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RESEARCH PAPER

Gas exchange and productivity of yellow passion fruit irrigated with saline water and fertilized with potassium and biofertilizer[1]

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Abstract

J.C. Nunes, L.F. Cavalcante, W.E. Pereira, J.T.A. Souza, D.J. Almeida, D. Oresca, and P.D. Fernandes. 2017. Gas exchange and productivity of yellow passion fruit irrigated with saline water and fertilized with potassium and biofertilizer. Cien. Inv. Agr. 44(2): 168-183. The salinity of irrigation water can affect the growth and development of most plants of commercial interest. Aiming to study these aspects in passion fruit culture, an experiment was performed to evaluate the effects of bovine biofertilizer and potassium fertilization on gas exchange and production of the passion fruit 'BRS Giant Yellow' irrigated with non-saline and saline water. The treatments were arranged in randomized blocks with sub-subdivided plots using the 2×(3×5) scheme, which refers to two levels of electrical conductivity of the irrigation water as the main plot (0.35 and 4.00 dS m^{-1}) and the combination of three potassic fertilization practices (without fertilization, fertilized with conventional and slow release KCl) with five doses of bovine biofertilizer (0, 25, 50, 75 and 100% of dose of 15 L m^{-2}) in the subplots, with three replicates and 12 plants per plot. The physiological variables and the productivity were evaluated in two harvests, and the data were submitted to statistical evaluation of samples repeated in time. The application of bovine biofertilizer and potassium in soil with a sandy texture irrigated with saline water did not inhibit the degenerative effect of the salts on the photosynthetic rates of the plants. The salinity of the irrigation water reduced stomatal conductance, transpiration and net photosynthesis of the plants, but in the second crop, the instantaneous water use efficiency was higher. Although the productivity decreased from the first to the second harvest, the biofertilizer associated with potassic fertilization increased the yield of the crop, which surpassed the average of Brazil, the Brazilian Northeast and the State of Paraiba, Brazil.

Key words: Fermented liquid manure, *Passiflora edulis* Sims, photosynthetic efficiency, salinity.

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Introduction

Agricultural activity throughout the world is facing a serious problem of water shortage of non-restrictive quality in meeting the needs of crops. This deficiency is more serious in semi-arid regions, including Brazil, where the water resources, in general, present saline concentrations at levels that are compromising the growth, development and production of crops of commercial interest, including yellow passion fruit (Cavalcante *et al.*, 2011; Freire *et al.*, 2014).

The high concentrations of salts in irrigation water or soil cause damage from the germination of the seeds for production of a crop because the restriction occurs in the division and the cellular elongation, with the morphological and physiological movements, which are reflected in smaller growth and production of plants. In addition to these changes, toxicity caused by the high content of specific ions such as Na^+ and Cl^- affects the physiological functioning of the cultures (Parihar *et al.*, 2015).

In the saline environment, there is usually a restriction in the potassium uptake due to the increased competition between Na^+ and K^+ for the adsorption sites or a greater potassium efflux of the roots. Among other physiological functions, this essential element participates in the control of cellular turgidity, in the activation of enzymes involved in respiration, in the water relationship, in photosynthesis and in the regulation of the processes of opening and closing of stomata (Wang *et al.*, 2013; Tatagiba *et al.*, 2014).

Despite the importance of potassium, most Brazilian soils have a low content of the element, requiring the application of potassium fertilizer to meet the nutrient requirements of plants. Traditionally, the supply of potassium to plants is carried out in the form of potassium chloride applied to the soil. However, it is estimated that more than 50% of the nutrient is lost to the environment, causing economic and environmental damage due to the pollution of the soils and water sources by the chloride that is the accompanying ion (Werle *et al.*, 2008). To reduce these losses, companies are investing in the coating of potassium chloride fertilizer with organic polymers to maintain nutrient release in a regular and continuous manner, reducing leaching losses and increasing fertilization efficiency (Chilundo *et al.*, 2016).

In the northeastern region of Brazil, in addition to soil potassium deficiency, the low productivity of the yellow passion fruit crop is also related to the quality of the irrigation water since most of the sources yield water with electrical conductivity that restricts the crop, and the irrigation can harm the germination of the seeds, the plant growth, gas exchange, nutritional status and crop yields of the passiculture (Dias *et al.*, 2011; Freire *et al.*, 2014).

To mitigate the effects of salts on plants, the use of bovine biofertilizer has been tested with promising results in the cultivation of yellow passion fruit in Brazil (Mesquita *et al.*, 2012; Nascimento *et al.*, 2016). The beneficial effects are demonstrated by the improvement in physical (Mellek et al., 2010; Benbouali *et al.*, 2013), chemical (Dias *et al.*, 2015) and biological soil conditions (Marrocos *et al.*, 2012). The respective input must promote the osmotic adjustment of the plants to the salts and, in fact, allow the use of waters with a saline concentration not tolerated by most crop plants of economic importance, such as yellow passion fruit, without high productivity losses (Diniz *et al.*, 2012).

