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Gas exchange and yield of grafted yellow passion fruit under salt stress and plastic mulching[1]

Trocas gasosas e produtividade de maracujazeiro-amarelo enxertado sob estresse salino e cobertura plástica

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HIGHLIGHTS:

High-salinity water did not limit CO_2 assimilation rate and yield of yellow passion fruit in soil with plastic film.
Yellow passion fruit grafted on Passiflora cincinnata *showed low yield.*
Under salt stress, the highest yield was observed in yellow passion fruit propagated by seed in soil with plastic mulching.

ABSTRACT: Irrigation with saline water is one of the main factors that limit gas exchange and yield of yellow passion fruit in the semi-arid region of Brazil. The use of wild species of *Passiflora* ssp. tolerant to salinity as a rootstock and the application of mulching with plastic film can attenuate the effects of salt stress. The objective of present study was to evaluate the application of plastic film mulching and irrigation with saline water on the gas exchange and yield of yellow passion fruit grafted on *P. cincinnata*. The experiment was carried out under field conditions, from September 2019 to February 2021, in a 2 × (2 × 2) factorial scheme, in randomized blocks, in split plots and four replications. The treatments were related to irrigation with low-salinity (0.5 dS m^{-1}) and high-salinity (4.5 dS m^{-1}) water in yellow passion fruit plants, accession ‘Guinezinho’, propagated by seed and grafted on *Passiflora cincinnata* in the soil without and with plastic mulching. Irrigation with 4.5 dS m^{-1} water reduced gas exchange and yield of yellow passion fruit, but did not affect plants in the plastic mulched soil. Yellow passion fruit grafted on *P. cincinnata* showed increases in CO_2 assimilation rate, but it was not reflected in fruit yield. For cultivation under high salinity conditions (4.5 dS m^{-1}), it is recommended to use yellow passion fruit propagated by seeds in the soil with plastic film mulching.

Key words: *Passiflora edulis* flavicarpa Deneger, water salinity, grafting, soil protection, physiology

RESUMO: A irrigação com água salina é um dos principais fatores que limitam as trocas gasosas e a produtividade do maracujazeiro-amarelo no semiárido do Brasil. A utilização de espécie silvestre de *Passiflora* ssp. tolerante à salinidade como porta-enxerto e a aplicação de mulching com filme plástico podem atenuar os efeitos do estresse salino. O objetivo do presente estudo foi avaliar a aplicação de mulching com filme plástico e a irrigação com água salina sob as trocas gasosas, a eficiência fotossintética e a produtividade do maracujazeiro-amarelo enxertado em *P. cincinnata*. O experimento foi conduzido em condições de campo, no período de setembro de 2019 a fevereiro de 2021, em esquema fatorial 2 × (2 × 2), em blocos casualizados, em parcelas subdividida e com quatro repetições. Os tratamentos foram referentes à irrigação das plantas com água de baixa salinidade (0,5 dS m^{-1}) e alta salinidade (4,5 dS m^{-1}), maracujazeiro-amarelo acesso ‘Guinezinho’ propagado por semente e enxertado em *Passiflora cincinnata* no solo sem e com mulching plástico. A irrigação com água de 4,5 dS m^{-1} reduziu as trocas gasosas, a eficiência fotossintética e a produtividade do maracujazeiro-amarelo, mas não afetou as plantas do solo com mulching plástico. As trocas gasosas do maracujazeiro-amarelo enxertado em *P. cincinnata* apresentou incrementos na taxa de assimilação de CO_2, mas não se refletiu em produtividade de frutos. Para o cultivo em condições de alta salinidade (4,5 dS m^{-1}) da água é recomendado a utilização de maracujazeiro-amarelo propagado por sementes no solo com mulching de filme plástico.

Palavras-chave: *Passiflora edulis* flavicarpa Deneger, salinidade da água, enxertia, proteção do solo, fisiologia

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Introduction

Yellow passion fruit (*Passiflora edulis* f. flavicarpa Deneger) is an economically important fruit for Brazil and especially for the Northeast region, where 71.2% of Brazilian passion fruit was harvested in 2020 (IBGE, 2021). In this region, the soil and climate conditions are favorable to the exploitation of the crop, with the exception of rain (Figueiredo et al., 2020), so irrigation is required, and the available water sources naturally contain high levels of soluble salts (Moura et al., 2020).

Under salt stress, plants have physiological limitations due to the reduction in water availability resulting from the decrease in the osmotic potential of the soil, which affects the efficiency of CO_2 assimilation (Negrão et al., 2017; Ren et al., 2021) and, consequently, reduces crop yield (Figueiredo et al., 2020; Lima et al., 2020). In this context, studies have shown that Passifloraceae species native to the semi-arid region have mechanisms of tolerance to salt stress, such as osmotic adjustment and stomatal regulation (Moura et al., 2020), and propagation by grafting could be a viable alternative in the production of yellow passion fruit (Veimrober Junior et al., 2022).

