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Gas exchange and yellow passion fruit production under irrigation strategies using brackish water and potassium[1]

Trocas gasosas e produção do maracujazeiro amarelo sob estratégias de irrigação com águas salobras e potássio

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ABSTRACT - The occurrence of water sources with high concentrations of salts is a common problem in the semi-arid region of north-eastern Brazil. The search for management strategies that can minimize the effect of salt stress on crops is therefore extremely important. As such, this study aimed to evaluate gas exchange and production in the yellow passion fruit 'BRS GA1'as a function of irrigation strategies using brackish water and doses of potassium. The research was carried out under field conditions in São Domingos, in the state of Paraíba, Brazil, using a randomized block design in a 6 × 2 factorial scheme, with treatments comprising six irrigation strategies using water (irrigation with low-salinity water throughout the cycle – WS; irrigation with high-salinity water during the vegetative stage – VE; during the flowering stage – FL; the fruiting stage – FR; during successive vegetative/flowering stages - VE/FL; successive vegetative/fruiting stages - VE/FR) and two doses of potassium (60% and 100% of the recommended dose of 345 g K_2O per plant per year), with four replications and three plants per plot. Two levels of water salinity (1.3 and 4.0 dS m^{-1}) were used during different phenological stages of the crop. Irrigation with water at 4.0 dS m^{-1} reduced the leaf water potential, leaf osmotic potential, stomatal conductance, transpiration, and rate of CO_2 assimilation of the yellow passion fruit, regardless of the irrigation strategy. The continuous salt stress during the vegetative and flowering stages compromised production in the yellow passion fruit.

Key words: Salt stress. Photosynthesis. Fertilizing. *Passiflora edulis* Sims.

RESUMO - A ocorrência de fontes hídricas com elevadas concentrações de sais é um problema frequente na região semiárida do Nordeste do Brasil. Assim, a busca por estratégias de manejo capazes de minimizar o efeito do estresse salino nas culturas é de extrema importância. Neste contexto, objetivou-se com este trabalho avaliar as trocas gasosas e a produção do maracujazeiro amarelo 'BRS GA1' em função das estratégias de irrigação com águas salobras e doses de potássio. A pesquisa foi desenvolvida sob condições de campo em São Domingos, PB, Brasil, utilizando-se o delineamento de blocos casualizados em esquema fatorial 6 × 2, sendo os tratamentos constituídos de seis estratégias de irrigação com águas salinas (SE - irrigação com água de baixa salinidade durante todo ciclo; irrigação com água de alta salinidade na fase vegetativa - VE; floração - FL; frutificação - FR; nas fases sucessivas vegetativa/floração - VE/FL; vegetativa/frutificação - VE/FR) e duas doses de potássio (60 e 100% (345 g de K_2O por planta por ano) da recomendação, com quatro repetições e três plantas por parcela. Utilizaram-se dois níveis de salinidade da água (1,3 e 4,0 dS m^{-1}), em diferentes fases fenológicas da cultura. A irrigação com água de 4,0 dS m^{-1} reduziu o potencial hídrico e osmótico foliar, a condutância estomática, a transpiração e a taxa de assimilação de CO_2 do maracujazeiro-azedo, independente da estratégia de irrigação. O estresse salino nas fases vegetativa e de floração de forma contínua comprometeu a produção do maracujazeiro-azedo.

Palavras-chave: Estresse salino. Fotossíntese. Adubação. *Passiflora edulis* Sims.

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INTRODUCTION

Belonging to the family Passifloraceae, the yellow passion fruit (*Passiflora edulis* Sims) has great social and economic importance in Brazil, which is currently the world's largest producer and consumer of the fruit (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2017). It is estimated that more than 60% of yellow passion fruit production is destined for fresh consumption, the juice being the main product (VIANNA-SILVA *et al*., 2008). It is considered a functional food, as it contains polyphenolic substances, polyunsaturated fatty acids, and fibers, in addition to the confirmed antioxidant capacity of the fruit peel (CAZARIN *et al*., 2014).

In 2018, Brazil produced 602.6 thousand tons of passion fruit, with the northeast of the country responsible for 62.3% of this total; among the states of the northeast, Bahia, Ceará and Rio Grande do Norte were the most important, with a production of 160.9, 147.5, and 18.4 thousand tons, respectively (INSTITUTO BRASILEIRO DE GEOGRAFIA E STATÍSTICA, 2019).

In the semi-arid region of north-eastern Brazil, some of the water sources used in irrigation are considered brackish, a determining factor for soil salinization and a reduction in crop yield. An excess of salts in the irrigation water promotes stress in the plants and has a negative effect on chlorophyll biosynthesis, photochemical efficiency and gas exchange, and consequently on production, due to the action of specific ions such as sodium (Na^+) and chlorine (Cl^-) (NUNES *et al*., 2017).

Given the scarcity of water resources in the semi-arid region of Brazil, it is often necessary to use water with moderate and high concentrations of salts in irrigated agriculture. It is therefore extremely important to find irrigation strategies that could minimize the harmful effects of salt stress on plants and ensure the long-term sustainability of crops.

Among the alternatives, the application of brackish water based on the developmental stage of the plants is important, as the tolerance and sensitivity of the plants vary for species, cultivar, cationic and/or anionic nature, stress intensity and duration, irrigation management, and soil and climate conditions in the region (SOARES *et al*., 2018). Several studies have shown the use of brackish water at different stages of plant development to be a promising alternative in reducing the negative impact of salt stress on plants, as seen in the melon (CORDÃO TERCEIRO NETO *et al*., 2012), cotton (SOARES *et al*., 2018) and watermelon (SILVA *et al*., 2020).

Another option that should be considered for reducing salt stress in plants is potassium fertilization, due to the role played by this element in enzyme activation, stomatal opening and closure, photosynthesis, protein synthesis, and the translocation of carbohydrates (TAIZ *et al*., 2017). K^+ helps in the cation-anion balance, osmoregulation, the movement of water and energy transfer, and helps to reduce the generation of reactive oxygen species (ROS) in plants (HASANUZZAMAN *et al*., 2018).

In this context, this study aimed to evaluate gas exchange and production in the yellow passion fruit 'BRS GA1' grown under different irrigation strategies using brackish water and potassium fertilization.