In this sense, we hypothesize that (i) the addition of bovine biofertilizer to soil with a sandy texture combined with potassium fertilization increases the availability of the nutrient in the root environment, contributing to the growth of plants adequately supplied with K, which tend to manifest more efficient physiological responses in plants subjected to saline stress. In addition, (ii) if the combination of the application of biofertilizer and potassium in soil with a sandy texture attenuates the harmful effect of the salts of the irrigation water, crop productivity should not be severely impaired during the first harvests.

Materials and methods

The experiment was carried out between May 2013 and May 2014 at the Sítio Macaquinhos property in the municipality of Remígio, State of Paraíba, Brazil, located at the geographical coordinates of 7° 00’ 15” S, 35° 47’ 55” W and an altitude of 561.7 m. The municipality is characterized by a warm and dry climate, type As’, with a rainy season beginning in March and ending in August, which may last until September. Rainfall at the experiment site in 2013 and 2014 was 798 and 844 mm, respectively, with an annual average temperature of 24 °C and relative humidity ranging from 70 to 80%.

Before the installation of the experiment, soil samples were collected at depths of 0–20 and 21–40 cm, and manure was collected for chemical characterization (Table 1) (Donagema *et al.*, 2011). Chemical attributes of the salinity (Richards, 1954) and physical properties (Table 2) (Donagema *et al.*, 2011) were determined. Soils in the experimental area were classified according to the Brazilian Soil Classification System as Regolithic Neosols, non-saline (Embrapa, 2013). The eutrophic character of the soil, as seen from the data contained in Table 1, with a saturation percentage of exchangeable bases above 67% in both layers, is a consequence of the application of limestone and simple superphosphate fertilization in the area for the last four years, before the installation of the experiment.

The treatments (Table 3) were arranged in randomized blocks with sub-subdivided plots, using the factorial scheme 2×(3×5), which refers to two levels of electrical conductivity of the irrigation water as the main plot (0.35 and 4.00 dS m^{-1}) and the combination of three potassic fertilization practices (without fertilization, fertilized with conventional and slow release – organic polymer coated) with five doses of bovine biofertilizer (0-control, 25, 50, 75 and 100% of the dose of 15 L m^{-2} (Mesquita *et al.*, 2007) in the subplots, applied 24 h before transplanting and every 90 d) with three replicates and 12 plants per plot.

Table 1. Chemical attributes of the soil for fertility in the 0–20 and 21–40 cm layers and bovine manure, prior to the preparation of the pits.

Chemical Attributes	0–20 cm	21–40 cm	Bovine manure
pH (H_2O)	6.00	6.21	8.64
P (mg dm^{-3})	23.51	12.06	36.11
K^+ (mg dm^{-3})	81.34	76.04	7892.3
Na^+ ($cmol_c$ dm^{-3})	0.07	0.07	3.86
H^++Al^{+3} ($cmol_c$ dm^{-3})	1.32	1.48	-
Al^{+3} ($cmol_c$ dm^{-3})	0.0	0.0	-
Ca^{+2} ($cmol_c$ dm^{-3})	2.45	2.20	5.40
Mg^{+2} ($cmol_c$ dm^{-3})	0.35	0.60	4.5
SB ($cmol_c$ dm^{-3})	3.08	3.05	-
CEC ($cmol_c$ dm^{-3})	4.40	4.54	-
V (%)	70.0	67.18	-
OMS (g kg^{-1})	6.41	4.14	591.68

SB=Sum of bases (Ca^{2+} + Mg^{2+} + K^+ + Na^+); CEC=Cation exchange capacity [SB + (H^+ + Al^{3+}); V = exchangeable base saturation (SB / CEC)×100; OMS=Soil organic matter.

Table 2. Chemical attributes, salinity and physical properties of the soil at the beginning of the experiment, in the 0–20 cm and 21–40 cm layers, average of four replications.

Chemical attributes	0-20 cm	21-40 cm	Physical attributes	0-20 cm	21-40 cm
ECes a 25°C (dS m^{-1})	0.43	0.29	Soil density (g cm^{-3})	1.61	1.59
pH	6.93	6.67	Density of particles (g cm^{-3})	2.66	2.65
Ca^{2+} ($mmol_c$ L^{-1})	0.87	0.72	Total porosity (m^3 m^{-3})	0.39	0.40
Mg^{2+} ($mmol_c$ L^{-1})	0.78	0.55	Sand (g kg^{-1})	847	821
Na^+ ($mmol_c$ L^{-1})	2.11	1.32	Silt (g kg^{-1})	102	124
K^+ ($mmol_c$ L^{-1})	0.56	0.34	Clay (g kg^{-1})	51	55
Cl^- ($mmol_c$ L^{-1})	2.66	1.93	Ada(g kg^{-1})	13	13
CO_3^{2-} ($mmol_c$ L^{-1})	0.00	0.00	DF (%)	74.5	76.4
HCO^{-3} ($mmol_c$ L^{-1})	0.89	0.61	ID (%)	25.5	23.6
SO_2^{-4} ($mmol_c$ L^{-1})	0.67	0.31	Ucc (g kg^{-1})	98.1	99.1
SAR (mmol L^{-1})	2.32	1.66	Upmp (g kg^{-1})	43.0	45.0
EST (%)	1.59	1.54	Adi (g kg^{-1})	55.1	54.1
Classification	NS	NS	Textural classification	Sand Franca	

