Ciência e Agrotecnologia
SCIENCE AND AGROTECHNOLOGY

Ciência e Agrotecnologia, 46:e022621, 2022
http://dx.doi.org/10.1590/1413-7054202246022621

Agricultural Sciences
eISSN 1981-1829

Brackish water irrigation strategies and potassium fertilization in the cultivation of yellow passion fruit

Estratégias de irrigação com água salobra e adubação potássica no cultivo de maracujazeiro amarelo

Francisco Wesley Alves Pinheiro[1], Geovani Soares de Lima[1*], Hans Raj Gheyi[1], Lauriane Almeida dos Anjos Soares[2], Reginaldo Gomes Nobre[3], Pedro Dantas Fernandes[1]

[1]Universidade Federal de Campina Grande/UFCG, Campina Grande, PB, Brasil
[2]Universidade Federal de Campina Grande/UFCG, Pombal, PB, Brasil
[3]Universidade Federal Rural do Semi-Árido/UFERSA, Caraúbas, RN , Brasil
[*]Corresponding author: geovanisoareslima@gmail.com
Received in November 7, 2021 and approved in February 10, 2022

ABSTRACT

The high concentration of salts in water sources in the semi-arid region of the Brazilian Northeast stands out as one of the limiting factors for the expansion of irrigated cultivation of fruit crops. Thus, the search for a strategy capable of mitigating the effect of saline stress on plants is of paramount importance. In this context, the objective of this study was to evaluate the gas exchange and yield of yellow passion fruit cultivated under brackish water irrigation strategies and potassium fertilization in two production cycles. The experiment was conducted under field conditions, using the randomized block design in a 6 × 2 factorial scheme, corresponding to six strategies of irrigation with brackish water applied in the different phenological stages of the crop: WS - without stress, irrigation with low-salinity water throughout the crop cycle; irrigation with high-salinity water only in the vegetative stage - VE; flowering stage - FL; fruiting stage - FR; and successively in the vegetative and flowering stages - VE/FL; and vegetative and fruiting stages - VE/FR, and two potassium doses (60 and 100% of the recommendation), with four replicates and three plants per plot. In irrigation, water with high (4.0 dS m^{-1}) or low (1.3 dS m^{-1}) electrical conductivity was used. The potassium dose of 100% recommendation corresponded to 345 g of K_2O per plant per year. The yellow passion fruit 'BRS GA1' was more sensitive to salt stress applied successively in the vegetative and flowering stages and vegetative and fruiting stages, showing reductions in the intercellular CO_2 concentration, CO_2 assimilation rate, instantaneous water use efficiency, number of fruits, and yield. Irrigation with water of 4.0 dS m^{-1} in the fruiting stage is a promising strategy, as it does not compromise production. The dose of potassium equivalent to 60% was better than 100% of recommendation in terms of gas exchange and yield.

Index terms: Osmoregulation; *Passiflora edulis* Sims.; salt stress.

RESUMO

A alta concentração de sais nas fontes hídricas do semiárido do Nordeste brasileiro se destaca como um dos fatores limitantes para a expansão da fruticultura irrigada. Assim, é de suma importância a busca por estratégia capaz de amenizar o efeito do estresse salino sobre as plantas. Neste contexto, objetivou-se com este trabalho avaliar as trocas gasosas e a produtividade do maracujazeiro amarelo cultivado sob diferentes estratégias de irrigação com água salobra e adubação potássica em dois ciclos de produção. O experimento foi conduzido em condições de campo, utilizando o delineamento de blocos casualizados em esquema fatorial 6 × 2, correspondendo a seis estratégias de irrigação com água salobra aplicadas nos diferentes estádios fenológicos da cultura: SE - sem estresse, irrigação com água de baixa salinidade ao longo do ciclo da cultura; irrigação com água de alta salinidade apenas na fase vegetativa - VE; fase de floração - FL; fase de frutificação - FR; e sucessivamente nas fases vegetativa e floração - VE / FL; e fases vegetativa e frutificação - VE/FR, e duas doses de potássio (60 e 100% da recomendação), com quatro repetições e três plantas por parcela. Foi utilizada água de irrigação com alta (4,0 dS m^{-1}) ou baixa (1,3 dS m^{-1}) condutividade elétrica. A dose de potássio de 100% da recomendação correspondeu a 345 g de K_2O por planta ao ano. O maracujazeiro amarelo 'BRS GA1' é sensível ao estresse salino aplicado sucessivamente nas fases vegetativa e floração e vegetativa e frutificação, apresentando reduções na concentração intercelular de CO_2, taxa de assimilação de CO_2, eficiência instantânea do uso da água, número de frutos, e produção por planta. A irrigação com água de 4,0 dS m^{-1} na fase de frutificação é uma estratégia promissora, pois não compromete a produção. A dose de potássio equivalente a 60% foi melhor que 100% da recomendação em termos de trocas gasosas e o rendimento.

Termos para indexação: Osmorregulação; *Passiflora edulis* Sims; estresse salino.

INTRODUCTION

Fruit growing is one of the agribusiness branches that have great importance for the Brazilian economy, thus comprising a significant portion of the national gross domestic product (Associação Brasileira dos Produtores Exportadores de Frutas e Derivados - ABRAFRUTAS, 2019). Among the main fruits with relevant economic importance, passion fruit stands out, and the species *Passiflora edulis* Sims is the main cultivated, occupying more than 90% of the Brazilian orchards (Silva et al., 2020), becoming an excellent alternative for small and medium-sized producers. The fruit stands out as it can be used completely without any waste and can be consumed fresh or processed, in addition to being widely used in traditional medicine for being rich in vitamins A and C, folic acid, and nutrients such as calcium, iron, and potassium (Corrêa et al., 2016).

However, of the nine states of Northeast Brazil, half have more than 85% of their area classified as semi-arid, where high temperatures, low rainfall, and high evapotranspiration rates occur during most of the year, resulting in a scenario with limitation of surface water sources (Bezerra et al., 2018; Lima et al., 2018). In this region, it is common to use groundwater in irrigation, such as water from artesian wells, which in general contain high levels of dissolved salts, consequently limiting the growth and development of crops, even of those classified as tolerant to salt stress (Dias et al., 2019; Cova et al., 2020).

When in excess, salts cause reduction of osmotic potential in the soil solution, hindering the absorption of water and nutrients that are essential to plant metabolism, leading to a nutritional imbalance, in addition to being able to cause toxicity of specific ions (Silva et al., 2018; Ahmadi; Souri, 2020; Shooshtari et al., 2020). Water and/or soil salinity also interferes in physiological processes such as photosynthesis and cellular respiration and causes changes in the enzymatic and metabolic functions of plants (Tavares Filho et al., 2020).

In the absence of low-salinity water, it is possible to adopt strategies that enable the use of high-salinity waters, minimizing the deleterious effects on plants, such as the application of high-salinity water alternated with water of low electrical conductivity, since the response of plants to salt stress varies according to factors such as duration and time of exposure to stress, edaphoclimatic conditions, stages of plant development, irrigation management, and fertilization (Silva et al., 2019; Lima et al., 2020a; Lima et al., 2020b), as well as the composition of salts that cause salinity (Ahmadi; Souri, 2018; Ahmadi; Souri, 2019).

Potassium fertilization should also be considered as a strategy to reduce salt stress in the cultivation of yellow passion fruit. Potassium is essential in processes such as photosynthesis and cellular respiration, acts as an enzymatic activator, in carbohydrate translocation and synthesis and degradation of starch, and promotes maintenance of ionic balance and cell turgor, enabling greater resistance of the plant to abiotic stresses such as drought and salt stress, besides contributing to the improvement of fruit quality (Hasanuzzaman et al., 2018).