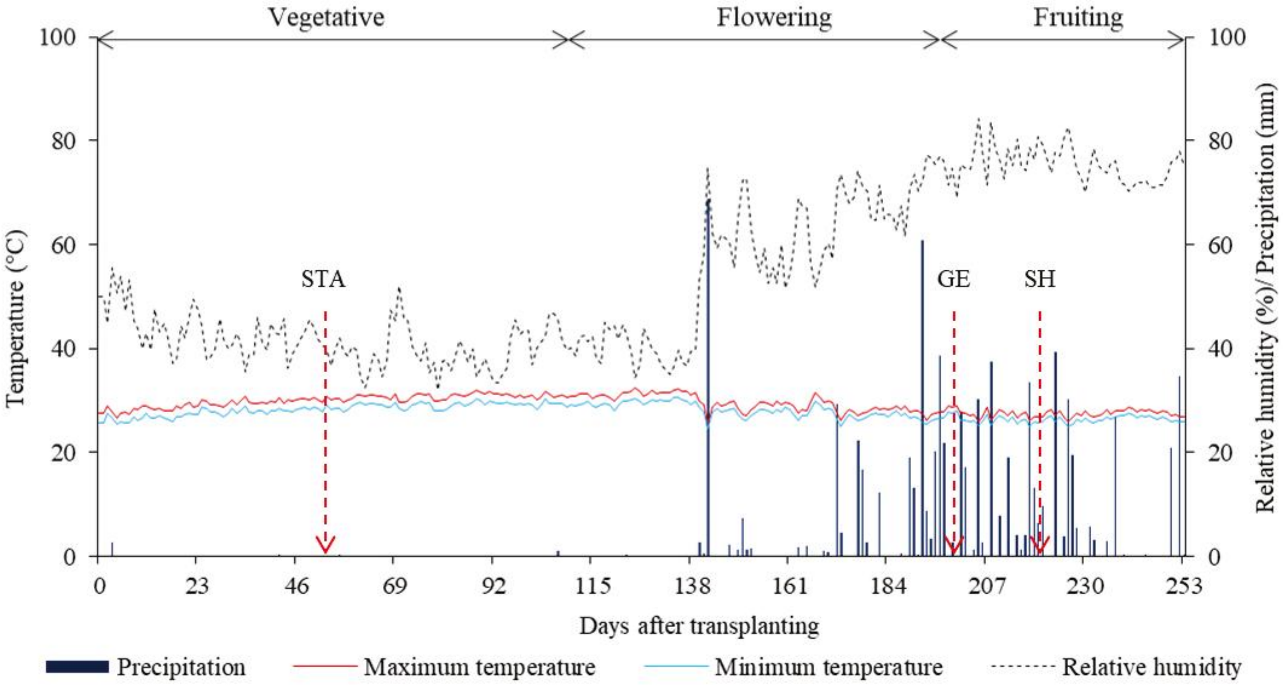
MATERIAL AND METHODS

The experiment was conducted from August 2019 to May 2020 at the 'Rolando Enrique Rivas Castellón' Experimental Farm, belonging to the Centre of Food Science and Technology (CCTA) of the Federal University of Campina Grande (UFCG) in Santo Domingos (06º48'50" S; 37º56'31" W, 190 m), in the state of Paraíba, Brazil. According to the Köppen classification adapted for Brazil, the district has a semi-arid tropical climate (BSh) with a mean annual rainfall of 700 mm (ALVARES *et al*., 2013). The data for air temperature (maximum and minimum), relative humidity, and rainfall, recorded during the experiment, are shown in Figure 1. It can be seen that rainfall occurred from 138 days after transplanting, with an accumulated total during the cycle of 780 mm.

The study included six brackish water irrigation strategies (irrigation with low-salinity water throughout the growth cycle - WS; irrigation with high-salinity water during the vegetative stage - VE; during the flowering stage - FL; the fruiting stage - FR; during successive vegetative/flowering stages - VE/FL; successive vegetative/fruiting stages - VE/FR) and two doses of potassium (60% and 100% of the recommended dose of K_2O conform Costa *et al*., 2008), distributed in randomized blocks in a 6 × 2 factorial scheme with four replications, making a total of 48 experimental units, each plot consisting of three plants. The 100% dose of potassium corresponded to 345 g K_2O per plant per year.

In setting up the management strategies, two sources of irrigation water were used, with an electrical conductivity (ECw) of 1.3 dS m^{-1} (low salinity) and 4.0 dS m^{-1} (high salinity), which were applied during the different stages of crop development: irrigation with low-salinity water throughout the growth cycle - WS (1-253 days after transplanting - DAT) and with high-salinity water during the VE stages - from the start of secondary-branch emission to the emergence of the floral primordium (50-113 DAT); FL – the emergence of the floral primordium and development of the floral bud (anthesis) (114-198 DAT); FR – from fertilization of the floral bud to the appearance of fruit

Figure 1 – Mean data for maximum and minimum air temperature, rainfall, and relative humidity of air during the experimental period



STA – Start of treatment application; GE - Determination of variables of gas exchange; SH – Start of the harvest

with interspersed yellow spots (199-253 DAT); VE/FL - during the vegetative and flowering stages (50-198 DAT); VE/FR - during the vegetative and fruiting stages (50-113 and 199-253 DAT).

Seeds of the ‘BRS GA1’ yellow passion fruit were used. To grow the seedlings, two seeds were sown in 500-mL plastic bags, 15 × 20 cm in size, filled with substrate consisting of (on the volume basis) 84% soil, 15% autoclaved sand and 1% decomposed bovine manure. Sixty-one days after sowing (DAS), the seedlings were transplanted to the field and irrigated with low-salinity water. Irrigation management with the different types of water was started at 50 DAT.

The soil was prepared by ploughing and harrowing to break up the soil clods and leveling the area. The soil of the experimental area was classified as a typical Eutrophic Ta Fluvic Neosol with a loamy sand texture. Before transplanting the seedlings to the field, soil samples were collected from the 0-40 cm layer of the experimental area. These were then mixed to form a composite sample whose chemical and physical characteristics (Table 1) were obtained as per the methodologies proposed by Teixeira *et al*. (2017).