Soil mulching can reduce the presence of salts in the passion fruit root zone, reducing the negative effects of salt stress and increasing photosynthetic efficiency and yield (Freire et al., 2014). Mulching with plastic film works to modify the edaphic microclimate by maintaining moisture and reducing water evaporation, contributing to the leaching of salts to the deeper layers (Zribi et al., 2015; Chen et al., 2018). In addition, the plastic film affects the reflectance of incident solar rays, increasing light absorption and increasing the photosynthetic efficiency of the plant (Amare & Desta, 2021; Costa et al., 2022). The importance of plastic mulching in increasing water use efficiency in plants irrigated with low- and high-salinity water is reported in the scientific literature, for example, for zucchini - *Cucurbita pepo* L. (El-Mageed et al., 2016), common bean - *Phaseolus vulgaris* L. (El-Wahed et al., 2017) and maize – *Zea mays* (Dong et al., 2018).

In this context, the objective of present study was to evaluate the application of mulching with plastic film and irrigation with high-salinity water on the gas exchange and yield of yellow passion fruit grafted on *P. cincinnata*.

Material and Methods

The experiment was carried out under field conditions from September 2019 to February 2021, in an experimental area located on the Macaquinhos Farm, Remígio, State of Paraíba, Brazil. The municipality is georeferenced by coordinates 7° 00' 1.95" S and 35° 47' 55" W, 562 m above sea level. The climate of the region, according to Köppen's classification, is of type As', which means tropical climate with dry summers and rainfall concentrated in the winter-autumn seasons (Alvares et al., 2013). During the experiment, the temperature and relative humidity of the air were recorded in Datalogger and the rainfall was recorded in a rain gauge; with average values, respectively, of 68.5%, 25.75 °C, and 852.2 mm (Figure 1).

The soil of the experimental area was classified, according to the criteria of the Key to Soil Taxonomy US Soil Survey Staff (2014), as *Psamment*. Before the installation of the experiment, soil collections were carried out in the experimental area, at a depth of 0-0.20 m for analysis of chemical attributes, such as fertility and salinity, and physical attributes (Teixeira et al., 2017), as presented in Table 1.

The experiment was carried out in a split-plot arrangement [2 × (2 × 2)] in randomized blocks, with four replications and three plants per subplot. The main plot was related to irrigation of plants with low-salinity (0.5 dS m^{-1}) and high-salinity

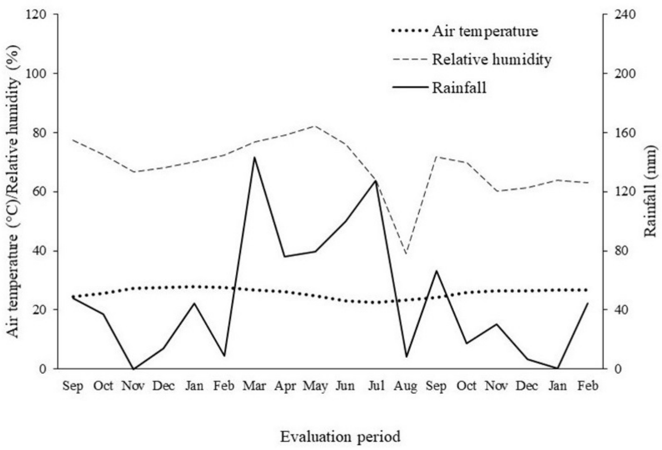


Figure 1. Monthly values of air temperature, relative humidity, and rainfall in the area during the experimental period

Table 1. Characterization of chemical attributes regarding fertility and salinity, and physical attributes of the soil of the experimental area before the installation of the experiment

Chemical attributes		Physical attributes	
pH in H_2O (1:2.5)	5.90	Sand (g kg^{-1})	843.0
ECse (dS m^{-1})	0.23	Silt (g kg^{-1})	97.0
P (mg dm^{-3})	25.75	Clay (g kg^{-1})	60.0
K^+ ($cmol_c$ dm^3)	0.08	DC (g (kg^{-1})	0.00
Ca^{2+} ($cmol_c$ dm^3)	1.40	DF (kg dm^{-3})	1,000
Mg^{2+} ($cmol_c$ dm^3)	1.73	Bd (kg dm^{-3})	1.53
Na^+ ($cmol_c$ dm^3)	0.04	Pd (kg dm^{-3})	2.63
SB ($cmol_c$ dm^3)	3.25	Tp (m^3 m^{-3})	0.42
$H^+ + Al^{3+}$ ($cmol_c$ dm^3)	1.27	$U_{0.01MPa}$ (g kg^{-1})	67
Al^{3+} ($cmol_c$ dm^3)	0.00	$U_{0.03MPa}$ (g kg^{-1})	48
CEC ($cmol_c$ dm^3)	4.52	$U_{1.50MPa}$ (g kg^{-1})	29
V (%)	71.90	Textural class	Sand
OM (g kg^{-1})	17.01		

SB - Sum of bases ($K^+ + Ca^{2+} + Mg^{2+} + Na^+$); CEC - Cation exchange capacity ($K^+ + Ca^{2+} + Mg^{2+} + Na^+ + H^+ + Al^{3+}$); V - Base saturation ([SB/CEC] × 100); OM - Organic matter; EC - Electric conductivity; SAR - Sodium adsorption ratio; DC – Dispersed clay; DF - Degree of flocculation; Bd - Bulk density; Pd - Particle density; Tp - Total porosity; U0.01MPa - Soil moisture at field capacity; U0.03MPa - Soil moisture at 80% field capacity; U1.5MPA - Soil moisture at permanent wilting point

(4.5 dS m^{-1}) water and the subplots to yellow passion fruit accession 'Guinezinho' propagated by seed (SP) and grafted on passion fruit - *Passiflora cincinnata* (GP) in soil without and with mulching with plastic film.