The application of this nutrient may result in the accumulation of osmolytes and an increase of antioxidant components in plants when subjected to salinity conditions (Ahanger et al., 2017). Moreover, in many high-yielding varieties of most horticultural crops higher dose of potassium is always beneficial in terms of higher yields and quality as well as resistance to adverse environmental factors (Mardanluo; Souri; Ahmadi, 2018; Tohidloo et al., 2018).

This study hypothesizes that irrigation with water of high electrical conductivity, varying with the stages of development of the crop, will mitigate the deleterious effects on gas exchange and production of yellow passion fruit since the intensity of stress depends on the phenological stage, duration of stress exposure and genotype, and that potassium can promote osmotic and oxidative homeostasis by osmoregulation and enzymatic activation.

In this context, the objective of present study was to evaluate the gas exchange and yield of 'BRS GA1' yellow passion fruit as a function of the strategies of irrigation with brackish water and potassium fertilization in two production cycles.

MATERIAL AND METHODS

The experiment was carried out from August 2019 to October 2020 under field conditions at the 'Rolando Enrique Rivas Castellón' Experimental Farm, belonging to the Center of Science and Agri-Food Technology - CCTA of the Federal University of Campina Grande – UFCG, in Pombal, PB, Brazil, located by the coordinates: 06º48'50" S latitude and 37º56'31" W longitude, at an altitude of 190 m. The data of temperature (maximum and minimum), mean relative humidity of the air, and precipitation of the first and second production cycles during the experimental period are shown in Figure 1. Precipitation occurred from 138 days after transplanting (DAT), with a total accumulated volume of 1145 mm.

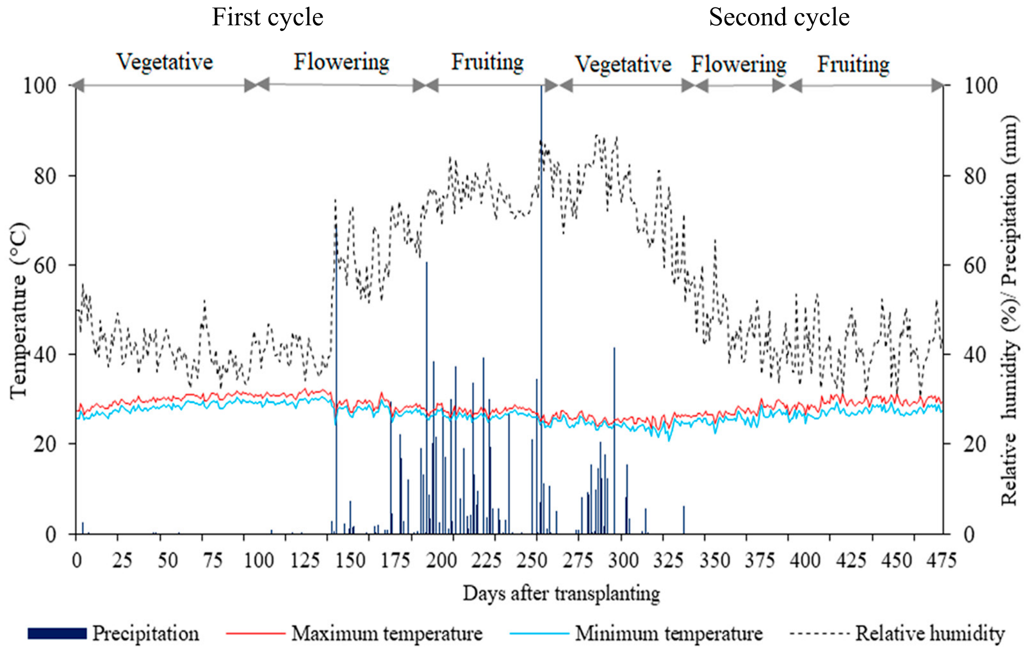

Figure 1: Data of precipitation, maximum and minimum temperature, and mean relative humidity of the air during the experimental period.

Treatments consisting of six brackish water irrigation management strategies - IMS: WS – without stress, irrigation with low-salinity water throughout the crop cycle as a control; irrigation with high-salinity water only in the vegetative stage - VE; flowering stage - FL; fruiting stage - FR; and successively in the vegetative and flowering stages - VE/FL; and vegetative and fruiting stages - VE/FR, and two doses of potassium (60 and 100% of the recommendation of Costa et al. (2008) were distributed in randomized blocks in a 6 × 2 factorial scheme with four replications, totaling 48 experimental units. Each plot consisted of 3 plants and a border of 3 m between plots. The dose of 100% potassium corresponded to the application of 345 g of K_2O per plant per year (Costa et al., 2008).

Two levels of irrigation water salinity were used, one with low (1.3 dS m^{-1}) and the other with high (4.0 dS m^{-1}) electrical conductivity, applied in the following stages of crop development in the first cycle: WS - irrigation with low-salinity water throughout the cultivation cycles (1-253 days after transplanting - DAT); irrigation with high-salinity water in the VE stage - from transplanting to the emergence of the floral primordium (50-113 DAT); FL - from the emergence of the floral primordium to the full development of the floral bud (anthesis) (114-198 DAT); FR - from fertilization of the floral bud to the appearance of fruits with yellow spots (199-253 DAT); VE/FL - in the vegetative and flowering stages (50-198 DAT); and VE/FR - in the vegetative and fruiting stages (50-113 and 199 -253 DAT). The same treatments were applied in the second cycle: WS - irrigation with low-salinity water throughout the second cultivation cycle (254 - 445 DAT); salt stress in VE stage (254 - 340 DAT); FL stage (341 -360 DAT); FR stage (361-445 DAT); VE/FL stages (254 - 360 DAT); and VE/FR stages (254 - 340 and 361 - 445 DAT).

Seeds of the yellow passion fruit 'BRS GA1' were used. For seedling formation, two seeds were sown in plastic bags with dimensions of 15 × 20 cm, filled with substrate, consisting of (volume basis) 84% soil (autoclaved), 15% sand, and 1% of aged bovine manure. At 61 days after sowing (DAS), transplanting to the field was performed.

Soil tillage consisted of plowing followed by harrowing, aiming at breaking soil clods and leveling the area. The soil of the experimental area was classified as an Entisol with loamy sand texture. Before transplanting the seedlings to the field, soil samples were collected at four different places in the experimental area in the 0-40 cm layer and then mixed to form a composite sample for chemical and physical characterization according to the methodologies recommended by Teixeira et al. (2017): Ca^{2+}, Mg^{2+}, Na^{+} , K^{+} , H^{+}+Al^{3+} = 2.44; 1.81; 0.81; 0.30; and 0 $cmol_c$ kg^{-1}, respectively; Exchangeable sodium percentage = 15.11%; Organic matter = 0.81 dag kg^{-1}; P = 10.60 mg kg^{-1}; electrical conductivity of the saturation extract = 1.52 dS m^{-1}; and pH in water (1:2.5) = 7.82; sand, silt and clay = 820.90; 170.10 and 9.00 g kg^{-1}, respectively; Apparent and particle density = 1.23 and 2.72 kg dm^{-3}, respectively.