The dimensions of each hole were 0.40 × 0.40 × 0.40 m. After opening the holes, fertilization was carried out using 20 L cattle manure and 50 g single superphosphate (18% P_2O_5 and 20% Ca^{2+}), as recommended by Costa *et al*. (2008). Fertilization with nitrogen and potassium was carried out monthly, using urea as the source of nitrogen (45% N) and potassium chloride (60% K_2O) as the source of potassium. During the crop formation stage, 65 g N was used per plant, while during the flowering and fruiting stages, 160 g N was used per plant. For the 100% dose of potassium, 65 g K_2O per plant was applied during the vegetative stage and 280 g K_2O per plant during the flowering and fruiting stage.

Micronutrients were applied every two weeks, using Dripsol micro compound (Mg^{2+} = 1.1%; Boron = 0.85%; Copper (Cu-EDTA) = 0.5%; Iron (Fe-EDTA) = 3.4%; Manganese (Mn-EDTA) = 3.2%; Molybdenum = 0.05%; Zinc = 4.2%) at a concentration of 1 g L^{-1}, sprayed onto the adaxial and abaxial surfaces of the leaves.

The rows were spaced 3 m apart, with 3 m between plants, using a vertical trellis system made from no. 14 smooth wire. A string was used to train the plant onto the trellis. When the plants reached a height of 10 cm above the trellis, the apical bud was pruned to allow emission of the secondary branches, with one branch on each side left to grow to a length of 1.10 m. Once the secondary branches had reached this length, the apical bud was again pruned to favor the emission of the tertiary branches, which were grown to a height of 30 cm from the ground to form a curtain. During the experiment, any tendrils and orthotropic stems were eliminated, to favour the development of the crop.

Table 1 - Chemical and physical characteristics of the soil (0-0.40 m layer) of the experimental area

Chemical characteristics								
pH (H_2O)	OM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+
(1:2.5)	dag kg^{-1}	(mg kg^{-1})	.... cmol$_c$ kg^{-1}					
7.82	0.81	10.60	0.30	0.81	2.44	1.81	0.00	0.00
-------------- Chemical characteristics ----------------				----------------------- Physical characteristics -----------------------				
ECse	CEC	SARse	ESP	Granulometric fraction (g kg^{-1})			Moisture (dag kg^{-1})	
(dS m^{-1})	cmol$_c$ kg^{-1}	(mmol $L^{-1})^{0.5}$	%	Areia	Silte	Argila	33.42 kPa[1]	1519.5 kPa[2]
1.52	5.36	6.67	15.11	820.90	170.10	9.00	12.87	5.29

pH – Hydrogen potential, OM – Organic matter: Wet digestion Walkley-Black; Ca^{2+} and Mg^{2+} extracted with KCl 1 M pH 7.0; Na^+ and K^+ extracted using NH_4OAc 1 M pH 7.0; Al^{3+} + H^+ extracted using CaOAc 0.5 M pH 7.0; ECse – Electrical conductivity of the saturation extract; CEC – Cation exchange capacity; SARse – Sodium adsorption ratio of the saturation extract; ESP – Exchangeable sodium percentage; [1]soil moisture at field capacity; [2]soil moisture at the permanent wilting point

The irrigation water for the treatment with the lowest level of electrical conductivity (1.3 dS m^{-1}) came from an artesian well located in the experimental area; the water of ECw of 4.0 dS m^{-1}, was prepared by dissolving iodine-free NaCl in the well water (ECw of 1.3 dS m^{-1}). To prepare the irrigation water with the highest salinity, the relation between the ECw and the salt concentration was considered, as per Eq. 1:

$$C = 10 \times ECw \tag{1}$$

where:

C = Concentration of salts in the irrigation water (mmol$_c$ L^{-1});

ECw = Electrical conductivity of the water (dS m^{-1}).

A drip irrigation system was adopted using 32-mm PVC tubes for the mainline, 16-mm low-density polyethylene tubes for the lateral lines, and drippers with a flow of 10 L h^{-1}. Two self-compensating drippers (Grapa GA 10) were installed 15 cm from the stem of each plant. The plants were irrigated daily at 07:00, following the adopted strategy. The irrigation depth was estimated based on the crop evapotranspiration, as per Bernardo, Soares and Mantovani (2013), obtained by Eq. 2:

$$ETc = Eto \times Kc \tag{2}$$

where:

ETc - crop evapotranspiration, mm day^{-1};

ETo - Penman-Monteith reference evapotranspiration, mm d^{-1};

Kc - crop coefficient, dimensionless.

The reference evapotranspiration (ETo) was determined daily from climate data collected from the São Gonçalo Weather Station, located in the district of Sousa, Paraíba, the data being used to determine the ETo using the Penman-Monteith method. A crop coefficient of 0.4 (from 50-113 DAT), 0.8 (from 114-198 DAT), and 1.2 (from 199-253 DAT) was used, following the recommendation of Nunes *et al*. (2017).

During the experiment, the cropping and phytosanitary treatments recommended for the crop were carried out, including weed control, monitoring the appearance of pests and diseases, and adopting control measures whenever necessary.

At 199 days after transplanting (DAT), gas exchange, leaf water potential (Ψw), leaf osmotic potential (Ψs), and the percentage cell damage (%D) were evaluated. Stomatal conductance - *gs* (mol H_2O m^{-2} s^{-1}), rate of transpiration - *E* (mmol H_2O m^{-2} s^{-1}), the net rate of CO_2 assimilation - *A* (μmol m^{-2} s^{-1}), and the intercellular CO_2 concentration – *Ci* (μmol m^{-2} s^{-1}) were measured in the third leaf from the apex of the fruiting branches, using the LCPro+ portable photosynthesis meter (ADC BioScientific Ltd). From these data, 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 - *EiCi* [(μmol m^{-2} s^{-1}(μmol m^{-2} $s^{-1})^{-1}$] were determined.

The Ψw was measured with the aid of a Scholander-type pressure chamber between the 3rd and 5th leaf from the apex in good phytosanitary condition (SCHOLANDER *et al*., 1965). To take the measurement, the chamber was pressurized with compressed gas until the liquid was exuded by the xylem, at that time the applied pressure was recorded.