The seeds of the yellow passion fruit accession 'Guinezinho' were obtained from fruits at full physiological maturity, that is, when the yellow color predominated over the green on the surface of the skin (Vianna-Silva et al., 2010), collected from mother plants near the experimental area. The scion variety of the yellow passion fruit was obtained from collections of tertiary branches in the vegetative stage in plants with one year of transplanting located near the experimental area. The grafting technique adopted was side cleft, when the seedlings were at 90 days after sowing (DAS). The rootstock was obtained from seedlings propagated by seeds of *P. cincinnata* collected from mother plants located in Cerro Corá, Rio Grande do Norte, Brazil.

Pit-holes were opened with the dimensions of 0.40 × 0.40 × 0.40 m (64 dm^3 of volume), separating the soil from the layer of 0-0.20 and 0.20-0.40 m. In the soil of the 0-0.20 m layer, 20 L of aged bovine manure (Table 2), 120 g of dolomitic limestone (CaO = 47%, MgO = 3.4% and RNV = 82%) were added in order to increase the percentage of base saturation in soil up to 70%, followed by the application of 50 g of FTE-BR12 (S = 3.9%; B = 1.8%; Cu = 0.85%; Mn = 2.0% and Zn = 9.0%), mixing and then the soil was put back into the hole..

The plant training system was the trellis with flat wire n° 12, fixed at the top of the stake at a height of 2.0 m, spaced 3 m apart, and posts of 0.20 m in diameter were fixed at the ends of the trellis. The yellow passion fruit seedlings were transplanted at 3 × 2 m spacing, representing a population density of 1,667 plants ha^{-1}. At 30 days after grafting, the seedlings were transplanted when they had four pairs of true leaves and height ranging from 0.25 to 0.30 m.

Irrigation water of 0.5 dS m^{-1} (low salinity) came from a surface dam located close to the experimental area and had the following characteristics: pH = 6.10; K^+ = 0.28; Ca^{2+} = 0.65; Mg^{2+} = 0.27; Na^+ = 1.88; Cl^- = 1.87; CO_3^{2-} = 0.00; SO_4^{2-} = 0.51, respectively, in $mmol_c\ L^{-1}$; SAR = 2.77 $(mmol\ L^{-1})^{1/2}$; EC = 0.5 dS m^{-1} and classification C_1S_1 = Low risk of salinizing and sodifying the soil according to Richards (1954). The water of 4.5 dS m^{-1} (high salinity) was obtained by dissolving sodium chloride [NaCl – 94% pure and not iodinated] in water of 0.5 dS m^{-1}, measuring the desired electrical conductivity with an Instrutherm portable conductivity meter model CD-850. To determine the amount of salt to be dissolved in the water to obtain ECiw = 4.5 dS m^{-1}, the relationship between ECiw and the concentration of salts in water was considered, using the formula proposed by Richards (1954): C = 10 × ECiw. Where: C = Amount of salts to be added ($mmol_c\ L^{-1}$) and ECiw = Electrical conductivity of irrigation water (dS m^{-1}).

Table 2. Chemical characterization of cattle manure used in the experiment

Organic carbon (g kg^{-1})	159.1
Nitrogen (g kg^{-1})	8.3
Carbon:nitrogen ratio	19.2
Phosphorus (g kg^{-1})	2.8
Potassium (g kg^{-1})	10.4
Calcium (g kg^{-1})	8.2
Magnesium (g kg^{-1})	5.0
Sulfur (g kg^{-1})	1.8
Boron (mg kg^{-1})	58.0
Copper (mg kg^{-1})	941.0
Iron (mg kg^{-1})	250.0
Manganese (mg kg^{-1})	8.0
Zinc (mg kg^{-1})	21.3
Sodium (mg kg^{-1})	79.0
Hydrogen potential (pH H_2O)	8.81

C - Carbon, oxidized by potassium dichromate and determined by colorimetry; N - Nitrogen N-Kjeldahl by wet digestion; Phosphorus - Mehlich 1 reading and photocolorimetry, 660 nm; S - Sulfur, spectrophotometry with wavelength readings at 420 nm; K^+ - Potassium and Na^+ - Sodium, determined by flame photometer; Ca^{2+} - Calcium and Mg^{2+} - Magnesium, determined by atomic absorption spectrophotometry at wavelengths of 422.7 and 285.2 nm, respectively; B - Boron and Fe - Iron, determined by UV-VIS spectrophotometry at wavelengths of 460 and 508 nm, respectively; Cu - Copper, determined by atomic absorption spectrophotometry (AAS) at a wavelength of 324.7 nm; Mn - Manganese and Zn - Zinc, determined by AAS with flame-acetylene air

In the first 30 days after transplanting (DAT), the plants were irrigated with water of 0.5 dS m^{-1} to facilitate the formation of the root system. After this period, irrigation was performed with each type of water, providing the volume of water according to the crop's evapotranspiration (ETc).