The dimensions of the planting holes were 0.40 × 0.40 × 0.40 m. After opening the holes, fertilization was performed with 20 L bovine manure (37.80 mg dm^{-3} Ca^{2+}; 37.80 mg dm^{-3} Mg^{2+}; 350.29 mg dm^{-3} Na^{+}; 551.07 mg dm^{-3} K^{+}) and 50 g single superphosphate (17% P_2O_5), as recommended by Costa et al. (2008). Nitrogen and potassium fertilization was performed monthly, using urea (45% N) and potassium chloride (60% K_2O) as sources of nitrogen and potassium, respectively. For nitrogen, 65 g per plant were used in the crop formation stage and 160 g were applied in the flowering and fruiting stages. Plots under the 100% potassium dose received 65 g K_2O per plant in the crop formation stage (vegetative stage) and 280 g K_2O per plant in the flowering and fruiting stages, while other plots received 60% of this amount according to treatment.

Micronutrient application was performed fortnightly using the compound Dripsol micro® (1.1% Mg^{2+}; 0.85% Boron; 0.5% Copper (Cu-EDTA); Iron (Fe - EDTA) 3.4%; Manganese (Mn-EDTA) - 3.2%; 0.05% Molybdenum; 4.2% Zinc; with 70% EDTA chelating agent) at a concentration of 1 g L^{-1}, sprayed on the abaxial and adaxial sides of the leaves.

Plant spacing and formative and cleaning prunings were according to Pinheiro et al. (2022). The second cycle started after the crown cleaning (at 254 DAT) carried out at the end of the fruiting stage of the first cycle. The tertiary and quaternary branches which had already fruited were pruned to about 0.40 m from the upper wire. The plants were left for a period of 10 days under irrigation with water of low electrical conductivity.

The irrigation water of the treatment with the lowest level of electrical conductivity (1.3 dS m^{-1}) came from an artesian well located in the experimental area of CCTA/UFCG, whereas the water with ECw of 4.0 dS m^{-1} was prepared by the dissolution of NaCl in well water with ECw of 2.7 dS m^{-1} considering the relationship between ECw and salt concentration (Richards, 1954), according to Equation 1:

$$C = 10 \times ECw \quad (1)$$

where: C = Amount of salt to be added ($mmol_c$ L^{-1}); ECw = Electrical conductivity of water (dS m^{-1}).

At 50 DAT, the treatments with brackish water started. A localized drip irrigation system was adopted, using 32-mm-diameter PVC tubes in the mainline and 16-mm-diameter low-density polyethylene tubes in the lateral lines, with drippers with the application rate of 10 L h^{-1}. Two pressure-compensating drippers (GA 10 Grapa model) were installed close to each plant, 15 cm from the stem on each side. The plants were irrigated daily at 7:00 a.m., with the respective water, according to the strategy adopted, and the water depth was estimated based on crop evapotranspiration, according to Bernardo, Soares, and Mantovani (2013), obtained by Equation 2:

$$ETc = ETo \times Kc \quad (2)$$

where: ETc - crop evapotranspiration, mm day^{-1}; ETo - Penman-Monteith reference evapotranspiration, mm d^{-1}; and Kc - crop coefficient, dimensionless.

Reference evapotranspiration (ETo) was determined daily from climatic data collected at the São Gonçalo Weather Station, located in the municipality of Sousa - PB, and the data were used to determine the ETo by the Penman-Monteith method. The crop coefficient (Kc) used was equal to 0.4 (from 50-113 DAT; 254 - 340 DAT), 0.8 (from 114-198 DAT; 341-360 DAT), and 1.2 (from 199-253 DAT; 361- 445 DAT), according to the recommendation of Nunes et al. (2017).

The following parameters were evaluated: gas exchange (at 245 and 430 DAT for the first and second production cycles, respectively). The determinations were carried out in the fruiting stage, that is, the time when the plants had been subjected to the other irrigation strategies in the vegetative and flowering stages or to VE/FL and VE/FR combined. Gas exchange was quantified by stomatal conductance - *gs* (mol H_2O m^{-2} s^{-1}), transpiration - *E* (mmol H_2O m^{-2} s^{-1}), CO_2 assimilation rate - *A* (μmol CO_2 m^{-2} s^{-1}), and internal CO_2 concentration (μmol CO_2 m^{-2} s^{-1}) (*Ci*). These data were then used to determine the instantaneous water use efficiency (*WUEi*) (A/E) [(μmol m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$) and the instantaneous carboxylation efficiency (*CEi*) [(μmol m^{-2} s^{-1} (μmol m^{-2} s^{-1})$^{-1}$]. The evaluations were carried out between 6:00 and 9:00 a. m. on the third fully expanded leaf counted from the apex of the fruiting branches, using the infrared gas analyzer - IRGA (LCpro – SD, from ADC Bioscientific, UK), under natural conditions of air temperature, CO_2 concentration, and using an artificial radiation source of 1200 μmol m^{-2} s^{-1}, established by the photosynthetic light saturation curve (Fernandes et al., 2021).

At harvest, for the first cycle (199 to 253 DAT) and second cycle (361 to 445 DAT), ripe fruits were harvested (those that showed yellow or reddish peel color). After harvest, the following production variables per plant were analyzed: total number of fruits (TNF), quantified by counting the fruits, and fruit yield (Y). Fruit yield (t ha^{-1}) was estimated by multiplying the average fruit production per plant by the number of plants per hectare (1111 based on the plant spacing adopted).

The data obtained were evaluated by analysis of variance after the normality and homogeneity test of the data using the Shapiro-Wilk test. In cases of significance, the Scott-Knott test ($p \leq 0.05$) was applied for brackish water irrigation strategies, and the F test ($p \leq 0.05$) was applied for potassium doses, using SISVAR software version 5.7 (Ferreira, 2019).

RESULTS AND DISCUSSION

In the first cycle, there were significant effects ($p \leq 0.01$) of brackish water irrigation management strategies (IMS) on stomatal conductance (*gs*), CO_2 assimilation rate (*A*), instantaneous water use efficiency (*WUEi*), instantaneous carboxylation efficiency (*CEi*), total number of fruits (TNF) and fruit yield (Y) of 'BRS GA1' yellow passion fruit (Table 1). Potassium doses (KD) and the interaction between the studied factors (IMS × KD) significantly influenced only the total number of fruits per plant (TNF).

In the second production cycle, the stomatal conductance (*gs*), intercellular CO_2 concentration (*Ci*), CO_2 assimilation rate (*A*), instantaneous water use efficiency (*WUEi*), instantaneous carboxylation efficiency (*CEi*), total number of fruits (TNF), and fruit yield (Y) of yellow passion fruit (Table 1) were significantly influenced by brackish water IMS. The total number of fruits per plant (TNF) and gas exchanges were not significantly affected by KD and by the interaction between the studied factors (IMS × KD).

The IMS significantly affected the *gs* of yellow passion fruit plants in the first cycle (Figure 2A). Plants under the WS strategy obtained greater stomatal conductance, differing significantly from those under the other strategies, which did not differ from each other. As in the first cycle, *gs* in the second cycle was also significantly reduced under the VE, FL, FR, VE/FL, and VE/FR strategies.

Table 1: Summary of the analysis of variance for stomatal conductance (*gs* - mol H_2O m^{-2} s^{-1}), transpiration (*E* - mmol H_2O m^{-2} s^{-1}), intercellular CO_2 concentration (*Ci* - μmol CO_2 m^{-2} s^{-1}), CO_2 assimilation rate (*A* - μmol CO_2 m^{-2} s^{-1}), instantaneous water use efficiency (*WUEi* - (μmol m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$), instantaneous carboxylation efficiency (*CEi* - (μmol m^{-2} s^{-1} (μmol m^{-2} s^{-1})$^{-1}$), total number of fruits (TNF) and yield (Y – t ha^{-1}), in the first and second cycles of 'BRS GA1' yellow passion fruit cultivated under brackish water irrigation management strategies (IMS) and potassium doses (KD).