To determine the leaf osmotic potential Ψs, leaves from the middle third of the plants were collected in each experimental plot, placed in plastic bags, and stored at 5 °C; to extract the cell juice, samples were placed in tubes and centrifuged at 10,000 × g for 10 min; the freezing point of the samples was determined in 5 mL aliquots using a microprocessor osmometer (PZL 1000) to obtain the osmolality of the sample in mOsmol kg^{-1} H_2O, which was converted to MPa, as recommended by Bagatta, Pacifico and Mandolino (2008), using Eq. 3.

$$\Psi s\,(\text{MPa}) = -\,C\,(\text{mOsmol kg}^{-1}) \times 2.58 \times 10^{-3} \quad (3)$$

To determine the percentage of cell-membrane damage, 10 leaf discs were prepared using a perforator with a diameter of 19.58 mm, washed with distilled water, and then placed in beakers containing 50 mL distilled water, and hermetically sealed. The beakers were kept at 25 ºC for 90 minutes when the initial electrical conductivity (Ci) was determined. The beakers were then placed in a forced-air ventilation oven and subjected to 80 ºC for 90 minutes, after cooling the final electrical conductivity (Cf) was measured. The percentage cell-membrane damage was obtained as per Scotti-Campos *et al*. (2013), using Eq. 4:

$$\%D = Ci/Cf \times 100 \quad (4)$$

where:

%D = percentage cell-membrane damage;

Ci = initial electrical conductivity (dS m^{-1});

Cf = final electrical conductivity (dS m^{-1}).

Passion fruit production was measured from 199 to 253 DAT, when the total production per plant (PROD) was determined from the sum of the weight of all the fruits harvested from each plant. The mean fruit weight (MFW) was determined from the ratio between the total fruit production and the number of fruits per plant.

After testing the normality and homogeneity of the data, the results were evaluated using analysis of variance by F-test. When the data were significant, the Scott-Knott test ($p < 0.05$) was used for the after cooling irrigation strategies, and Tukey's test ($p < 0.05$) for the doses of potassium, using the SISVAR ESAL statistical software.

RESULTS AND DISCUSSION

There was a significant effect of the brackish water irrigation strategies on leaf water potential (Ψw), leaf osmotic potential (Ψs), percentage cell damage (%D), stomatal conductance (gs), transpiration (E), intercellular CO_2 concentration (Ci), and net rate of CO_2 assimilation (A) in the 'BRS GA1' yellow passion fruit (Table 2). On the other hand, the doses of potassium, and the interaction between the irrigation management strategies using brackish water and doses of potassium (IMS × DK), had no significant influence on the analysed variables at 199 days after transplanting.

The leaf water potential (Ψw) in the plants of the 'BRS GA1' yellow passion fruit (Figure 2A) irrigated with high-salinity water (4.0 dS m^{-1}) during the VE, FL, FR, and VE/FL stages was reduced significantly compared to those submitted to the WS strategies. Comparing the plants grown under the WS and VE/FR strategies, no significant difference can be seen between them. Despite the lack of a significant difference between the VE and VE/FR strategies, the Ψw of the plants grown under an ECw of 4.0 during the VE/FR stages was greater. This maybe related to the rainfall that occurred during the fruiting stage (413 mm), which must have contributed to a reduction in salt concentration in the root zone. These reductions in Ψw due to the increase in the salinity level of the water, reflect the accumulation of ions in the cells of the leaf tissue, especially Na^+ and Cl^-, found in high concentrations in the irrigation water. The Ψw of the leaf is effectively reduced by salinity, and this reduction leads to a loss of turgor, inducing stomatal closure and, consequently, a reduction in crop transpiration (SILVA *et al*., 2016).

For the leaf osmotic potential Ψs of the yellow passion fruit (Figure 2B), it can be seen that the plants irrigated with low ECw water (WS) obtained the highest value (-0.4461 MPa) compared to those submitted to the

Table 2 - Summary of the F-test for leaf water potential (Ψw), leaf osmotic potential (Ψs), percentage cell damage (%D), stomatal conductance (*gs*), transpiration (*E*), intercellular CO_2 concentration (*Ci*), and net rate of CO_2 assimilation (*A*) in the 'BRS GA1' yellow passion fruit grown under irrigation management strategies (IMS) using salt water and doses of potassium (DK), 199 days after transplanting

Source of variation	F-test						
	Ψw	Ψs	%D	*gs*	*E*	*Ci*	*A*
Irrigation management strategy (IMS)	**	**	**	**	**	**	**
Doses of potassium (DK)	ns	ns	ns	ns	ns	ns	ns
Interaction (IMS × DK)	ns	ns	ns	ns	ns	ns	ns
Blocks	ns	ns	ns	ns	ns	ns	ns
CV (%)	38.43	25.90	18.34	35.62	23.67	13.02	23.03

