaches the mesophyll cells, thus denoting that these plants have undergone possible metabolic restrictions to the Calvin cycle (SOARES et al., 2013), a reduction in the synthesis of sugars in the photosynthetic process (FREIRE et al., 2014), and a reduction in the substrate for RuBisCO (SILVA et al., 2015). In addition to these factors, as the stress becomes more severe, the mesophyll cells dehydrate, the mesophyll metabolism is damaged and, consequently, the carboxylation efficiency is compromised (TAIZ; ZEIGER, 2013).

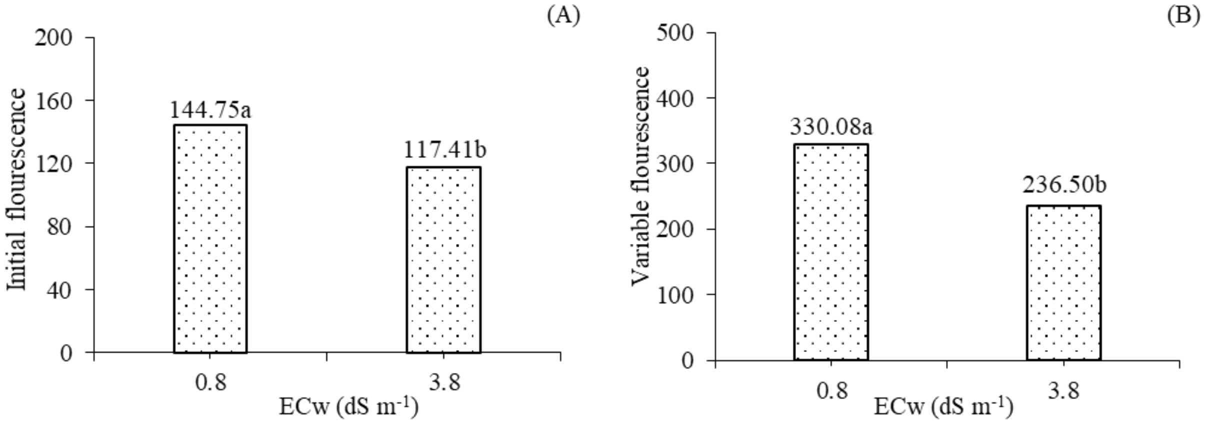
Determining chlorophyll *a* fluorescence signals is an important tool to assess photosynthetic apparatus integrity and the possible influence of non-stomatal factors on CEi. In relation to variables relative to chlorophyll *a* fluorescence (Fo, Fm, Fv, Fv/Fm) and photosynthetic pigments (Chl *a*, Chl *b* and carotenoids), the F test results (Table 2) revealed a significant influence of the irrigation water salinity on all the variables analysed. Potassium doses significantly affected only the content of chlorophyll *b* in the West Indian cherry leaves. Interaction between the studied factors (SL x KD) significantly influenced the maximum fluorescence, potential quantum efficiency and Chl *b* content.

Table 2. Summary of F test for initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), potential quantum efficiency (Fv/Fm), chlorophyll *a* content (Chl *a*), chlorophyll *b* content (Chl *b*) and carotenoid (Car) content in leaves of grafted West Indian cherry plants grown under water salinity and potassium doses, at 400 days after transplanting.

Source of variation	Test F						
	Fo	Fm	Fv	Fv/Fm	Chl *a*	Chl *b*	Car
Saline levels (SL)	**	*	**	**	*	**	**
K dose (KD)	ns	ns	ns	ns	ns	**	ns
Interaction (SL x KD)	ns	*	ns	*	ns	**	ns
Blocks	ns	ns	ns	ns	ns	ns	ns
CV (%)	7.79	16.93	13.22	19.77	23.79	24.02	15.29

ns,**, * respectively not significant, significant at $p < 0.01$ and $p < 0.05$ probability levels.