SV	DF	Mean squares							
		gs	*E*	*Ci*	*A*	*WUEi*	*CEi*	TNF[1]	Y
First cycle									
IMS	5	0.13^{**}	0.96^{ns}	2890.7^{ns}	163.7^{**}	6.13^{**}	0.005^{**}	367.03^{*}	24.2970^{**}
KD	1	0.05^{ns}	0.04^{ns}	6792.5^{ns}	18.9^{ns}	0.91^{ns}	0.0005^{ns}	295.02^{*}	16.8033^{**}
IMS × KD	5	0.01^{ns}	0.43^{ns}	1587.0^{ns}	12.5^{ns}	0.69^{ns}	0.0004^{ns}	143.67^{*}	6.2474^{ns}
Blocks	3	0.20^{ns}	1.22^{ns}	5458.5^{ns}	14.83^{ns}	0.04^{ns}	0.0005^{ns}	21.57^{ns}	1.5102^{ns}
Residual	33	0.01	0.68	1079.8	14.67	508.4	0.0006	57.42	3.5423
CV%		23.92	18.22	14.83	21.12	17.08	28.77	23.18	25.64
Second cycle									
IMS	5	0.061^{**}	0.48^{ns}	4227.4^{*}	65.11^{**}	4.20^{*}	0.0016^{**}	191.78^{**}	11.0331^{**}
KD	1	0.0080^{ns}	0.45^{ns}	553.5^{ns}	0.14^{ns}	1.97^{ns}	0.00010^{ns}	120.33^{ns}	0.2279^{ns}
IMS × KD	5	0.0095^{ns}	0.91^{ns}	268.9^{ns}	2.11^{ns}	1.26^{ns}	0.000032^{ns}	83.03^{ns}	2.0896^{ns}
Blocks	3	0.0058^{ns}	1.09^{ns}	2055.1^{ns}	0.99^{ns}	1.93^{ns}	0.000074^{ns}	65.47^{ns}	6.0661^{ns}
Residual	33	0.01	0.67	1764.35	6.59	1.44	0.00033	48.94	2.7960^{ns}
CV%		33.38	31.66	18.77	27.28	31.64	40.86	27.48	30.91

SV - Source of variation; DF - Degrees of freedom; CV (%) - Coefficient of variation; *significant at 0.05 probability level; **significant at 0.01 probability level; ns not significant. [1]Fruits harvested during 199 - 253 days after transplanting (DAT) in the first cycle and during 361 - 445 DAT in the second cycle.

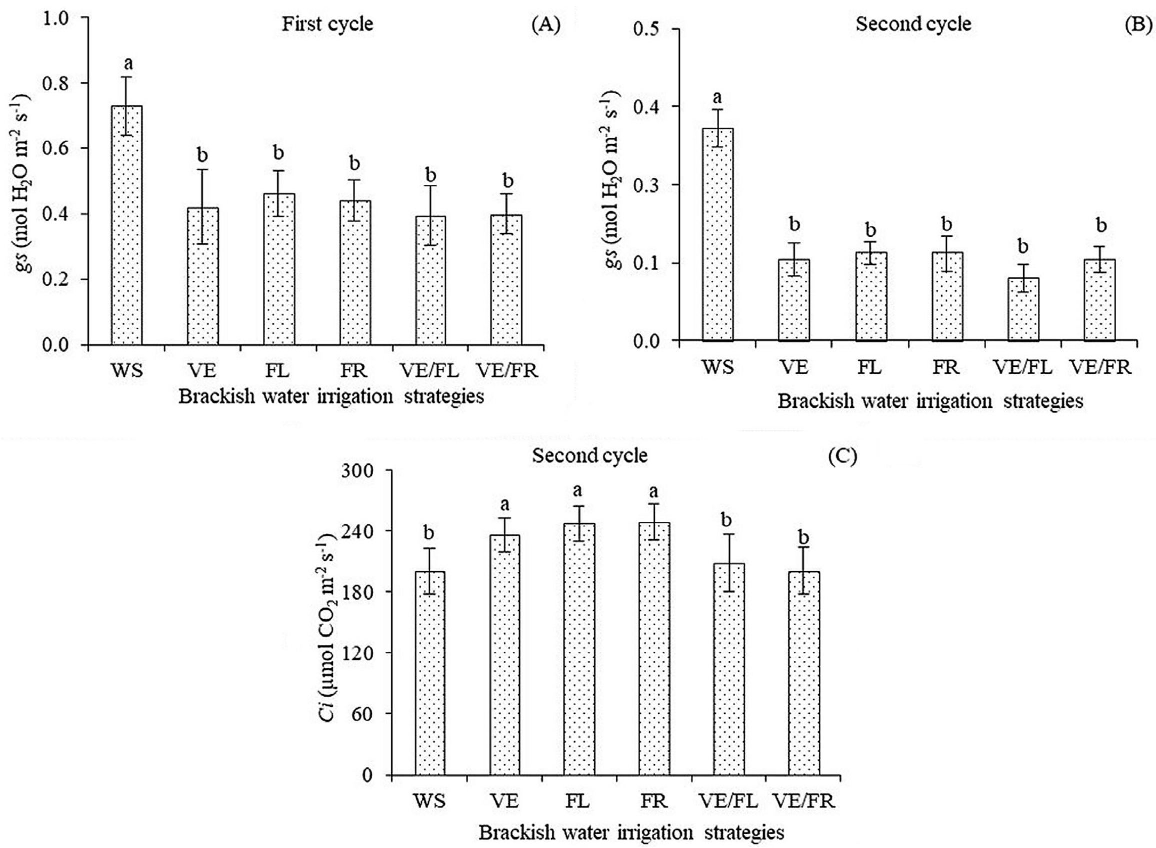

Figure 2: Stomatal conductance - *gs* in the first (A) and second (B) cultivation cycle and intercellular CO_2 concentration - *Ci* in the second cultivation cycle (C) of 'BRS GA1' yellow passion fruit as a function of brackish water irrigation strategies.

Means followed by the same letter indicate no significant difference between treatments by the Scott-Knott test ($p \leq 0.05$). WS - irrigation with low-salinity water throughout the cultivation cycle (1-253 and 254-445 days after transplanting - DAT, respectively, in the first - I and second - II cycle); salt stress in VE = vegetative stage (50-113 in cycle I and 254-340 DAT in cycle II); FL = flowering stage (114-198 in cycle I and 341-360 DAT in cycle II); FR = fruiting stage (199-253 in cycle I and 361-445 DAT in cycle II); VE/FL = vegetative and flowering stages (50-198 in cycle I and 254-360 DAT in cycle II); VE/FR = vegetative and fruiting stages (50-113 and 199-253 in cycle I and 254-340 and 361-445 DAT in cycle II). Vertical bars represent the standard error of the mean (n=4).

The effect of salt stress on stomatal conductance was more intense in the second production cycle (445 DAT) due to the greater accumulation of salts from irrigation water, which may have reduced the osmotic potential of the soil solution, restricting the absorption of water and nutrients by plants. In addition, the decrease in *gs* may be associated with the tolerance mechanism of the species, to reduce the loss of water to the atmosphere and the absorption of water and nutrients from the soil solution without compromising the photosynthesis activity (Dias et al., 2018).