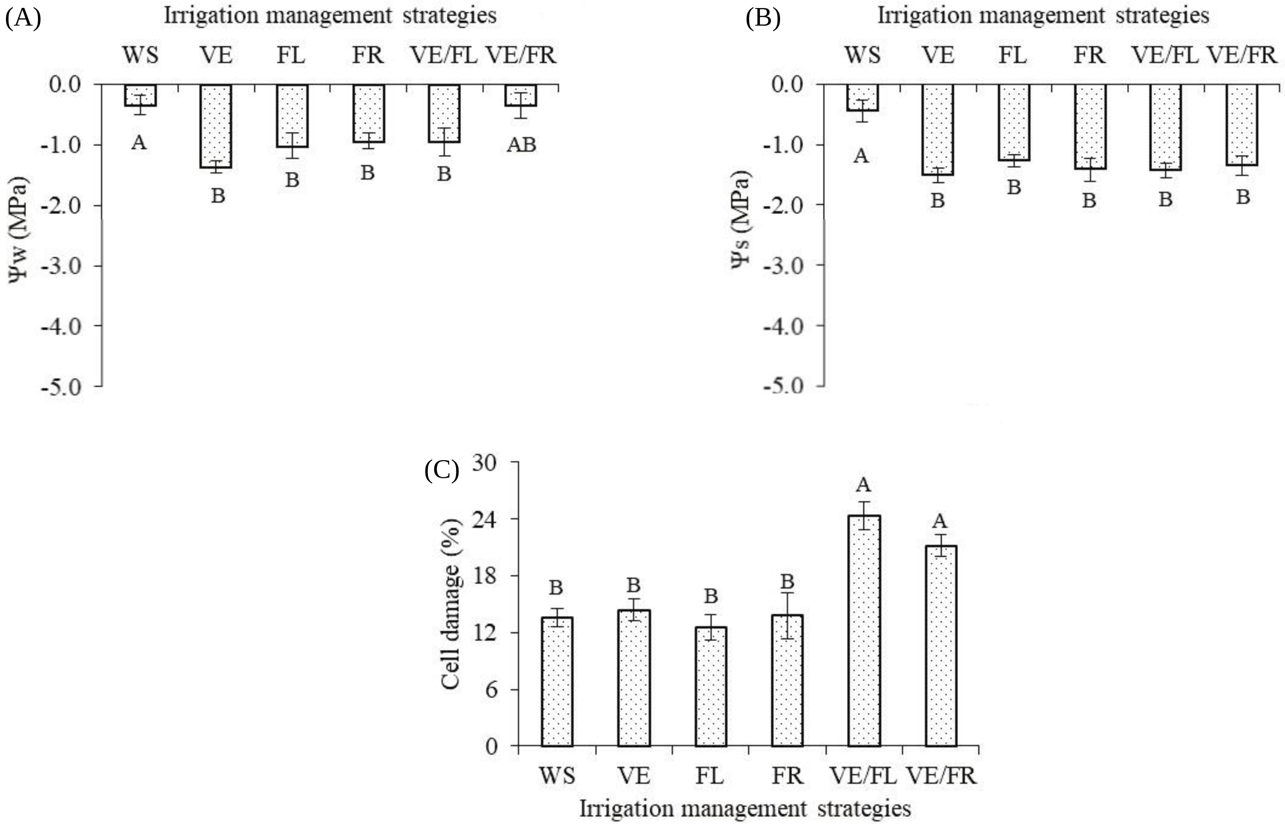
ns - not significant, ** - significant at $p < 0.01$

VE, FL, FR, and VE/FL strategies. When comparing the Ψs of plants submitted to the VE, FL, FR, VE/FL, and VE/FR strategies, no significant effect is seen among them. The reduction in osmotic potential due to the increase in salts in the irrigation water is a plant response that favors the potential gradient and contributes to the absorption of water and nutrients (CRUZ *et al*., 2018). It should be noted that this happens due to salts accumulating in the leaf tissue, which on the one hand favors osmotic adjustment, however, when in high concentrations, can have a direct effect on the cell metabolism.

The strategies using salt water significantly influenced the percentage of cell damage in the 'BRS GA1' yellow passion fruit (Figure 2C). It can be seen that plants irrigated with low ECw water (WS) throughout the growth cycle, and subjected to brackish stress during the vegetative (VE), flowering (FL), and fruiting (FR) stages had the lowest percentage of cell damage (13.59, 14.40, 12.59, and 13.78%), respectively, differing significantly from the plants irrigated with high-salinity water during the vegetative/flowering (VE/FL) and vegetative/fruiting (VE/FR) stages which had the highest values, 24.39% and 21.21%, respectively. The increase in %D may reflect the period of stress undergone by the plants, considering that during the VE/FL (50-198 DAT) and VE/FR (50-113/199-253 DAT) stages there were 369 and 413 mm of rainfall, respectively. During the vegetative stage, there was no contribution from the rainfall, and during the flowering stage, the rainfall events started from 138 DAT and were poorly distributed throughout the cycle. It should be noted that during these stages (VE/FL and VE/FR) the rainfall was concentrated over 26 and 27 days, respectively.

Another factor that may have contributed was ionic effects since an increase in the salt concentration of the water can change the nutritional balance, including the availability of Ca^{2+}, an element that is essential for cell-wall formation, generating an increase in the percentage of electrolyte leakage with increasing salinity

Figure 2 - Leaf water potential - Ψw (A), leaf osmotic potential - Ψs (B), and percentage cell damage - %D (C) in the 'BRS GA1' yellow passion fruit as a function of irrigation management strategies using salt water and doses of potassium, at 199 days after transplanting



Mean values followed by different letters show a significant difference between treatments by the Scott-Knott test ($p < 0.05$). Vertical bars represent the standard error of the mean (n=4); WS - irrigation with low-salinity water throughout the growth cycle (1-253 days after transplanting - DAT); salt stress during the VE = vegetative stage (50-113 DAT); FL = flowering stage (114-198 DAT); FR = fruiting stage (199-253 DAT); VE and FL = vegetative and flowering stage (50-198 DAT); VE/FR = vegetative and fruiting stage (50-113/199-253 DAT)

(FERRAZ *et al*., 2015). The reduction in cell damage in plants grown under the FL strategies may be related to the pH-reducing effect of the rainfall that occurred during this phenological stage. It should be noted that the flowering stage covered the period from 114 to 198 DAT, i.e. 84 days, however, during this period there were 368 mm of rainfall, concentrated over 26 days.

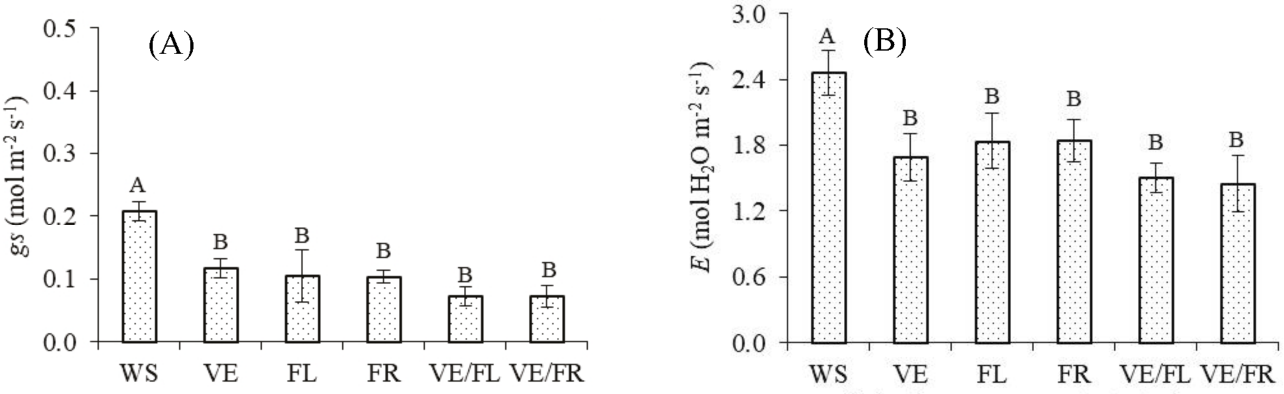
Testing the mean values for *gs* and *E* (Figure 3A and B), a significant difference can be seen between the plants irrigated with low-salinity water (WS) and those that were submitted to the other salt-water management strategies (VE, FL, FR, VE/FL, VE/FR). Plants that were not subjected to stress (WS) had the highest values for *gs* and *E* (0.2081 mol m^{-2} s^{-1} and 2.4581 mol H_2O m^{-2} s^{-1}, respectively). Stomatal regulation is considered an important tolerance mechanism to salt stress in plants, as it reduces the rate of transpiration and, therefore, the loss of water to the atmosphere, also reducing the absorption of water and salts (DIAS *et al*., 2018), and reflecting in a lower accumulation of ions in the plant tissue, an important factor for most glycophytes exposed to salt stress (BEZERRA *et al*., 2018).