Figure 3A shows that irrigation using 3.8 dS m^{-1} water caused an initial fluorescence (Fo) of 117.42 in the West Indian cherry leaves, whereas in plants irrigated with ECw of 0.8 dS m^{-1} Fo was equal to 144.75. Alterations in Fo may occur when there is damage to the photosystem II reaction center or due to a reduction in the transfer of excitation energy from the light-harvesting system to the reaction center (BAKER; ROSENQVIST, 2004). Thus, the increase of salt concentration in irrigation water caused damage to the PSII reaction center or depletion in the transfer of excitation energy, possibly due to the biochemical and physiological changes caused in the plant by the stress, since Fo emission occurs within the first phase of fluorescence and represents the energy released by chlorophyll *a* molecules from the photosystem II antenna, before the electrons moved to the P680 reaction center (PSII), a minimum component of the fluorescence signal (VIEIRA et al., 2010) being emitted when all dark-adapted reaction centers are open (GORBE; CALATAYUD, 2012).



Means followed by the same letter do not differ by Tukey test ($p<0.05$).

Figure 3. Initial fluorescence - Fo (A) and variable fluorescence - Fv (B) of grafted West Indian cherry, as a function of irrigation water salinity – ECw, at 400 days after transplanting.

With a similar trend to that of Fo, the variable fluorescence of West Indian cherry was lower in plants subjected to high salinity (3.8 dS m^{-1}) in the irrigation water (Figure 3B). Plants irrigated with low-salinity water had Fv of 330.08, which was 39.57% higher than that found in plants subjected to irrigation with 3.8 dS m^{-1}. Such reduction of Fv in West Indian cherry reflects losses of photochemical activity in the leaves. For Baker (2008), the variable fluorescence reflects the capacity of the plant to transfer energy from electrons ejected from pigment molecules to the formation of NADPH, ATP and reduced ferredoxin (Fdr) and, consequently, a higher capacity for CO_2 assimilation in the biochemical phase of photosynthesis. Freire et al. (2014) report that the reduction in Fv indicates damage to the photosynthetic apparatus due to the use of saline water, consequently compromising PSII.

Silva et al. (2015) observed that the highest value of variable fluorescence (1842.13) occurred with the application of 166% ETc, representing a 29% increment compared to the application of 33% ETc, i.e., higher water availability led to an increase in Fv, from which it can be inferred that Fv was negatively affected not only by the deleterious effects of salinity, but also by the reduction in water availability to the West Indian cherry plants caused by the decrease in the osmotic potential of the soil solution due to irrigation with saline water.

The maximum fluorescence of the West Indian cherry plants responded significantly to the interaction between the salinity levels and potassium doses (Figure 4A) and, according to the regression equations, the data fitted to a quadratic model. The regression equations (Figure 4A) showed that, in plants irrigated using water of the lowest salinity (0.8 dS m^{-1}), the increment in K dose caused an increase in Fm up to the estimated dose equivalent to 83% of the recommendation of Musser (409.78), from which this variable decreased. Under irrigation using 3.8 dS m^{-1} water, there was an initial reduction in Fm between the doses of 50 and 70% of the K recommendation, with increments from this point on, and the highest value for this variable (468) was found in plants fertilized with 125% of the K_2O recommendation, which is equivalent to an increase of 11.82% compared to those cultivated with a K dose of 50% of the recommendation.