Irrigation management was performed daily, considering crop evapotranspiration and crop coefficient (Kc) of 0.69 in the vegetative phase, 0.82 in the flowering phase, and 1.09 in the fruiting phase (Freire et al., 2011). Irrigation was performed by the drip method, installed before the application of the plastic film. In each plant, four pressure-compensating hydraulically loaded drippers were used - two in the east direction and two in the west direction, distanced, respectively, at 0.20 and 0.40 m from the plant stem, with flow rate of 4 L h^{-1} and working at a pressure of 0.20 MPa.

Mulching with plastic film with a white face, resistance of 320 μ, was used to protect the soil surface of the three plants per plot that received soil protection. In the plots, the mulching was installed in the dimensions of 1.30 m wide, fixed at 2.0 m distance between the rows, 12 m in length and covered area of 24 m^2. In the area where the seedlings were transplanted, holes measuring 0.40 m were opened and then the unprotected area was covered with plastic film to avoid water loss by evaporation.

Topdressing fertilization with nitrogen (N), phosphorus (P) and potassium (K) was done through fertigation using a Venturi-type injector (Borges & Coelho, 2009). Nitrogen and potassium were supplied every 15 days, in the proportion of 1N:1K in the form of urea (45% of N) and potassium sulfate (50% of K_2O and 45% of S) and phosphorus, supplied monthly, through monoammonium phosphate – MAP (50% P_2O_5 and 10% N). The doses of N and K were 1.5 g from 30 to 60 days after transplanting (DAT), 3 and 5 g from 60 to 90 DAT, 10 and 10 g from 105 to 180 DAT and 15 g N and 15 g K from 195 DAT to the end of the crop cycle, all diluted in the irrigation water to provide necessary dose (Borges & Coelho, 2009). Fertigation with MAP was performed with 5, 10, 10, 10, 10, 15, 15, and 15 g P_2O_5 at 30, 60, 90, 120, 150, 180, 210, and 300 DAT, respectively (Borges & Coelho, 2009). Fertilizations with the micronutrients [boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn)] were carried out via foliar application. The micronutrient sources were Ajifol® Gold (B = 0.3%; Cu = 0.5% Mn = 5.0%; Mo = 0.2%, and Zn = 1.0%) at a dose of 1.5 L ha^{-1}, Niphokam 585 (B = 0.5%; Cu = 0.2%, Mn =0.5%, and Zn = 1.0%) at a dose of 1.0 L ha^{-1} and Iron Chelate EDTA (Fe = 12%) at a dose of 150 g $100L^{-1}$.

When the yellow passion fruit plant was in full bloom, at 120 DAT, the third pair of leaves from the branches located in the middle third of the plants was selected for evaluation of leaf gas exchange (Freire et al., 2014). Readings were taken in the morning between 8:00 and 11:00 am with a portable infrared gas analyzer (IRGA), model LCPro+ Portable Photosynthesis System® (ADC BioScientific Limited, UK), with temperature set at 25 °C, irradiation of 1,200 μmol photons m^{-2} s^{-1} and air flow of 200 mL min^{-1} (Freire et al., 2014). The variables measured were stomatal conductance – gs (mol H_2O m^{-2} s^{-1}), CO_2 assimilation rate – A (μmol CO_2 m^{-2} s^{-1}), leaf transpiration – E (mmol H_2O m^{-2} s^{-1}) and the internal concentration of carbon dioxide – Ci (mmol CO_2 m^{-2} s^{-1}). From the determination of these variables, the water use efficiency– WUE = A/E (mmol CO_2 mol^{-1} H_2O) and the instantaneous carboxylation efficiency – CEi = A/Ci (mmol CO_2 mol^{-1} CO_2) were calculated.

Fruit yield (t ha^{-1}) was related to the accumulated production of two consecutive flowerings, with harvests, respectively, from September to December 2019 and from April to July 2021, and obtained by the product of production per plant by density of plants per hectare (1,667 plants ha^{-1}). The fruits were harvested 60 days after anthesis, when they reached physiological maturity and the highest juice yield (Vianna-Silva et al., 2010).

Data were subjected to analysis of variance by the F test at 0.05 probability level, after performing a test for normality and data homogeneity using the Shapiro-Wilk test. The means referring to the sources of variation and the interactions were compared by the Tukey test ($p \leq 0.05$) using the statistical software Sisvar 5.6 (Ferreira, 2019).

Results and Discussion

As observed in Figure 2A, the leaf stomatal conductance of the yellow passion fruit responded to the interaction of salinity of irrigation water × plastic mulching (F = 4.24; p = 0.04). The gs of yellow passion fruit irrigated with of low-salinity and high-salinity water, respectively, did not show significant differences for the soil without and with plastic mulching. However, in soil with plastic film, irrigation with water of 4.5 dS m^{-1} increased the stomatal conductance from 0.039 to 0.056 mol CO_2 m^{-2} s^{-1}.

The higher values of gs in plants with plastic mulching, even under stress condition, are due to increased levels of moisture and water infiltration into the soil (Danierhan et al., 2013; Zhao et al., 2016; El-Wahed et al., 2017), which prevented the capillary rise of soluble salts from the deepest layer to the surface part of the soil, where the largest volumes of yellow passion fruit roots are located. On the other hand, when evaluating soil mulching with silk grass (*Cynodon dactylon* L.), Freire et al. (2014) found no significant differences for stomatal conductance in yellow passion fruit irrigated with low- and high-salinity water, respectively. However, salt stress can induce a series of physiological changes in plants, which include the partial closure of stomata, which leads to a reduction in stomatal conductance and leaf transpiration, affecting photosynthesis and the internal balance of CO_2 (Ren et al., 2021).