SAR=Sodium adsorption ratio=$Na^+/[(Ca^{2+} + Mg^{2+}) / 2]^{1/2}$; ESP=exchangeable sodium

The pits for transplanting the seedlings were opened to the dimensions of 40×40×50 cm, spaced 3 m between plants and 2 m between rows, relative to a density of 1,666 plants per hectare. As a function of the average calcium content and low magnesium content in the 0-40 cm layer of the soil, 12 g of one mixture per pit containing 75% of dolomitic limestone (28% CaO, 15% MgO and 81% (24% CaO, 16% S, 0.81% P_2O_5 and 14% moisture)) was added to raise the percentage of soil saturation by exchangeable bases to 80% together with 10 liters of manure with a C/N ratio of 18:1 and less moisture at 8%.

Seedlings of passion fruit were obtained by the seminiferous method for the cultivar BRS Giant Yellow with a germination rate of 87%. The transplanting of the seedlings was carried out in the second half of July 2013 and was followed by the standardization of the seedlings, considering the criteria of seedlings with heights between 25–35 cm and five or six pairs of leaves that were emitting the first tendrils.

The support system of the plants was in espalier with a smooth wire n° 12 installed at the top of the stakes, at the height of 2.2 m. The seedlings were led on a single stem until reaching the support wire, and a pruning was carried out when the stem passed 15 cm above the espalier for the emission of two lateral branches, which were conducted in opposite directions and pruned again when they reached 1.5 m. The productive branches, emitted from both lateral branches, grew pendulous, forming a curtain, and were pruned 30 cm away from the ground. Throughout the experimental period, the cultural treatments and phytosanitary management recommended for culture were carried out.

The preparation of the salinized water was done by dilution of ground and non-iodized sodium chloride (NaCl) with the water of a surface dam, with low electrical conductivity (0.35 dS m^{-1}) classified as C_1S_1 according to Rhoades *et al*. (2000). The salinized water was stored in plastic boxes with a volume of 3 m^3 and covered to avoid evaporation with the consequent change in electrical conductivity.

The bovine biofertilizer was produced by mixing equal volumes of non-saline water (ECw=0.35

Table 3. Description of the treatments used in the experiment.

Treatment	ECiw	BD ($L\ m^{-2}$) Mixture NSiw	PB	Practice of potassic fertilization	Harvest	
01	0.35	15.00	0	Without KCl	First	Second
02	0.35	11.25	3.75	Without KCl	First	Second
03	0.35	7.50	7.50	Without KCl	First	Second
04	0.35	3.75	11.25	Without KCl	First	Second
05	0.35	0	15.00	Without KCl	First	Second
06	0.35	15.00	0	Conventional KCl	First	Second
07	0.35	11.25	3.75	Conventional KCl	First	Second
08	0.35	7.50	7.50	Conventional KCl	First	Second
09	0.35	3.75	11.25	Conventional KCl	First	Second
10	0.35	0	15.00	Conventional KCl	First	Second
11	0.35	15.00	0	Protected KCl	First	Second
12	0.35	11.25	3.75	Protected KCl	First	Second
13	0.35	7.50	7.50	Protected KCl	First	Second
14	0.35	3.75	11.25	Protected KCl	First	Second
15	0.35	0	15.00	Protected KCl	First	Second
16	4.00	15.00	0	Without KCl	First	Second
17	4.00	11.25	3.75	Without KCl	First	Second
18	4.00	7.50	7.50	Without KCl	First	Second
19	4.00	3.75	11.25	Without KCl	First	Second
20	4.00	0	15.00	Without KCl	First	Second
21	4.00	15.00	0	Conventional KCl	First	Second
22	4.00	11.25	3.75	Conventional KCl	First	Second
23	4.00	7.50	7.50	Conventional KCl	First	Second
24	4.00	3.75	11.25	Conventional KCl	First	Second
25	4.00	0	15.00	Conventional KCl	First	Second
26	4.00	15.00	0	Protected KCl	First	Second
27	4.00	11.25	3.75	Protected KCl	First	Second
28	4.00	7.50	7.50	Protected KCl	First	Second
29	4.00	3.75	11.25	Protected KCl	First	Second
30	4.00	0	15.00	Protected KCl	First	Second

ECiw=Electrical conductivity of irrigation water; BD=Bovine biofertilizer dose; NSiw=Non-saline irrigation water; PB=Pure Biofertilizer.

dS m^{-1}) and fresh bovine manure in a plastic biodigester, maintaining 20% of its free volume, to be occupied by methane gas produced during a methanogenic fermentation. To release the gas produced by bacteria, one end of a thin hose was connected to the top of the biodigester, while another was submerged in a vessel with water (Mesquita et al., 2007).