According to Gonçalves *et al*. (2010), there is a direct relationship between *E* and *gs*, and the water vapor flow to the atmosphere being reduced as the stomata close. As a result, there is a reduction in stomatal conductance, with a consequent reduction in transpiration. Similar results were found by Sousa *et al*. (2016), who, working with irrigation water salinity levels of between 0.6 and 3.0 dS m^{-1}, found a significant reduction in *gs*, *A*, and *E* in citrus irrigated with high-salinity water.

For the intercellular CO_2 concentration (Figure 4A), the plants submitted to the VE/FL and VE/FR salinity management strategies had the highest values (298.31 and 272.50 µmol m^{-2} s^{-1}) differing statistically from the plants grown under the other irrigation strategies (WS, VE, FL, and FR). The plants subjected to salt stress show a reduction in stomatal conductance, rate of photosynthesis, and internal CO_2 concentration; there may however be an increase in the intercellular CO_2 concentration under severe stress conditions, possibly due to non-stomatal effects on the photosynthetic apparatus (LACERDA *et al*., 2020; TAIZ *et al*., 2017). The data obtained in the VE/FL and VE/FR treatments show the occurrence of these non-stomatal effects, with an increase seen in membrane damage (Figure 2C) and the internal CO_2 concentration (Figure 4A), and greater reductions in the rate of photosynthesis (Figure 4B).

For the net rate of CO_2 assimilation - *A* in the yellow passion fruit (Figure 4B), the greatest value (15.59 µmol m^{-2} s^{-1}) is seen for plants submitted to the WS strategy, differing statistically from those submitted to the other irrigation management strategies (VE, FL, FR, VE/FL, and VE/FR). When comparing plants of the yellow passion fruit submitted to different salt-water irrigation strategies, the greatest reductions can be seen to occur during the VE/FL and VE/FR stages, with a reduction in the net CO_2 assimilation rate of 8.32 and 9.44 µmol m^{-2} s^{-1} in plants that received the lowest level of ECw (WS) throughout the cycle. The reduction in *A* seen in the yellow passion fruit maybe related to the time the plants were exposed to salt stress, considering that in the VE/FL and VE/FR strategies the period of application of the high-salinity

Figure 3 - Stomatal conductance - *gs* (A) and transpiration - *E* (B) in the 'BRS GA1' yellow passion fruit as a function of irrigation management strategies using brackish water, at 199 days after transplanting



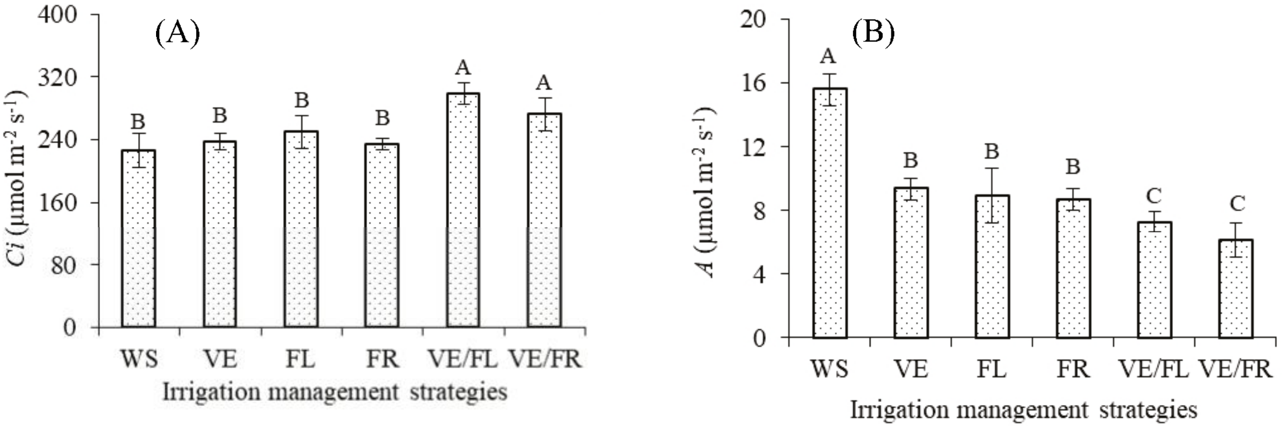
Mean values followed by different letters show a significant difference between treatments by the Scott-Knott test ($p < 0.05$). Vertical bars represent the standard error of the mean (n=4); WS - irrigation with low-salinity water throughout the growth cycle (1-253 days after transplanting - DAT); salt stress during the VE = vegetative stage (50-113 DAT); FL = flowering stage (114-198 DAT); FR = fruiting stage (199-253 DAT); VE and FL = vegetative and flowering stage (50-198 DAT); VE/FR = vegetative and fruiting stage (50-113/199-253 DAT) water was 148 and 90 days, respectively (considering the rainfall that occurred during this stage). There are statistical differences in plants of the yellow passion fruit between the VE, FL, and FR strategies compared to the VE/FL and VE/FR strategies. One aspect to be considered is that salt-water irrigation (ECw = 4.0 dS m^{-1}) reduced the rate of net CO_2 assimilation compared to those plants that received water at a lower level of salinity (1.3 dS m^{-1}) irrespective of the phenological stage of the plants. A similar situation also occurred with stomatal conductance (Figure 3A) and transpiration (Figure 3B).