Plants under the VE, FL, and FR strategies stood out with the highest values (on average 244.20 µmol mol^{-1}) of intercellular CO_2 concentration (*Ci*) in the second cultivation cycle (Figure 2C), significantly differing from plants subjected to the WS, VE/FL, and VE/FR strategies, which obtained the lowest values (on average 203.33 µmol CO_2 mol^{-1}). The decrease in *Ci* may be associated with the reduction in *gs* and can be attributed to the longer exposure to the deleterious effects of salt stress. Moreover, during the flowering and fruiting stages, there were no precipitation events (Figure 1), which may have contributed to the increase in the effect of salt stress on the physiology of plants under stress in the VE/FL and VE/FR stages. Salinity induces several changes in physiological processes, but the magnitude of the damage depends on the genotype, nutritional status, environmental conditions (Tedeschi et al., 2017), and severity and duration of stress (Gupta; Huang, 2018).

Regarding the CO_2 assimilation rate in the first cultivation cycle (Figure 3A), it was verified that plants under the VE, FR, and VE/FL strategies did not differ from each other and had the lowest values (12.39, 16.32, and 14.27 μmol m^{-2} s^{-1}) compared to WS, FL, and VE/FR, whose values were on average 34.69% higher. In the second cycle (Figure 3B), plants subjected to the FR, VE/FL, and VE/FR strategies had the lowest mean values of *A* (7.61, 6.15, and 7.28 μmol m^{-2} s^{-1}) compared to those under the other strategies, which did not differ significantly from one another. The decrease in the CO_2 assimilation rate (at 253 and 445 DAT) may be a consequence of the decrease in *gs* (Figure 2A and B) and demonstrates that the limitations are of non-stomatal origin because, in this treatment, the plants did not have restriction in CO_2 diffusion to the substomatal chamber (Figure 2C), that is, there was availability of carbon dioxide for the photosynthetic process, but there may have been inhibition in the activity of ribulose-1.5-bisphosphate carboxylase/oxygenase.

It is worth pointing out that, in both cycles, yellow passion fruit plants subjected to the FL strategy stood out with the highest values of *A* (Figure 3A and B) and did not differ from plants that were grown under the WS strategy. On the other hand, plants irrigated with ECw of 4.0 dS m^{-1} in the VE stage obtained the lowest values of *A* in the first cycle, but in the second cycle, they reached the highest values and did not differ significantly from those cultivated under the WS strategy. The increase in *A* in plants grown in the second cultivation cycle may be related to the mitigating effect of the precipitation events (Figure 1) that occurred during this phenological stage (360.2 mm), concentrated in 86 days, which may have contributed to the reduction of salt concentration in the root zone.

Brackish water irrigation strategies also influenced the *WUEi* of 'BRS GA1' yellow passion fruit in the first and second production cycle (Figure 4A and 4B). Plants in the first cycle under the FL strategy obtained statistically higher *WUEi* compared to those that received the other strategies of irrigation with brackish water. In the second cycle, plants under the strategies FR, VE/FL, and VE/FR were the ones that showed the lowest mean values of *WUEi* (3.34, 2.91, and 3.27 μmol m^{-2} s^{-1}/ μmol mol^{-1}), not differing from each other.

In general, in the first and second cycles of cultivation, the salt stress imposed on the yellow passion fruit in the FR, VE/FL, and VE/FR stages reduced the *WUEi*, which can be attributed to the change in the osmotic potential of the soil caused by excess salts, resulting in decreased availability of water to plants; in addition, this reduction may be associated with a decrease in *A* (Figure 3), since this variable is directly linked to *WUEi* because its estimation depends on the relationship with transpiration (*E*). The decrease in *WUEi* may also be a consequence of the reduction in stomatal conductance (Figure 2) because when *gs* is limited to reduce water loss, there are also reductions in CO_2 influx to the cell and CO_2 assimilation rate (Silva et al., 2018).

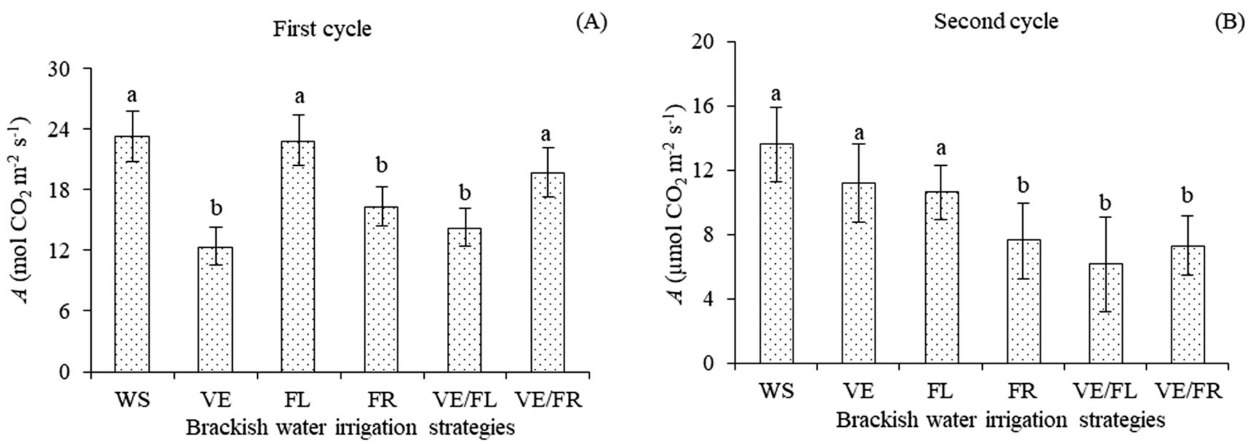

Figure 3: CO_2 assimilation rate - *A* of 'BRS GA1' yellow passion fruit as a function of brackish water irrigation strategies in the first (A) and second (B) production cycle.
For the description of the treatments see Figure 2.

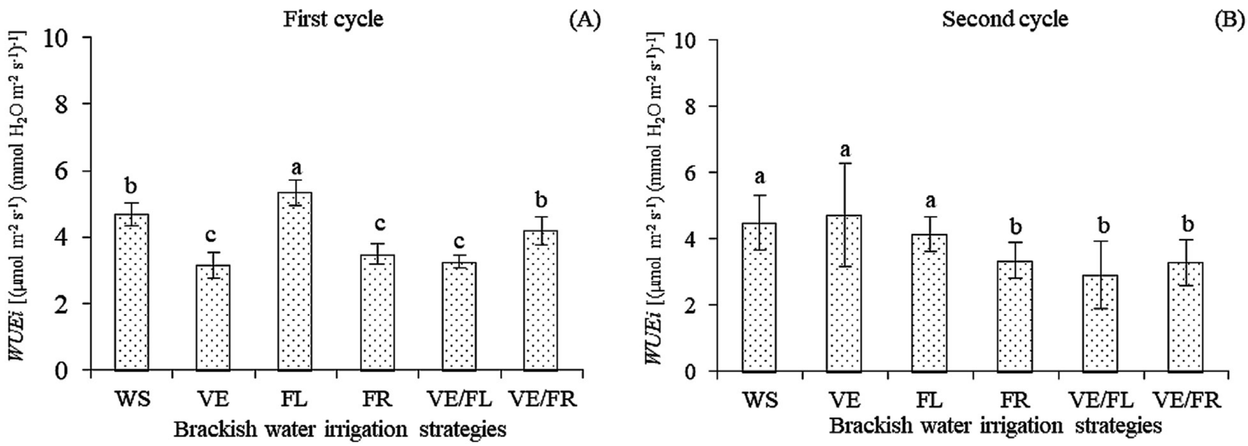

Figure 4: Instantaneous water use efficiency - *WUEi* of 'BRS GA1' yellow passion fruit as a function of brackish water irrigation strategies in the first (A) and second (B) production cycle.
For the description of the treatments see Figure 2.