The concentrations of biofertilizer were prepared by diluting the input to non-saline water (ECw=0.35 dS m^{-1}) in plastic boxes with a capacity of 1 m^3. Then, the electrical conductivity of the biofertilizer mixture and water was measured (Table 4), and 7.5 L of each mixture was manually delivered in an area of 0.5 m^2, with the plant stem in the center of the pit. In the dry matter of the bovine biofertilizer, the macro, micronutrients and sodium content were determined according to the methodologies adopted by Donagema *et al.* (2011). The chemical attributes in the dry matter of the biofertilizer applied to the soil included the following: N=21.8 g kg^{-1}; P=7.4 g kg^{-1}; K=14.7 g kg^{-1}; Ca=8.8 g kg^{-1}; Mg=8.0 g kg^{-1}; S=3.3 g kg^{-1}; B=17.0 mg kg^{-1}; Cu=23.5 mg kg^{-1}; Fe=1875.0 mg kg^{-1}; Mn=365.0 mg kg^{-1}; Zn=148.5 mg kg^{-1}; and Na=2975.0 mg kg^{-1}.

On the day of transplantation, 5 g of urea (45% N), 10 g of superphosphate (18% P_2O_5, 16% Ca and 8% S) and 5 g of conventional potassium chloride protected with polymers (60% K_2O) were applied per pit. During the execution of the experiment, 670, 880 and 476 kg ha^{-1} yr^{-1} of urea, single superphosphate and potassium chloride, respectively, were applied. The urea and each potassium source were distributed monthly, and phosphate fertilization was applied every two months.

Irrigation using the two qualities of water was performed in 48-h irrigation shifts by the drip method using two self-compensating drippers per plant with a flow rate of 10 L h^{-1}. The water volume applied was based on the evapotranspiration data for the crop (ETc), obtained by the potential evapotranspiration (ETo) and the crop coefficient (Kc) in the different stages of the crop (ETc=ETo x Kc). Potential evapotranspiration was estimated by the product of the evaporation of the class 'A' tank (Eta), installed near the experiment, by the product of the correction factor 0.75 (ETo=ETa x 0.75). Kc values were 0.4, 0.8 and 1.2 for the first 60 d after transplanting the seedlings (DAT), from 60 to 90 DAT and from flowering to harvest, respectively, as reported by Souza *et al.* (2009) in Pentecoste, the semi-arid region of the State of Ceará, Brazil. In the treatments with saline water (4.00 dS m^{-1}), despite the sandy texture of the soil, a 10% higher irrigation blade was applied to leach the salts of the root environment (Rhoades *et al.*, 2000).

The stomatal conductance, transpiration, liquid photosynthesis and internal carbon concentration were evaluated at full bloom in the first cycle of the plants, at 132 d after transplanting, and at 300 DAT, at flowering of the plants in the second cycle. The readings were carried out between 10:00 and 11:30 am on the middle leaf of the intermediate productive branch of the plant (Freire *et al.*, 2014). A portable infrared carbon analyzer (IRGA), model LCPro$^+$ Portable Photosynthesis System (ADC BioScientific Limited, UK), with temperature set

Table 4. Chemical composition as the salinity of irrigation water and bovine biofertilizer concentrations in non-saline water (ECw=0.35 dS m^{-1}).

Variables	Types of water		Biofertilizer doses (%)			
	NSW	SW	25	50	75	100
pH	6.12	6.25	6.28	6.37	6.50	7.68
ECw (dS m^{-1})	0.35	4.00	1.90	3.10	3.69	4.55
SAR (mmol $L^{-1})^{1/2}$	1.57	12.83	1.71	1.49	1.58	1.92
Ca^{2+} ($mmol_c$ L^{-1})	1.19	2.51	3.31	6.97	8.61	10.26
Mg^{2+}($mmol_c$ L^{-1})	0.59	7.92	5.46	8.85	10.55	13.02
Na^+ ($mmol_c$ L^{-1})	1.48	29.31	3.57	4.18	4.88	6.56
K^+ ($mmol_c$ L^{-1})	0.19	0.38	6.52	10.47	12.59	15.53
SC ($mmol_c$ L^{-1})	3.45	40.12	18.86	30.47	36.63	45.37
CO_3^{2-} ($mmol_c$ L^{-1})	Abs	0.11	Abs	Abs	Abs	Abs
HCO_3^- ($mmol_c$ L^{-1})	0.54	2.85	2.87	4.65	5.59	6.79
Cl^- ($mmol_c$ L^{-1})	2.51	36.56	13.51	21.97	25.48	32.02
SO_4^{2-} ($mmol_c$ L^{-1})	0.36	0.24	2.82	3.53	5.69	6.67
SA ($mmol_c$ L^{-1})	3.41	39.65	12.20	30.15	36.76	45.48
Classification	C_1S_1	C_4S_1	C_3S_1	C_4S_1	C_4S_1	C_4S_1