There is a significant effect of the brackish water irrigation strategies on the instantaneous carboxylation efficiency (*EiCi*), instantaneous water use efficiency (*WUEi*), total production per plant (PROD), and mean fruit weight (MFW) in the 'BRS GA1' yellow passion fruit (Table 3). The doses of potassium and the interaction between the factors (IMS × DK) had no significant effect ($p > 0.05$) on any of the variables under analysis.

The instantaneous water use efficiency (Figure 5A) in plants grown under saline stress during the flowering stage (FL) was lower than those that received water at a lower level of salinity (1.3 dS m^{-1}) throughout the growth cycle (WS), and ECw of 4.0 dS m^{-1} during the VE, FR, VE/FL, and VE/FR stages. The *WUEi* relates the amount of carbon that the plant fixes to each unit of water that is lost during the process of photosynthesis (SILVA *et al*., 2015); as such, better instantaneous water use efficiency ensures greater CO_2 absorption with a minimum of water loss (FURTADO *et al*., 2013).

The instantaneous carboxylation efficiency (*EiCi*) of the yellow passion fruit 'BRS GA1' also differed significantly depending on the salt-water irrigation strategy, where the highest value [0.0553 µmol m^{-2} s^{-1}(µmol m^{-2} s^{-1})$^{-1}$] was

Figure 4 - Intercellular CO_2 concentration - *Ci* (A), and net rate of CO_2 - *A* assimilation (B) in the 'BRS GA1' yellow passion fruit as a function of irrigation management strategies using brackish water, at 199 days after transplanting



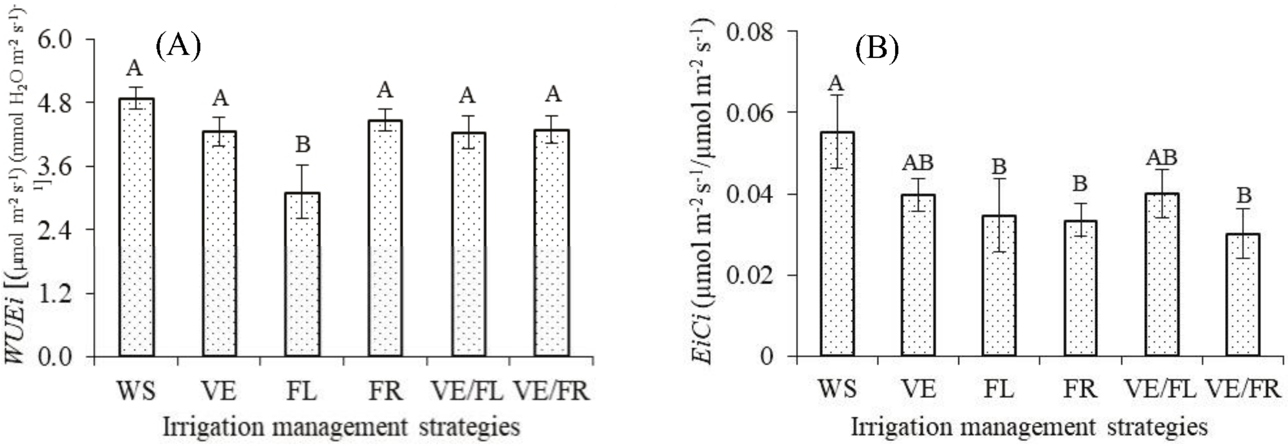
Mean values followed by different letters show a significant difference between treatments by the Scott-Knott test ($p < 0.05$). Vertical bars represent the standard error of the mean (n=4); WS - irrigation with low-salinity water throughout the growth cycle (1-253 days after transplanting - DAT); salt stress during the VE = vegetative stage (50-113 DAT); FL = flowering stage (114-198 DAT); FR = fruiting stage (199-253 DAT); VE and FL = vegetative and flowering stage (50-198 DAT); VE/FR = vegetative and fruiting stage (50-113/199-253 DAT)

Table 3 - Summary of the F-test for instantaneous water use efficiency (*WUEi*) and instantaneous carboxylation efficiency (*EiCi*) 199 days after transplanting (DAT), with the total yield per plant (PROD) and mean fruit weight (MFW), in the 'BRS GA1' yellow passion fruit grown under irrigation management strategies (IMS) using brackish water and doses of potassium, harvested from 199 to 253 DAT

Source of variation	Teste F			
	WUEi	*EiCi*	PROD	MFW
Irrigation management strategy (IMS)	**	**	**	*
Doses of potassium (DK)	ns	ns	ns	ns
Interaction (IMS × DK)	ns	ns	ns	ns
Blocks	ns	ns	ns	ns
CV (%)	15.21	32.12	25.63	17.76

ns - not significant, ** - significant at $p < 0.01$

Figure 5 - Instantaneous water use efficiency - *WUEi* (A) and instantaneous carboxylation efficiency - *EiCi* (B), in plants of the yellow passion fruit ‘BRS GA1’ as a function of the irrigation management strategies using brackish water, at 199 days after transplanting



Mean values followed by different letters show a significant difference between treatments by the Scott-Knott test ($p < 0.05$). Vertical bars represent the standard error of the mean (n=4); WS - irrigation with low-salinity water throughout the growth cycle (1-253 days after transplanting - DAT); salt stress during the VE = vegetative stage (50-113 DAT); FL = flowering stage (114-198 DAT); FR = fruiting stage (199-253 DAT); VE and FL = vegetative and flowering stage (50-198 DAT); VE/FR = vegetative and fruiting stage (50-113/199-253 DAT)

obtained when low-salinity water was used throughout the growth cycle during the WS stage, not differing statistically from the VE or VE/FL strategies (Figure 5B). On the other hand, plants irrigated under the FL, FR, and VE/FR strategies showed a reduction in *EiCi* of 0.0207, 0.0218, and 0.0251 [μmol m^{-2} s^{-1}(μmol m^{-2} s^{-1})$^{-1}$], respectively, compared to the control treatment (WS).