The instantaneous carboxylation efficiency of yellow passion fruit (Figure 5A and 5B) was also significantly affected by brackish water irrigation strategies. In the first crop cycle, plants under irrigation with brackish waters in the stages VE, FR, and VE/FL had lower values of *CEi*, differing from those under WS, FL, and VE/FR. In the second cycle, irrigation with brackish water in the stages VE, FL, FR, VE/FL, and VE/FR resulted in lower *CEi* values, significantly differing from the WS strategy. *CEi* is a way of evaluating whether or not non-stomatal factors influence the photosynthetic rate of plants. When *Ci* increases as a result of the stomatal opening rate, the *A/Ci* ratio decrease; perhaps the entry of CO_2 in the leaf mesophyll may have decreased due to the decrease in *gs*.

The decrease in the *CEi* of yellow passion fruit may also be related to the deleterious effects of salt stress on plants, which may have affected photosynthetic activity, along with the reduction in the CO_2 assimilation rate (Figure 3). In addition, this result is probably a consequence of the low CO_2 assimilation rate, compared to the CO_2 found in the substomatal chamber of these plants, because if *Ci* increases and there is a reduction in CO_2 consumption in chloroplasts due to a reduction in photosynthetic activity, the *A*/*Ci* ratio (*CEi*) will also decrease (Soares et al., 2018).

The analysis of the interaction between brackish water irrigation strategies and each K dose for the total number of yellow passion fruits (TNF) in the first cultivation cycle (Figure 6A) showed a significant difference in the irrigation strategies for the two K doses. For plants fertilized with 60% of the K recommendation, the ones under the FL (27.00), VE/FL (22.50), and VE/FR (33.5) strategies obtained the lowest mean values of TNF, differing from those under the other irrigation strategies, which on average had 42.67 fruits per plant. On the other hand, plants fertilized with 100% of the recommended dose and under the VE (25.75) and VE/FL(19.50) strategies obtained the lowest mean values of TNF, differing from those under the other strategies, which did not differ from each other and had an average of 34.0 fruits per plant.

In the second cycle (Figure 6B), plants irrigated with water of high electrical conductivity in the VE/FL stages significantly reduced their TNF compared to those that were subjected to the other irrigation management strategies. The lower mean values of TNF observed in plants under the VE/FL strategies (Figure 6A and 6B) can be attributed to the limitations that occurred in *gs* (Figure 2A and B) and *A* (Figure 3A and B); in addition, these plants as well as those under the VE/FR strategy (Figure 6A) in the first production cycle were under greater exposure to salt stress, since they were irrigated with higher ECw in two phenological stages for 211 days, which may have caused changes in physiology, affecting their growth and production.

Following the analysis of K doses in the irrigation management strategies (IMS) for TNF in the first cycle (Figure 6A), there was a significant effect only for plants subjected to the VE strategy, whose fertilization with 100% of the recommendation of Costa et al. (2008) resulted in lower values of TNF (25.75 fruits) when compared to those fertilized with 60% K, which obtained the highest values of TNF (39.25 fruits), with a decrease of 34.40% as the K dose increased. The reduction observed in plants fertilized with the K_2O dose of 100% may be due to the salinity of irrigation water (4.0 dS m^{-1}) and the potassium source (KCl) used in this study, which may have accentuated salt stress on plants.

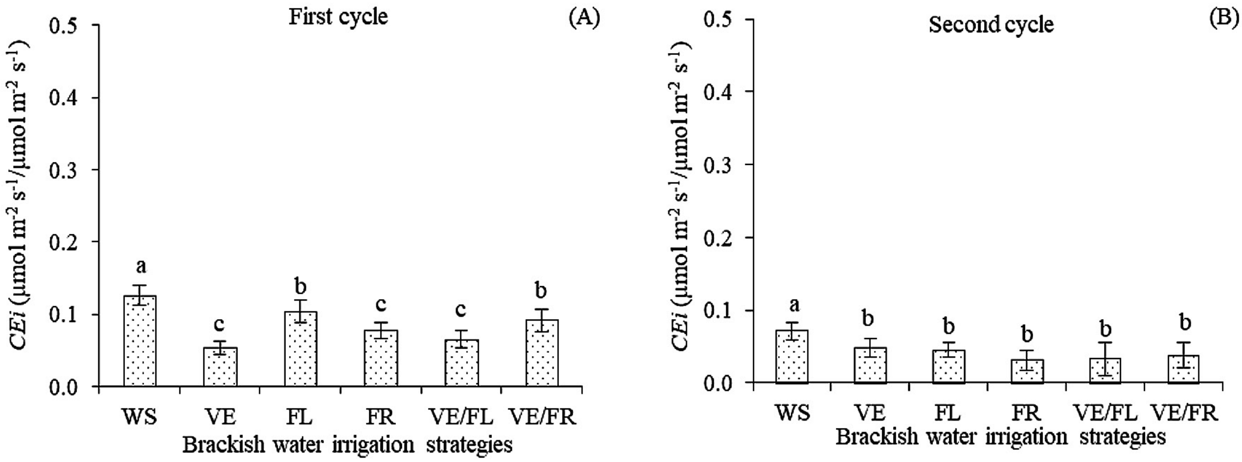

Figure 5: Instantaneous carboxylation efficiency - *CEi* of 'BRS GA1' yellow passion fruit as a function of brackish water irrigation strategies, in the first (A) and second (B) production cycle.

For the description of the treatments see Figure 2.

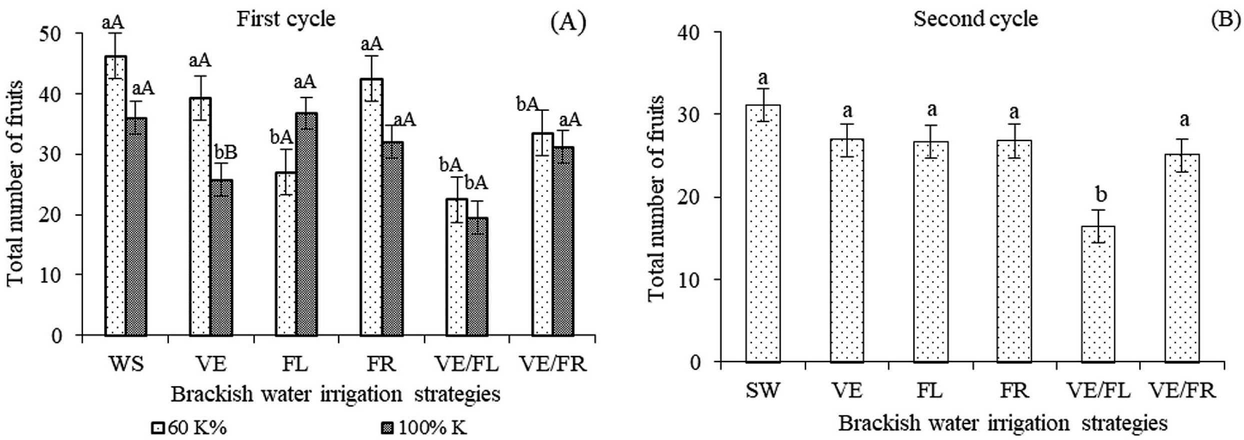

Figure 6: Total number of fruits - TNF of 'BRS GA1' yellow passion fruit harvested as a function of the interaction between brackish water irrigation strategies and potassium doses, in the first cycle (A); and as a function of brackish water irrigation strategies, in the second production cycle (B).