ECw=Electrical conductivity of water; NSW=Non-saline surface dam water; SW=Salt water rich in sodium chloride; SAR=$Na^+/[(Ca^{2+} + Mg^{2+})/2]^{1/2}$; SC=sum of cations; SA=Sum of anions; C1, C3 and C4=Low, high and very high risk of salinizing soil in relation to irrigation water; S1=Low soil sodification risk with irrigation.

at 25 °C, irradiation of 1800 µmol photons m^{-2} s^{-1} and air flow of 200 mL min^{-1} was used.

The instantaneous water-use efficiency (WUE) was obtained from the relationship between liquid photosynthesis (A) and transpiration (E), and the instantaneous efficiency of carboxylation (EiC) was obtained by relating the net photosynthesis (A) to the internal concentration of carbon (Ci).

During the two harvests (first - from 12/16/2013 to 02/20/2014 and second - from 03/12/2014 to 05/12/2014), the harvests were carried out every two days, removing the fruits with at least 40% of the area of yellowish bark. The fruits were then packed in plastic boxes for calculation of productivity.

The results were submitted to an analysis of variance, the two harvests being considered as measures repeated in time. The means of the water types were compared by the F test, conclusive for two levels. The potassium fertilization averages were compared by the Tukey test at 5% probability. The biofertilizer doses were evaluated by regression, and the Pearson correlation estimates were obtained between the physiological variables and plant productivity using the software SAS version 9.3 (SAS, 2011).

Results and discussion

No variable significantly responded to the effects of the interaction between water, potassium, bovine biofertilizer and harvest (Table 5). However, liquid photosynthesis was influenced by the interaction among potassium sources, evaluation period and doses of biofertilizer; the internal

Table 5. Summary of variance analysis (calculated F) of stomatal conductance (gS), transpiration (E), net photosynthesis (A), internal carbon concentration (Ci), instantaneous water use efficiency (WUE), instantaneous efficiency of carboxylation (EiC) and productivity (Product) of passion fruit plants BRS Giant Yellow.

Source of variation	DF	gS	E	A	Ci	WUE	EiC	Product
Block	2	4.32^{ns}	0.67^{ns}	1.04^{ns}	92.11^{*}	24.76^{ns}	1.52^{ns}	13.72^{ns}
Type of water (W)	1	8.78^{ns}	19.98^{**}	7.76^{ns}	1.56^{ns}	0.23^{ns}	3.20^{ns}	7.40^{ns}
Residue a	2							
Potassium source (K)	2	2.51^{ns}	6.96^{**}	2.01^{ns}	0.28^{ns}	0.82^{ns}	1.02^{ns}	0.95^{ns}
Biofertilizer (B)	4	0.62^{ns}	2.70^{*}	0.94^{ns}	2.53^{ns}	0.75^{ns}	0.88^{ns}	2.44^{ns}
W × K	2	0.82^{ns}	0.72^{ns}	1.33^{ns}	3.93^{*}	0.74^{ns}	1.60^{ns}	0.09^{ns}
W × B	4	2.75^{*}	8.24^{**}	2.39^{ns}	1.22^{ns}	0.79^{ns}	0.64^{ns}	1.47^{ns}
K × B	8	0.72^{ns}	1.52^{ns}	0.79^{ns}	1.57^{ns}	1.30^{ns}	1.15^{ns}	3.22^{**}
W × K × B	8	1.35^{ns}	1.86^{ns}	3.00^{**}	1.34^{ns}	1.72^{ns}	1.51^{ns}	1.31^{ns}
Residue b	56							
Harvest (H)	1	51.86^{**}	163.36^{**}	29.05^{**}	1.95^{ns}	20.67^{**}	0.97^{ns}	15.71^{**}
W × H	1	3.53^{ns}	0.39^{ns}	5.54^{*}	0.42^{ns}	2.68^{ns}	3.15^{ns}	1.81^{ns}
K × H	2	3.38^{**}	0.28^{ns}	4.84^{*}	1.17^{ns}	1.58^{ns}	1.65^{ns}	0.39^{ns}
B × H	4	0.79^{ns}	1.99^{ns}	0.20^{ns}	0.72^{ns}	0.27^{ns}	0.87^{ns}	0.58^{ns}
W × K × H	2	0.24^{ns}	0.17^{ns}	1.00^{ns}	0.73^{ns}	0.96^{ns}	1.20^{ns}	0.28^{ns}
W × B × H	4	0.95^{ns}	0.36^{ns}	0.67^{ns}	0.57^{ns}	0.60^{ns}	0.86^{ns}	0.50^{ns}
K × B × H	8	1.62^{ns}	1.61^{ns}	2.55^{**}	1.41^{ns}	0.62^{ns}	1.39^{ns}	0.97^{ns}
W × K × B × H	8	0.74^{ns}	0.76^{ns}	1.58^{ns}	1.18^{ns}	0.68^{ns}	1.40^{ns}	1.73^{ns}
Residue c	60							
Total	179							