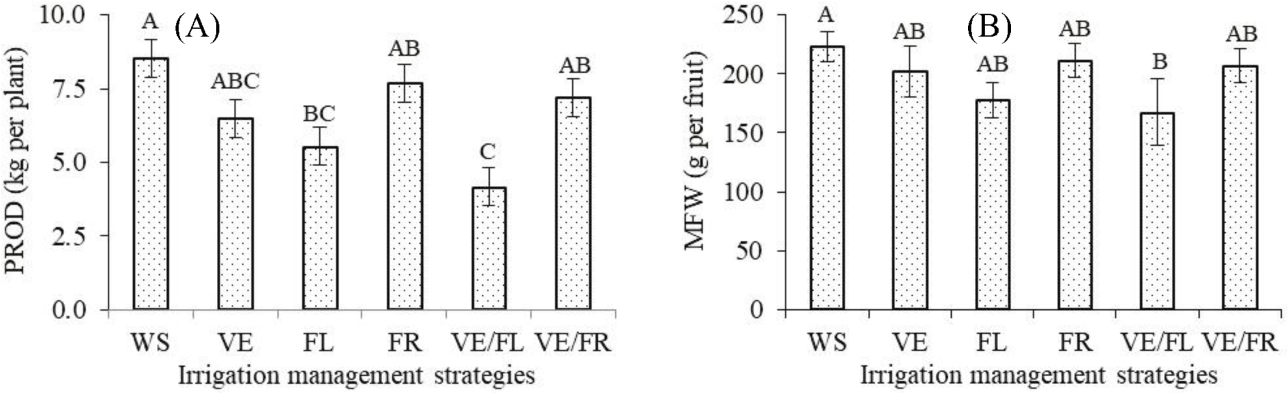
According to Oliveira *et al*. (2017), with the increase in salt concentration in the soil, the plants have greater difficulty in absorbing water and nutrients, using stomatal closure to prevent excessive water loss to the environment and, as a result, reducing the entry of CO_2 into the substomatal chamber, and compromising, among other variables, the carboxylation efficiency.

Total plant production in the yellow passion fruit ‘BRS GA1’ was also affected by the use of the salt-water strategies. According to the Scott-Knott test (Figure 6A), the plants irrigated with low ECw water (WS) obtained the highest PROD value (8.53 kg per plant), differing statistically from those submitted to the FL and VE/FL strategies, which reached values of 5.54 and 4.16 kg per plant, respectively. However, a comparison of plants grown under irrigation with low-salinity water (WS) with those irrigated high ECw during the VE, FR, and VE/FR stages showed no significant difference. Dias *et al*. (2011), in an experiment with yellow passion fruit irrigated with water at increasing levels of salinity throughout the growth cycle in polyethylene containers observed that the production per plant was reduced by 37.17% (4 kg per plant) when the ECw increased from 0.5 to 4.5 dS m^{-1}. It should be noted that plants subjected to an ECw of 1.5 dS m^{-1} under the conditions described above, achieved production of 8.76 kg per plant, i.e. a similar value to that of the present study in plants grown under an ECw of 1.3 dS m^{-1} throughout the cycle.

The highest mean fruit weight in the yellow passion fruit ‘BRS GA1’ was obtained with the plants irrigated with low-salinity water (Figure 6B); however, there was no statistical difference from the other treatments that were irrigated with high-salinity water (4.0 dS m^{-1}), except under the VE/FL strategy, which showed a reduction of 24.91% concerning the plants submitted to the WS strategies. It should be noted that there were no significant differences between the VE, FL, and FR strategies. During the reproductive stage, the fruit is one of the main drains of photoassimilates in the plants (TAIZ *et al*., 2017), possibly reducing the weight of the fruit when the number of fruit increases. In this respect, Nunes *et al*. (2017) found that the salinity of the irrigation water reduces carbon dioxide assimilation in plants of the yellow passion fruit, thereby showing a negative effect on the biochemical reactions that occur in the stroma of the chloroplasts (CRUZ *et al*., 2017), as well as stimulating stomatal closure, reducing gas exchange, and affecting crop production. Dias *et al*. (2012) found a reduction of 12.5 g in passion fruit production per unit increase in the electrical conductivity of the irrigation water.

The reduction in fruit production and mean fruit weight in the yellow passion fruit reflects the sensitive nature of the plant to the continuous application of water with an electrical conductivity of 4.0 dS m^{-1} during both the vegetative and flowering stages, and during the flowering stage only. It should be noted that the FL and VE/FL stages comprised a period of 84 and 148 days of stress, respectively, and that during water irrigation in the VE/

Figure 6 - Total production per plant - PROD (A) and mean fruit weight - MFW (B) in the yellow passion fruit ‘BRS GA1’ as a function of the irrigation management strategies using brackish water and doses of potassium, evaluated during the fruiting stage from 199 to 253 days after transplanting



Mean values followed by different letters show a significant difference between treatments by the Scott-Knott test ($p < 0.05$). Vertical bars represent the standard error of the mean (n=4); WS - irrigation with low-salinity water throughout the growth cycle (1-253 days after transplanting - DAT); salt stress during the VE = vegetative stage (50-113 DAT); FL = flowering stage (114-198 DAT); FR = fruiting stage (199-253 DAT); VE and FL = vegetative and flowering stage (50-198 DAT); VE/FR = vegetative and fruiting stage (50-113/199-253 DAT)

FL stages there were rainfall events (368 mm) concentrated over 26 days, with irregular distribution during the flowering stage (FL) only. It can be said, therefore, that during the VE/FL and FL stages stress occurred with greater intensity, and that the occurrence of rainfall during this period did not alleviate the effects of stress on the crop.

CONCLUSIONS

1. Irrigation with high-salinity water (4.0 dS m^{-1}) reduces the leaf osmotic potential, leaf water potential, stomatal conductance, transpiration, and rate of CO_2 assimilation of the yellow passion fruit, regardless of the irrigation management strategy;
2. The application of water with an electrical conductivity of 4.0 dS m^{-1} during the successive vegetative and flowering stages increases the percentage of cell damage and compromises passion fruit production;
3. Doses of potassium do not reduce the effect of salt stress on plants of the yellow passion fruit ‘BRS GA1’;
4. Interaction between the strategic factors of brackish water irrigation management and the doses of potassium does not significantly influence any of the variables in the yellow passion fruit.

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