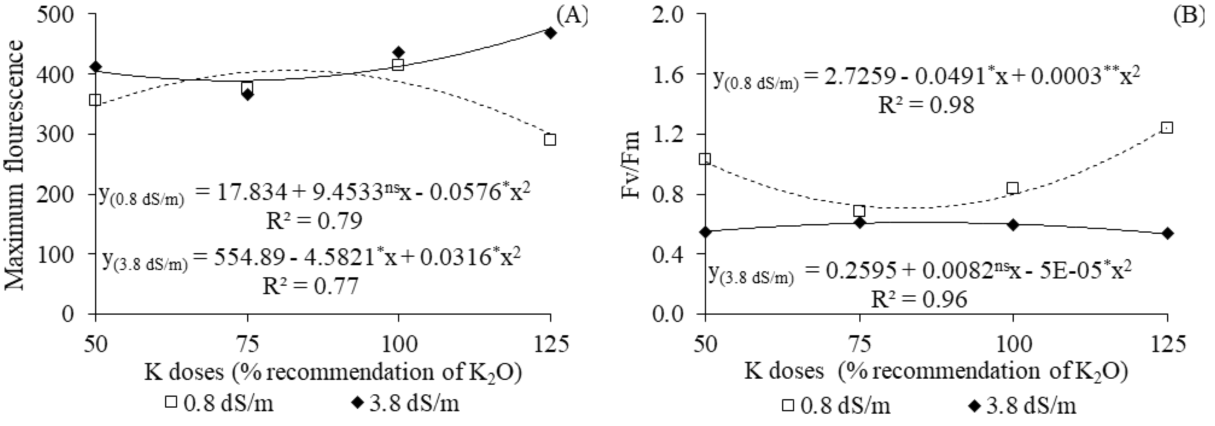


Figure 4. Maximum fluorescence – Fm (A) and potential quantum efficiency - Fv/Fm (B) in grafted West Indian cherry, as a function of the interaction between irrigation water salinity – ECw and potassium doses, at 400 days after transplanting.

The reduction of Fm observed in plants irrigated with 0.8 dS m^{-1} and fertilized with the highest dose of K (125% of the K_2O recommendation) can be explained by the use of KCl in the present study as a source of K, since it has a high salt index (116.3) and, when associated with salt stress, can induce a reduction in the water availability to plants as a consequence of the decrease in the osmotic potential of the soil solution. For Silva et al. (2015), the maximum fluorescence represents the maximum intensity of the fluorescence emitted, when almost all the quinone is reduced and the reaction centers reach their maximum capacity for photochemical reactions, a process which requires electrons from water. By contrast, the increase of Fm in plants subjected to salt stress reflects the benefits of K for plants, which are associated with characteristics that lead to efficient water use, such as regulation of turgidity, stomatal opening and closure, and control of transpiration.

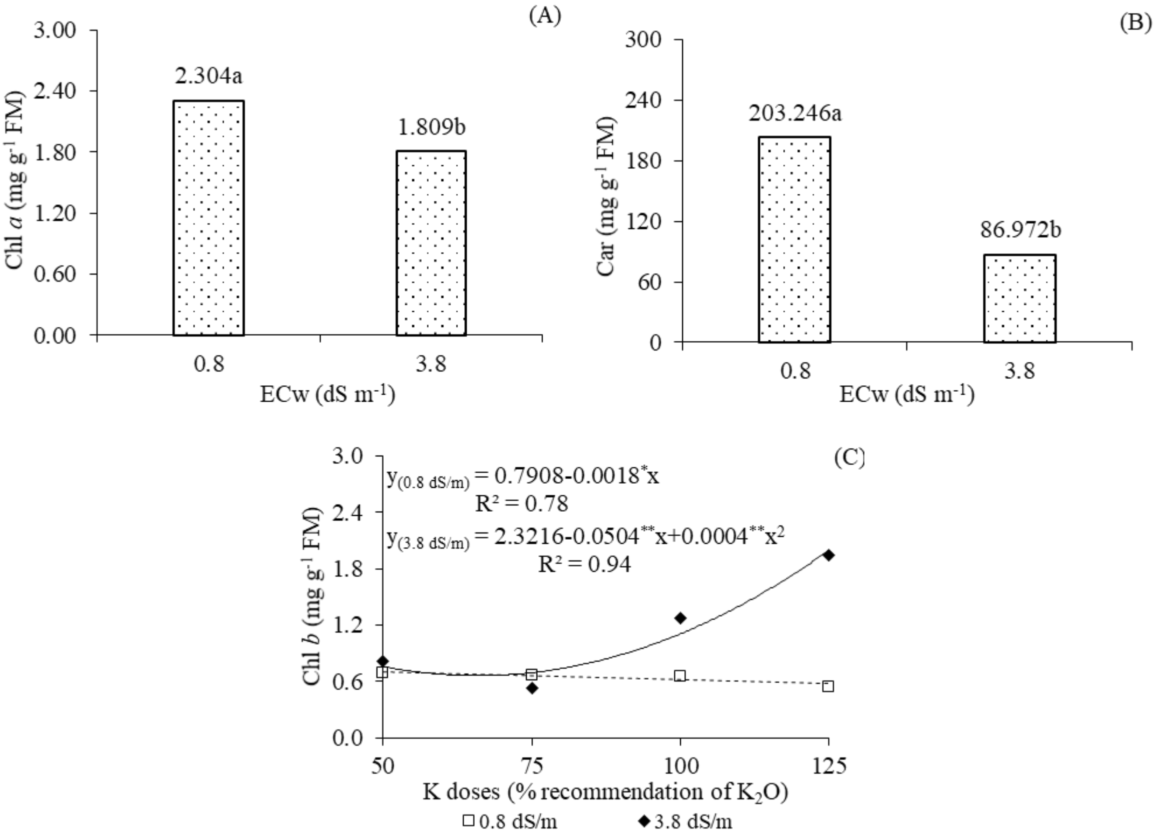
As observed for the maximum fluorescence, the interaction between the studied factors (SL x KD) also significantly influenced the potential quantum efficiency of PSII. According to the regression equations (Figure 4B), the Fv/Fm data of the West Indian cherry plants irrigated with 0.8 and 3.8 dS m^{-1} fitted to a quadratic model. For plants subjected to irrigation with 0.8 dS m^{-1} there was a reduction in the quantum efficiency of those which received 75% of the K_2O recommendation compared to plants fertilized with 50%. However, from this dose on there was an increase of Fv/Fm as a function of K fertilization and, according to the regression equation, the maximum value of Fv/Fm (1.23) was estimated in the West Indian cherry plants fertilized with 125% of K, representing a 16.24% increase in quantum efficiency compared to those which received a K dose of 50%. The increase in photochemical efficiency as a function of K fertilization is due to higher activity of ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) and the photosynthetic rate caused by the increase of K content in the leaves (MENDES et al., 2013).