DF=Degree of freedom; ns=not significant; * and ** denote significance at 5% and 1%, respectively.

carbon concentration through the interaction of water×doses of biofertilizer; and transpiration and water use efficiency, which statistically responded to the isolated effects of the evaluation period. The interaction type of water×biofertilizer dose exerted influence on transpiration and stomatal conductance, which is also influenced by the interaction sources of potassium×evaluation period. Productivity was influenced by the interaction between types of potassium×biofertilizer doses and the isolated effects of the harvest. Also noted is that of all the variables studied, only instantaneous carboxylation efficiency (EiC) did not respond to the effects of any source of variation or the interactions between them (Table 5).

In the plants irrigated with saline water (4.00 dS m^{-1}), the increase in the doses of biofertilizer up to 47.5% reduced the stomatal conductance of 0.2409 to the lowest value of 0.195 mol m^{-2} s^{-1}. This dose increased the organic feedstock, resulting in greater stomatal conductance values of plants, but always lower than the average value of 0.2414 mol m^{-2} s^{-1} between the plants irrigated with water of lower salinity (Figure 1A).This situation, according to Wang *et al.* (2013) and Jákli *et al.* (2017), is a response of the stomatal closure in saline stressed plants, with strategies to reduce water loss through transpiration, as also recorded by Tatagiba *et al.* (2014) and Prazeres *et al.* (2015), who studied photosynthetic limitations of tomato plants (*Solanum lycopersicum*) and cowpeas (*Vigna unguiculata*) subjected to salt stress ranging from 0 to 15 dS m^{-1} of NaCl and 0.8 to 5.0 dS m^{-1}, respectively. The behavior of the data agrees with Freire *et al.* (2014), who concluded that stomatal conductance in yellow passion fruit plants was significantly harmed by increasing water salinity from 0.5 to 4.5 dS m^{-1} but diverges from Nascimento *et al.* (2011) after verifying that the biofertilizer attenuated the deleterious effects of the salts of the irrigation water due to the improvement of the nutritional state of the plants.

The stomatal conductance during the first harvest, while not distinguishing between the plants without K and the nutrient supplied by the conventional potassium chloride KCl and while protected with the organic polymer, outperformed that in the second harvest plants (Figure 1B). Despite the reduction between harvests, the values are consistent with a range of 0.18 to 0.34 mol m^{-2} s^{-1} recorded by Freire *et al.* (2014) in passion fruit with non-saline water at the beginning of the first harvest plants.

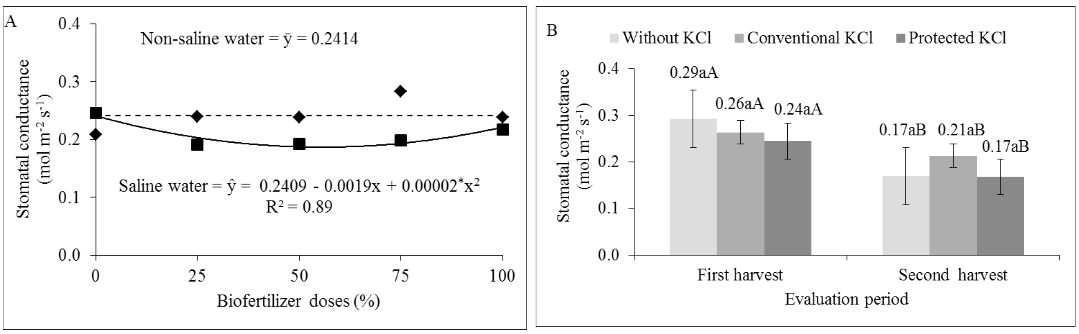

Figure 1. Stomatal conductance of BRS Giant Yellow passion fruit plants in functional biofertilizer doses (A) irrigated with non-saline water (----) and saline (——) in the soil without and with conventional and protected potassium chloride evaluated in the first and second harvests (B).

p values of the equations: *= >0.05> p≥0.01

Means followed by the same lowercase letter under the same conditions of water salinity and different types of potassium chloride and uppercase letter under the different conditions of water salinity and the same source of potassium chloride do not differ statistically from each other by the Tukey test (P<0,05).