The yellow passion fruit net CO_2 assimilation rate responded to interactions between irrigation water salinity × forms of propagation (F = 11.04; p = 0.0038), irrigation water salinity × plastic mulching (F = 8, 0; p = 0.0085) and forms of propagation × plastic mulching (F = 15.12; p = 0.0007) (Figures 2B, C, and D).

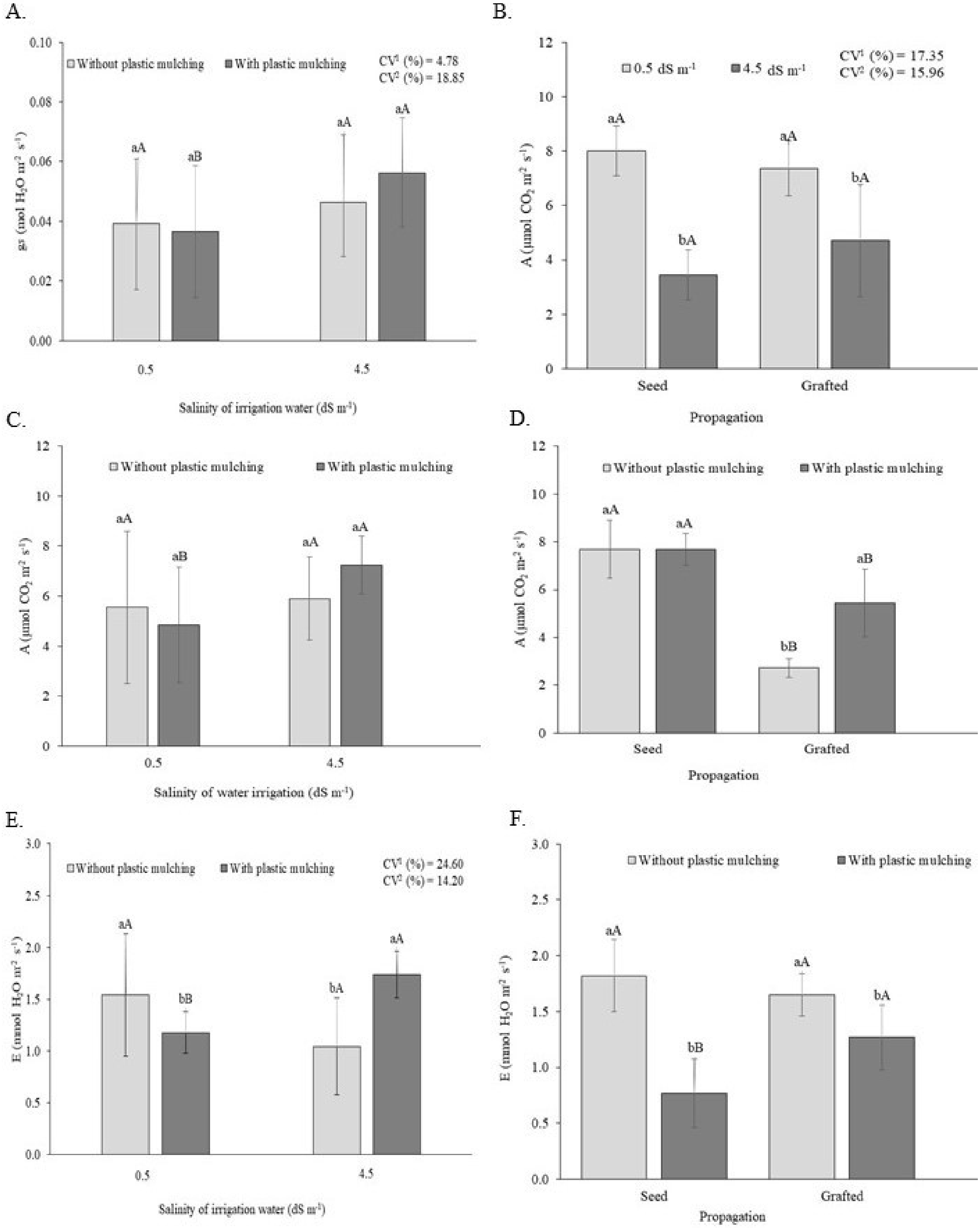
The salinity of the water reduced the net CO_2 assimilation rate of yellow passion fruit, regardless of the propagation method (Figure 2B). The greatest reduction of A was observed in yellow passion fruit propagated by seeds (57%) compared to plants grafted on *P. cincinnata* (36%). The reduction in the CO_2 assimilation rate with the accumulation of salts in the soil is caused by the decrease in the osmotic potential, which reduces the plant's ability to absorb water and nutrients from the soil and, consequently, can inactivate the transport of electrons via intercellular space and/or the toxic effect caused by the absorption and accumulation of Na^+ and Cl^- ions, which inhibit the absorption of essential elements for photosynthesis by the roots, such as nitrogen (Negrão et al., 2017; Safdar et al., 2019).