For the description of the treatments see Figure 2. Figure A - means with the same uppercase letters indicate that there were no significant differences between potassium doses in the same brackish water irrigation strategy by the F test at 0.05 probability level; and means with the same lowercase letters at the same potassium dose indicate that there was no significant difference between brackish water irrigation strategies by Scott-Knott test at $p \leq 0.05$. Figure B - Means followed by the same letter indicate no significant difference between treatments by the Scott-Knott test at $p \leq 0.05$.

In the second cycle (Figure 6B), the total number of fruits of yellow passion fruit under the VE strategy (86 days of exposure to higher ECw) is among the highest values of TNF, unlike plants subjected to the VE strategy (63 days of exposure to the highest level of ECw) in the first cycle (Figure 6A), which obtained the lowest values of TNF when fertilized with 100% of the recommendation. The higher TNF obtained in the second production cycle (Figure 6B) may have resulted from the precipitation events (Figure1) that occurred in the vegetative stage (360.2 mm distributed in 86 days), which contributed to the reduction in the accumulated of salts in the root zone and thereby influenced the production of the plants.

The deleterious effects of salts on gas exchange, observed mainly in *A* (Figure 3), may have decreased the TNF of plants under the VE strategy in the first cycle (Figure

6A), due to restriction of water potential, confirmed by the results of the present study, in which the effects of salt stress from irrigation water of higher ECw compromised gas exchange, as observed in the first cycle (Figure 3A).

The yield of yellow passion fruit (Figure 7A and 7C) was also influenced by brackish irrigation strategies. In the first production cycle (Figure 7A), the plants subjected to the WS, VE, FR, and VR/FR strategies had statistically higher Y than those that were irrigated with high salinity water in the FL and VE/FL stages. A similar result also occurred in the second cycle (Figure 7C), except for plants under irrigation with brackish water in the VE and VE/FR stages, which also had lower yield values. Irrigation with brackish water in the vegetative and flowering stages caused reductions in yield, which may have occurred due to the excess of salts causing malformation during the development of the plants' reproductive structures, especially in the anther and pollen grain (Araújo et al., 2016).

Dias et al. (2011), while evaluating the effects of different electrical conductivities of irrigation water (ECw from 0.5 to 4.5 dS m^{-1}), associated with stage of application of biofertilizer on yellow passion fruit production, obtained yields of 8.86 t ha^{-1} in plants irrigated with ECw of 3.5 and 4.5 dS m^{-1} and 14.35 t ha^{-1} for those irrigated with water of 0.5 dS m^{-1}. In the present study, irrigation with water with electrical conductivity of 1.3 dS m^{-1} during the first and second cycle resulted in yields of 9.48 and 6.98 t ha^{-1}, respectively. On the other hand, the decrease in passion fruit yield observed in plants subjected to the FL and VE/FL strategies compared to the study conducted by Dias et al. (2011) may be related to the differences in the edaphoclimatic conditions of the region and the studied genotype.

Potassium doses influenced the yield in first cycle (Figure 7B) of 'BRS GA1' yellow passion fruit. Fertilization with 60% dose of the potassium recommendation resulted in 14.9% higher yield (1.18 t ha^{-1}), differing significantly from the value obtained by plants fertilized with the dose of 100%. Possibly the reduction in yield with the higher dose of potassium occurred due to the potassium source (KCl) used in this study, which has a high salt index, as mentioned earlier; in addition, the increase in the dose of potassium may have caused difficulty in the absorption of Ca^{2+} and Mg^{2+} by the plant (Sousa et al., 2014).

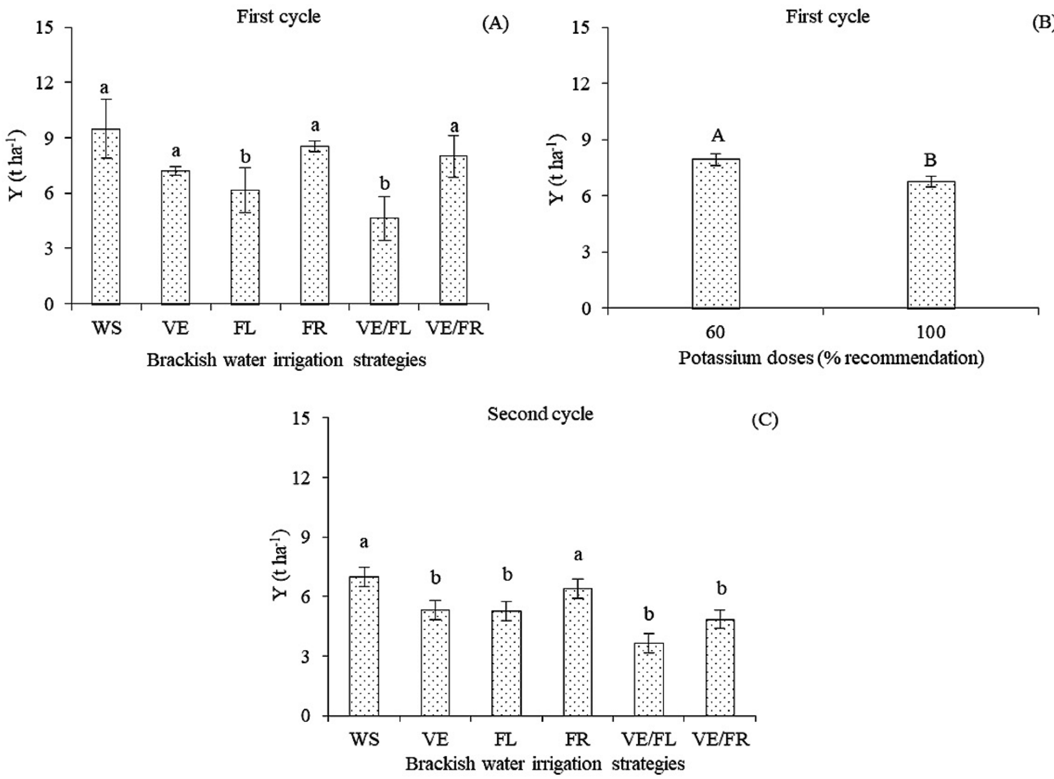

Figure 7: Yield – Y of 'BRS GA1'yellow passion fruit as a function of brackish water irrigation strategies in the first (A) and second production cycle (C) and potassium doses (B), in the first cycle.
For the description of the treatments see Figure 2.

CONCLUSIONS

'BRS GA1' yellow passion fruit is sensitive to salt stress applied successively in the vegetative and flowering stages and vegetative and fruiting stages, showing reductions in the intercellular CO_2 concentration, CO_2 assimilation rate, instantaneous water use efficiency, number of fruits, and yield. Irrigation with water of 4.0 dS m^{-1} electrical conductivity in the fruiting stage is a promising strategy for the cultivation of 'BRS GA1' yellow passion fruit, as it does not compromise production. For the cultivation of 'BRS GA1' yellow passion fruit, the dose of potassium equivalent to 60%, in comparison to 100% recommendation, is the most adequate in terms of gas exchange and yield.