For plants subjected to irrigation with 3.8 dS m^{-1} water, the regression equation (Figure 4B) shows that the maximum estimated value of Fv/Fm (0.59) occurred at the dose of 83% of the K_2O recommendation. According to Silva et al. (2015), Fv/Fm values ranging from 0.75 to 0.85 indicate that the photosynthetic apparatus is intact. However, the Fv/Fm values presented in this study for plants irrigated with 3.8 dS m^{-1} are below the proposed interval, regardless of the K dose. Therefore, it can be inferred that the K doses tested were not able to mitigate the deleterious effects of the salt stress on photosystem II.

For Freire et al. (2013), one of the factors linked to the photosynthetic efficiency of plants (Fv/Fm) and, consequently, to their growth and adaptability to adverse environments, is the content of chlorophyll and carotenoids in their leaves. In the present study, the lowest contents of chlorophyll *a* (Figure 5A) and carotenoids (Figure 5B) were found in plants irrigated with high-salinity water (3.8 dS m^{-1}). Compared to plants irrigated using water of the lowest ECw level (0.8 dS m^{-1}), there were reductions of 21.48 and 57.21% in the Chl *a* and Car contents, respectively (Figure 5A and 5B).

Reduction in the chlorophyll *a* content in plants exposed to water salinity is probably due to the increase of the enzyme chlorophyllase, which degrades the molecules of this photosynthesizing pigment, as observed by Freire et al. (2013). On the other hand, the decrease in carotenoid content may be attributed, among other causes, to the fact that salt stress leads to a reduction in the production of photosynthetic pigments, inducing the degradation of β-carotene, causing a decrease in the content of carotenoids, which are integrated components of the thylakoids, acting in the absorption and transfer of light to chlorophyll (SILVA et al., 2016).