The net CO_2 assimilation rate of yellow passion fruit in soil without mulching did not differ between plants irrigated with water of 0.5 and 4.5 dS m^{-1}; however, in soil with plastic mulching, the CO_2 assimilation rate of plants irrigated with high-salinity water was 49.4% higher than that of plants irrigated with low-salinity water (Figure 2C). Plastic mulching increased CO_2 assimilation rate by 99.6% of yellow passion fruit grafted onto *P. cincinnata*, but did not interfere with plants propagated by seed (Figure 2D).

In both situations (Figures 2C and D), plastic mulching interfered with the edaphic microclimate, reducing water losses from the soil, keeping it moister and with less soluble salts, especially in the root growth zone, which contributes to the increases in photosynthesis in this situation, as also reported by Chen et al. (2018) and Costa et al. (2022). In addition, mulching with white plastic film can reflect a greater number of photons, contributing to greater absorption of light by the plant (Costa et al., 2022).

CO_2 assimilation rate in passion fruit propagated by seeds was always higher than in grafted plants, with increases from 2.72 to 7.68 μmol CO_2 m^{-2} s^{-1} and from 5.43 to 7.69 μmol CO_2 m^{-2} s^{-1}, respectively, in plants without and with plastic film mulching (Figure 2D). When evaluating gas exchange in yellow passion fruit grafted on *Passiflora edulis*, *Passiflora cincinnata*, and *Passiflora gibertti*, Moura et al. (2020) found no significant differences in CO_2 assimilation rate of plants in full bloom (136 DAS).

The interactions between irrigation water salinity × plastic mulching (F = 27.0; p = 0.0001) and forms of propagation × plastic mulching (F = 27.0; p = 0.00001) significantly influenced transpiration (E) of yellow passion fruit (Figures 1E and F). Leaf transpiration of irrigated yellow passion fruit showed different results with the application of plastic mulching (Figure 1E). In plants irrigated with water of 0.5 dS m^{-1}, the use of mulching reduced the E from 1.54 to 1.17 mmol H_2O m^{-2} s^{-1}, while in plants irrigated with water of 4.5 dS m^{-1} it increased E from 1.04 to 1.73 mmol H_2O m^{-2} s^{-1}. Under saline conditions, mulching promotes improvements in the water status of the soil and, consequently, of the yellow passion fruit, allowing greater gas exchange between the plants and the environment, avoiding stress due to water scarcity (Freire et al., 2014).



Vertical bar represents the standard error of the mean (n = 4). For the same treatment means with the same lowercase letter indicate no significant difference ($p > 0.05$) for soil without and with plastic mulching (A, C D, E and F) or for irrigation with low-salinity and high-salinity water (B). For the similar treatment with the same uppercase letter indicate no significant difference ($p > 0.05$) for irrigation with low and high-salinity water (A, C and E) or between seed propagation and grafting (B, D and F). CV[1] - Coefficient of variation of the plot and CV[2] - Coefficient of variation of the subplots

Figure 2. Stomatal conductance, CO_2 assimilation rate and transpiration of yellow passion fruit irrigated with saline water and in soil with and without plastic mulching (A C and E), CO_2 assimilation rate and transpiration of yellow passion fruit propagated by seeds and grafted on *P. cincinnata* irrigated with saline water (B and F), CO_2 assimilation rate of yellow passion fruit propagated by seeds and grafted onto *P. cincinnata* and in the soil with plastic mulching (D)

With plastic mulching, the salinity of the irrigation water increased by 47.9% the leaf transpiration of yellow passion fruit plants compared to that of plants irrigated with low-salinity water. Under these conditions, according to Taiz et al. (2017), as there were no restrictions on stomatal opening (Figure 2A) and water losses through transpiration (Figure 1E) with the application of plastic mulching, photosynthetic activity was high in yellow passion fruit even under salt stress conditions (Figure 2C). A similar result was verified by Freire et al. (2014), when they found that the transpiration of yellow passion fruit irrigated with 4.5 dS m^{-1} water and fertilized with bovine biofertilizer was increased from 0.86 to 1.70 mmol H_2O m^{-2} s^{-1} with application of mulch on the soil surface.

Plastic mulching reduced transpiration of yellow passion fruit propagated by seeds and grafted onto *P. cincinnata* by 58.2 and 22.6%, respectively (Figure 2F). In plants without plastic mulching, E did not show differences for forms of propagation, but when cultivated in soil with mulching, plants propagated by seed showed 38.7% lower leaf transpiration than those grafted on *P. cincinnata*. In contrast, Santos et al. (2016) did not find significant differences in leaf transpiration of *Passiflora cincinnata* propagated by seeds and cuttings.