AUTHOR CONTRIBUTION

Data collection: Pinheiro, F. W. A.; Conceptual Idea: Lima, G. S.; Methodology design: Gheyi, H. R.; Soares, L. A. A.; Data analysis and interpretation: Gheyi, H. R.; Nobre, R. G.; Fernandes, P. D.; Funding acquisition: Lima, G. S. and Writing and editing: Lima, G. S.; Gheyi, H. R.; Soares, L. A. A.

ACKNOWLEDGMENTS

To the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for providing the financial support (Proc. CNPq 429732/2018-0).

REFERENCES

AHANGER, M. A. et al. Plant growth under water/salt stress: ROS production; antioxidants and significance of added potassium under such conditions. Physiology and Molecular Biology of Plants, 23:731-744, 2017.

AHMADI, M.; SOURI, M. K. Growth and mineral elements of coriander (*Corianderum sativum* L.) plants under mild salinity with different salts. Acta Physiologia Plantarum, 40:194, 2018.

AHMADI, M.; SOURI, M. K. Nutrient uptake, proline content and antioxidant enzymes activity of pepper (*Capsicum annuum* L.) under higher electrical conductivity of nutrient solution created by nitrate or chloride salts of potassium and calcium. Acta Scientiarum Polonorum Hortorum Cultus, 18(5):113-122, 2019.

AHMADI, M.; SOURI, M. K. Growth characteristics and fruit quality of chili pepper under higher electrical conductivity of nutrient solution induced by various salts. AGRIVITA Journal of Agricultural Science, 42(1):143-152, 2020.

ARAÚJO, E. B. G. et al. Crescimento inicial e tolerância de cultivares de meloeiro à salinidade da água. Revista Ambiente & Água, 11(2):462-471, 2016.

ASSOCIAÇÃO BRASILEIRA DOS PRODUTORES EXPORTADORES DE FRUTAS E DERIVADOS - ABRAFRUTAS. Estatísticas de exportações de frutas no primeiro semestre de 2019. 2021. Available in: <https://abrafrutas.org/2019/07/estatistica-de-exportacoes-de-frutas-no-primeiro-semestre-de-2019/>. Access in: February, 10, 2022.

BERNARDO, S.; SOARES, A. A.; MANTOVANI, E. C. Manual de irrigação. 8.ed. Viçosa: Ed. UFV. 2013. 625p.

BEZERRA, I. L. et al. Morphophysiology of guava under saline water irrigation and nitrogen fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental, 22(1):32-37, 2018.

CORRÊA, R. et al. The past decade findings related with nutritional composition, bioactive molecules and biotechnological applications of *Passiflora* spp. (passion fruit). Trends in Food Science & Technology, 58:79-95, 2016.

COSTA, A. F. S. et al. Recomendações técnicas para o cultivo do maracujazeiro. Vitória: Incaper, 2008. 56p. Incaper. Documentos, 162.

COVA, A. M. W. et al. Physiological and biochemical responses and fruit production of noni (*Morinda citrifolia* L.) plants irrigated with brackish water. Scientia Horticulturae, 260:108852, 2020.

DIAS, A. S. et al. Gas exchanges and photochemical efficiency of West Indian cherry cultivated with saline water and potassium fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental, 22(9):628-633, 2018.

DIAS, A. S. et al. Gas exchanges, quantum yield and photosynthetic pigments of West Indian cherry under salt stress and potassium fertilization. Revista Caatinga, 32(2):429-439, 2019.

DIAS, T. J. et al. Produção do maracujazeiro e resistência mecânica do solo com biofertilizante sob irrigação com águas salinas. Revista Ciência Agronômica, 42(3):644-651, 2011.

FERNANDES, E. A. et al. Cell damage, gas exchange, and growth of *Annona squamosa* L. under saline water irrigation and potassium fertilization. Semina: Ciências Agrárias, 42(3):999-1018, 2021.

FERREIRA, D. F. SISVAR: A computer analysis system to fixed effects split plot type designs. Revista Brasileira de Biometria, 37(4):529-535, 2019.

GUPTA, B.; HUANG, B. Mechanism of salinity tolerance in plants: Physiological, biochemical, and molecular characterization. International Journal of Genomics, 2014:701596, 2018.

HASANUZZAMAN, M. et al. Potassium: A vital regulator of plant responses and tolerance to abiotic stresses. Agronomy, 8(3):31, 2018.

LIMA, G. S. de. et al. Potassium does not attenuate salt stress in yellow passion fruit under irrigation management strategies. Revista Caatinga, 33(4):1082-1091, 2020b.

LIMA, G. S. de. et al. Production characteristics of sesame genotypes under different strategies of saline water application. Revista Caatinga, 33(2):490-499, 2020a.

LIMA, G. S. de. et al. Salinity and cationic nature of irrigation water on castor bean cultivation. Revista Brasileira de Engenharia Agrícola e Ambiental, 22(4):267-272, 2018.

MARDANLUO, S.; SOURI, M. K.; AHMADI, M. Plant growth and fruit quality of two pepper cultivars under different potassium levels of nutrient solutions. Journal of Plant Nutrition, 41(12):1604-1614, 2018.

NUNES, J. C. et al. Gas exchange and productivity of yellow passion fruit irrigated with saline water and fertilized with potassium and biofertilizer. Ciencia e Investigación Agraria, 44(2):168-183, 2017.

PINHEIRO, F. W. A. et al. Gas exchange and yellow passion fruit production under irrigation strategies using brackish water and potassium. Revista Ciência Agronômica, 53:e20217816, 2022.

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

SHOOSHTARI, F. Z. et al. Glycine mitigates fertilizer requirements of agricultural crops: Case study with cucumber as a high fertilizer demanding crop. Chemical and Biological Technologies in Agriculture, 7(1):1-10, 2020.

SILVA, E. M. da. et al. Growth and gas exchanges in soursop under irrigation with saline water and nitrogen sources. Revista Brasileira de Engenharia Agrícola e Ambiental, 22(11):776-781, 2018.

SILVA, G. S. S. de. et al. Physicochemical quality, bioactive compounds and *in vitro* antioxidant activity of a new variety of passion fruit cv. BRS Sertão Forte (*Passiflora cincinnata* Mast.) from Brazilian semiarid region. Scientia Horticulturae, 272:109595, 2020.

SILVA, S. S. da. et al. Gas exchanges and production of watermelon plant under salinity management and nitrogen fertilization. Pesquisa Agropecuária Tropical, 49:e54822, 2019.

SOARES, L. A. A. dos. et al. Gas exchanges and production of colored cotton irrigated with saline water at different phenological stages. Revista Ciência Agronômica, 49(2):239-248, 2018.

SOUSA, G. G. de et al. Fertirrigação potássica na cultura do morango no litoral Cearense. Bragantia, 73(1):39-44, 2014.

TAVARES FILHO, G. S. et al. Desenvolvimento de mudas de moringa oleífera (LAM) submetida a diferentes níveis de água salina. Brazilian Journal of Development, 6(7):48671-48683, 2020.

TEDESCHI, A. et al. Effect of salinity on growth parameters, soil water potential and ion composition in *Cucumis melo* cv. Huanghemi in North-Western China. Journal of Agronomy and Crop Science, 203:41-55, 2017.

TEIXEIRA, P. C. et al. Manual de métodos de análise de solo. 3.ed., Brasília: Embrapa Solos. 2017. 573p.

TOHIDLOO, G.; SOURI, M. K.; ESKANDARPOUR, S. Growth and fruit biochemical characteristics of three strawberry genotypes under different potassium concentrations of nutrient solution. Open Agriculture, 3:356-362, 2018.