The plants at the beginning of the first harvest presented higher transpiration (5.43 mmol m^{-2} s^{-1}) rates than the values recorded in the second crop (3.41 mmol m^{-2} s^{-1}). When correlating these values, we verified that the transpiration rate of the plants in the second harvest was 59.2% smaller than the transpiration rate of the first harvest (Figure 2A). The lowest values of stomatal conductance in the second crop (Figure 1B) indicate that the plants closed part of the stomata due to stress, resulting in a lower transpiration rate (Neves *et al*., 2009; Sousa *et al*., 2016).

The increase in the biofertilizer dose increased the transpiration rates of the plants irrigated with non-saline water and reduced the transpiration rates of the plants treated with saline water (Figure 2B). In relation to the values of 4.4 and 3.8 mmol m^{-2} s^{-1} in the highest biofertilizer dose, in the treatments irrigated with non-saline and saline water, respectively, saline stress was found to reduce the transpiration rate of plants by 15.8%. This situation differs from Freire *et al*. (2014), who did not find an effect of the interaction type of water versus biofertilizer doses on the transpiration rate in the passion fruit crop. Tatagiba *et al*. (2014) state that the concentration of salts significantly reduces the transpiration rate of tomato plants (*Solanum lycopersicum*) because this variable is directly related to the decrease in stomatal conductance and consequently to a reduction in transpiration (Prazeres *et al*., 2015).

The average photosynthetic efficiency data of plants irrigated with non-saline water with and without conventional and polymer-coated potassium chloride did not conform to the regression models tested, with mean values of 19.75, 20.41 and 20.09 µmol CO_2 m^{-2} s^{-1}, respectively (Figure 3A).

In the treatments irrigated with saline water without potassium fertilization, the increase in the biofertilizer dose reduced the photosynthetic efficiency of the plants to a minimum value of 13.6 µmol CO_2 m^{-2} s^{-1} at the biofertilizer dose of 75.5%. In the treatments treated with conventional potassium chloride and protected with the organic polymer, the mean values were 20.20 and 16.51 µmol CO_2 m^{-2} s^{-1} (Figure 3B).

In both plant evaluation periods, mean photosynthetic efficiency data for the plants with and without conventional and polymer-coated potassium chloride did not conform to the regression models tested (Figure 3C and 3D). However, photosynthetic rates in the second period (Figure 3C) in both treatments were lower than in the first period (Figure 3D). Despite the chemical characterization of the soil at the beginning of the flowering of the first harvest, the addition of the biofertilizer increased the potassium content of the soil irrigated with non-saline and saline water, and in both situations, the contents were classified as adequate but lower in treatments

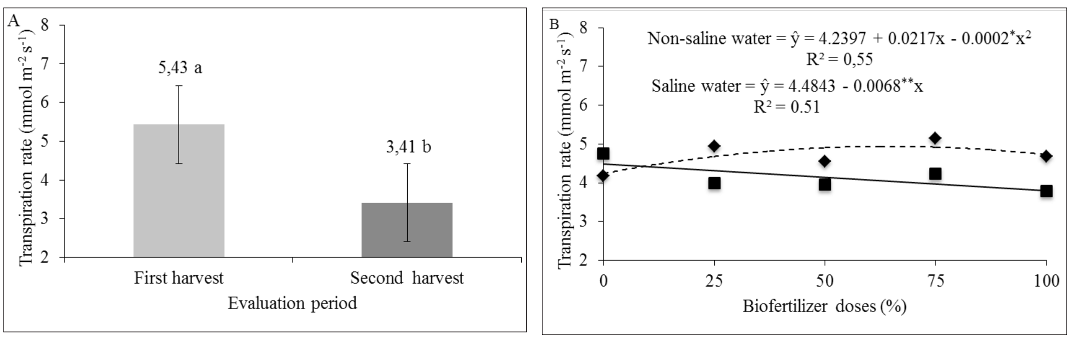

Figure 2. Transpiration rate of passion fruit plants BRS Giant Yellow, according to the evaluation period (A) and doses of biofertilizer (B) irrigated with non-saline (----) and saline (——) water.

p values of the equations: * and ** denote $0.05 > p \geq 0.01$ and $0.01 > p \geq 0.001$, respectively.

Means followed by the same letter do not differ statistically from each other by the F test ($P < 0.05$).

without potassium fertilization (Nunes, 2016). These results indicate that in the absence of potassium fertilization, in soil irrigated with NaCl-rich salt water, the application of the bovine biofertilizer contributes to the increase of the electrical conductivity of the saturation extract, and because there is less potassium in the soil, this results in a higher accumulation of sodium in the leaves (Nunes, 2016), restricting the use of water by plants due to lower transpiration rates (Figure 2A), which is consequently reflected in the lower photosynthetic efficiency of the plants (Silveira *et al.*, 2010).