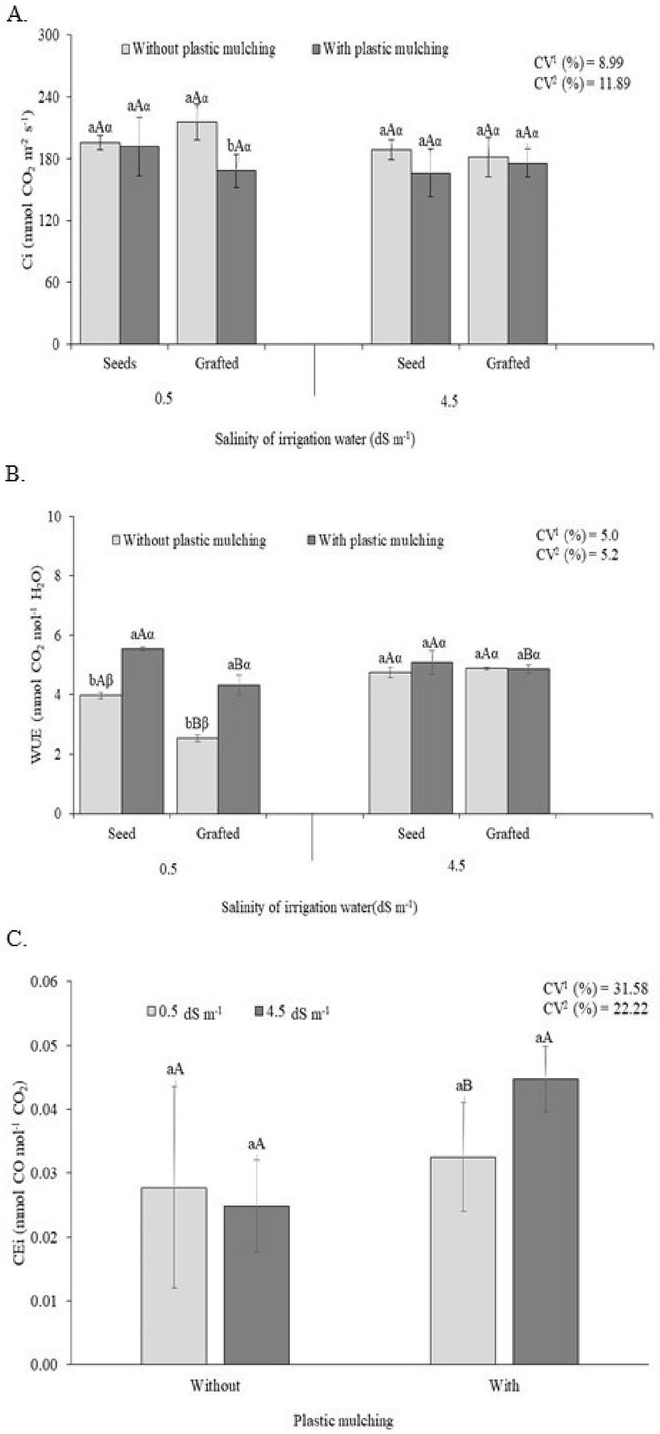
The internal carbon concentration (F = 5.92; p = 0.0252) and the water use efficiency (F = 6.00; p = 0.0248) in yellow passion fruit, according to Figures 3A and B, were influenced by the interaction between irrigation water salinity × forms of propagation × plastic mulching. The instantaneous carboxylation efficiency (F = 4.55; p = 0.0468) responded to the interaction between irrigation water salinity and the application of plastic mulching on the soil surface (Figure 3C).

Ci showed a difference only in yellow passion fruit grafted on *P. cincinnata* under irrigation with low-salinity water (Figure 3A). In this situation, the application of plastic mulching in the soil reduced the internal concentration of CO_2 from 215.25 to 168.32 mmol CO_2 m^{-2} s^{-1}, which represents a reduction of 21.80%. Under these conditions, it favors greater absorption of water used in the photosynthetic process and CO_2 assimilation by the plants (Freire et al., 2014; Zribi et al., 2015; El-Mageed et al., 2016).

The application of plastic mulching increased the water use efficiency (WUE) of yellow passion fruit irrigated with water of 0.5 dS m^{-1}, with increments of 38.2% in those propagated by seed and 71.1% in those grafted on *P. cincinnata* (Figure 3B). However, there was no significant difference in WUE in plants irrigated with water of 4.5 dS m^{-1} in mulched soil, showing a difference only in the form of propagation, with superiority in yellow passion fruit propagated by seed.

The increase in WUE with the application of mulching with plastic film is due to its impact on reducing crop transpiration and maintaining soil moisture, which reduced the need for water replacement of plants (Amare & Desta, 2021).

In the soil without mulching, irrigation with high-salinity water increased the WUE from 3.98 to 4.75 mmol CO_2 mol^{-1} H_2O in yellow passion fruit propagated by seeds and from 2.53 to 4.88 mmol CO_2 mol^{-1} CO_2 in yellow passion fruit grafted on *P. cincinnata*, representing increments of 19.3 and 92.9%, respectively (Figure 3B). These results corroborate those observed by Figueiredo et al. (2020), who found that the



Vertical bar represents the standard error of the mean (n = 4). For the same treatment means with the same lowercase letter indicate no significant difference (p > 0.05) for soil without and with plastic mulching, means with the same uppercase letter indicate no significant difference (p > 0.05) for seed propagation and grafting and means with the same Greek letter indicate no difference for irrigation with low and high-salinity water (A and B). Means with the same lowercase letter indicate no significant difference (p > 0.05) for soil without and with plastic mulching for the same treatment and means with the same uppercase letter indicate no significant difference (p>0.05) for irrigation with low and high-salinity water (C). CV¹ - Coefficient of variation of the plot and CV² - Coefficient of variation of the subplots

Figure 3. Internal carbon concentration and water use efficiency of yellow passion fruit propagated by seeds and grafted onto *P. cincinnata* irrigated with high-salinity water in the soil with plastic mulching (A and B); and instantaneous carboxylation efficiency of yellow passion fruit irrigated with saline water in the soil with plastic mulching (C)

yellow passion fruit plant irrigated with saline water increased its WUE, leading to the conclusion that the crop has a certain tolerance to salt stress due to the maintenance, to a certain extent, of carbon assimilation.