Moreover, these reductions can be considered as the acclimation of the plants to the salt stress imposed, in an attempt to conserve energy and, consequently, capture less light energy, and so reduce the flow of electrons to the electron transfer chain, thus avoiding any photo-oxidative stresses (SILVA et al., 2016). Tatagiba et al. (2014) explain that the contents of chlorophyll and carotenoids decrease under high salt concentrations and that the significant reductions found in *A*, as observed in the present study, may also be attributed to the loss of these photosynthetic pigments because, according to Taiz and Zeiger (2013), these pigments are an integral part of the light-harvesting complex for the photosynthetic process.



Means followed by the same letter do not differ by Tukey test ($p<0.05$).

Figure 5. Contents of chlorophyll *a* – Chl *a* (A) and carotenoids – Car (B) in grafted West Indian cherry, as a function of irrigation water salinity – ECw and chlorophyll b content – Chl *b* (C), as a function of the interaction between ECw and potassium doses.

Regarding the chlorophyll *b* of the West Indian cherry plants, the interaction between the studied factors (saline levels and potassium doses) had a significant effect on its content in the leaves. According to Figure 5C, for plants irrigated using water of the lowest salinity (0.8 dS m^{-1}), the data fitted best to a decreasing linear model and, according to the regression equation (Figure 5C), Chl *b* contents decreased by 19.26% between plants fertilized with 125% of the K recommendation and those subjected to 50%, which represents a reduction of 0.14 mg g^{-1} FM. For the Chl *b* contents in plants irrigated with 3.8 dS m^{-1} water, the data fitted to a quadratic model and, according to the regression equation, this variable decreased between K doses of 50 and 70% and increased from this point on, reaching its highest value (1.94 mg g^{-1} FM) in plants fertilized with 125% of the K_2O recommendation. From the increase of Chl *b* contents in the leaves of the West Indian cherry plants subjected to salinity in response to K fertilization, it can be inferred that the supplementation with this nutrient reduced the deleterious effects of salt stress on this pigment, an important fact because it is directly related to photosynthesis and its increment may improve the photosynthetic rate.

It is believed that, as observed for Fm (Figure 4A), the reduction in Chl *b* content can be explained by the possible negative effects of high doses of K on plants subjected to salt stress, which has already been reported in the literature (LACERDA et al., 2003; PRAZERES et al., 2015), as well as by the decrease in Ca and Mg contents in the plants, as a consequence of the effect of competitive inhibition between these two ions so that the increase in K^+ induces the deficiency of Ca^{2+} and Mg^{2+} (SILVA; TREVIZAM, 2015). Therefore, it is related to the chlorophyll content, since Mg participates in the structure of the chlorophyll molecule, occupying a central position, and is also a cofactor in ATP hydrolysis (BONFIM-SILVA et al., 2011). This hypothesis is supported by Melo et al. (2014), who observed that Ca and Mg contents in the leaves of “Prata-Anã” banana decreased as the K doses applied by fertigation increased.

The increase observed in the chlorophyll content of plants irrigated with 3.8 dS m^{-1} in response to K fertilization is associated with the role played by this nutrient in the plant. Although K does not participate in the structure of chlorophyll molecules, or any organic compound, it plays an important role in the N metabolism, which requires adequate quantities of K in the cytoplasm (VIANA; KIEHL, 2010), fundamental for the synthesis of this pigment, the production of amino acids in the activation of enzymes, and the synthesis of proteins. Porto et al. (2013) observed an increase in SPAD readings in plants when the K_2O doses increased. These authors also claim that the obtained results reflect better N use in plants under K supply, as well as higher water use efficiency in these plants.

CONCLUSIONS

The gas exchanges, chlorophyll *a* fluorescence and photosynthetic pigments of West Indian cherry are negatively affected by irrigation using water with an electrical conductivity of 3.8 dS m^{-1}, which compromised the photosynthetic apparatus, a situation evidenced by the reduction in photosystem II quantum efficiency.

Potassium doses led to increments in the transpiration, chlorophyll *a* maximum fluorescence and chlorophyll *b* content of West Indian cherry grown under salt stress. Potassium doses of up to 125% of the recommendation do not attenuate the negative effects of irrigation with 3.8 dS m^{-1} water on the potential quantum efficiency of West Indian cherry leaves.

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