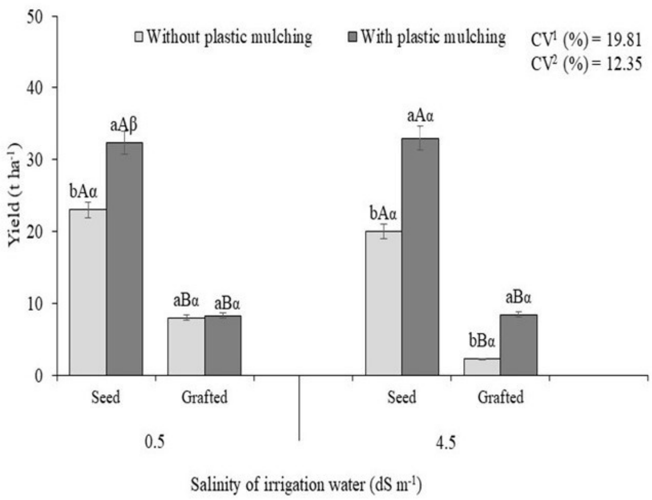
Yellow passion fruit in soil without plastic mulching showed no significant difference for CEi values when irrigated with water of 0.5 and 4.5 dS m^{-1} (Figure 3C). In soil with plastic mulching, yellow passion fruit plants irrigated with high-salinity water showed higher instantaneous carboxylation efficiency compared to those irrigated with low-salinity water, with an increase from 0.032 to 0.044 mmol CO_2 mol^{-1} CO_2. The application of plastic mulching on the soil, by keeping it moister and by reducing the presence of toxic salts in the root zone of the plants (Zribi et al., 2015; Zhao et al., 2016), attenuated the effects of salinity on the carboxylation efficiency of yellow passion fruit, which is normally reduced under salt stress, as also verified by Figueiredo et al. (2020) and Lima et al. (2020).

The yield of yellow passion fruit was influenced by the interaction of irrigation water salinity × forms of propagation × plastic mulching (F = 12.85; p = 0.0021), as seen in Figure 4.

The application of plastic mulching in the yellow passion fruit contributed to increasing its yield, except for grafted plants under irrigation with low-salinity water, which did not show a significant difference (Figure 4). The greatest increases in yield were observed in yellow passion fruit propagated by seed, with increases from 23.0 to 32.4 t ha^{-1} in plants irrigated with water of 0.5 dS m^{-1} and from 20.0 to 33.0 t ha^{-1} in those irrigated with water of 4.5 dS m^{-1}.

The application of plastic mulching contributes to increased yield under salt stress conditions, by reducing the evaporation of water available to plants, preventing salts from accumulating on the soil surface and close to the plant root system (Costa et al., 2021). A similar result was verified by Uchôa et al. (2018), when they found that the application of mulching in an organic cultivation system of yellow passion fruit in sandy soil promoted an increase in the yield capacity of the crop.

In fact, the yields of yellow passion fruit propagated by seeds were higher than those of yellow passion fruit grafted on *Passiflora cincinnata*, regardless of irrigation water salinity and application of plastic mulching. During the experiment, it was found that yellow passion fruit grafted on *P. cincinnata*, despite the promising beginning in the vegetative development, lost vigor over time, resulting in low production of flowers and fruits, affecting its yield compared to plants propagated by seed. However, Veimrober Júnior et al. (2022), evaluating forms of propagation (seeds and cuttings) under reduced irrigation depths, did not find significant differences in yield of yellow passion fruit cv. BRS GA1. The maximum yields obtained in yellow passion fruit propagated by seeds and under plastic mulching on the soil surface (32.4 t ha^{-1} - 0.5 dS m^{-1} and 33.0 t ha^{-1} - 4.5 dS m^{-1}) were 118 and 123% higher than the average Brazilian yield – 14.87 t ha^{-1} (IBGE, 2021).



Vertical bar represents the standard error of the mean (n = 4). For the same treatment means with the same lowercase letter indicate no significant difference (p > 0.05) for soil without and with plastic mulching, means with the same uppercase letter indicate no significant difference (p > 0.05) for seed propagation and grafting for the same type of mulch, and means with the same Greek letter indicate no significant differences (p > 0.05) for irrigation with low and high-salinity water. CV[1] - Coefficient of variation of the plot and CV[2] - Coefficient of variation of the subplots

Figure 4. Yield of yellow passion fruit propagated by seeds and grafted onto *P. cincinnata* irrigated with saline water in the soil with plastic mulching

Conclusions

1. Irrigation water salinity does not limit the gas exchange of yellow passion fruit in soil with plastic mulching, increasing its water use efficiency, fixation of carbon dioxide and yield, mainly in plants propagated by seeds.

2. Yellow passion fruit grafted on *Passiflora cincinnata* shows increases in gas exchange rates under salt stress conditions, but this did not result in high yields.

3. Application of plastic mulching and propagation via seeds in yellow passion fruit are indicated to obtain high fruit yield under conditions of high water salinity (4.5 dS m^{-1}).

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