By correlating the values of the photosynthetic efficiency of the irrigated plants with non-saline and saline water, we verified that the water salinity compromises the liquid photosynthesis of the plants (Figure 3A and 3B). This situation is compatible with Freire *et al.* (2014), who found that salinity of irrigation water (4.5 dS m^{-1}) reduced the photosynthetic rate by 30% compared to plants irrigated with low water salinity.

The increase in salinity from 0.35 to 4.00 dS m^{-1} reduced the photosynthetic rate of the plants in

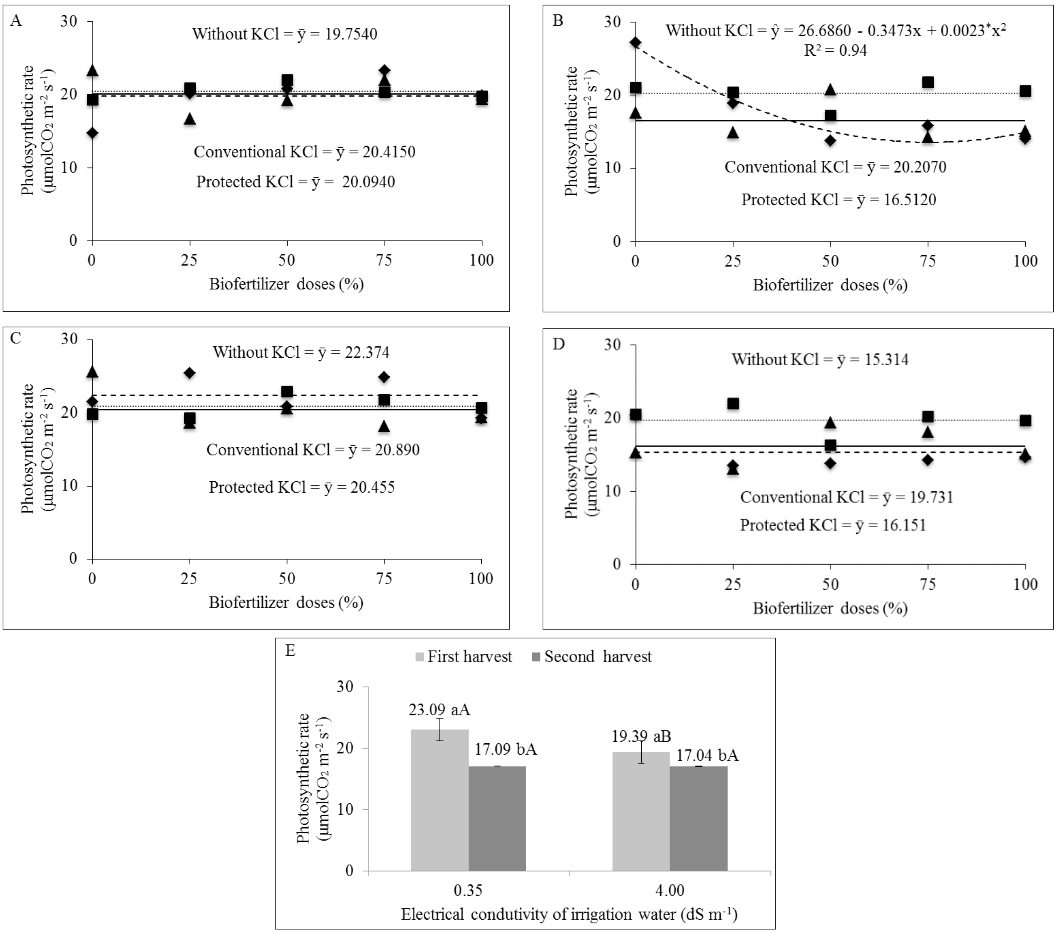

Figure 3. Photosynthetic rate in BRS Giant Yellow passion fruit plants with the function of biofertilizer doses in the soil without (----) and with conventional potassium chloride (······) and protected (——), irrigated with non-saline water (A) and salt (B) in the first (C) and second harvest (D) and in the function of the electrical conductivity of the irrigation water and evaluation period (E).

p values of the equations: * = >0.05>p≥0.01

E - Means followed by the same lowercase letter in the same salinity conditions of the water and different harvest and uppercase letter in the different salinity conditions of the water and the same harvest do not differ statistically in the Tukey test (P<0.05).

the first crop by 19.08% (Figure 3E). Neves *et al*. (2009), irrigating string bean plants (*Vigna unguiculata*) with water of electrical conductivity of 0.8 and 5.0 dS m^{-1}, found that at 42 days after planting, there is a reduction in liquid photosynthesis of the plants irrigated with saline water. This decline is consonant with the lower stomatal conductance (Figure 1) and lower transpiration of the plants (Figure 2) irrigated with water of higher saline content. Possibly, the salinity of the irrigation water did not have a significant effect on the photosynthetic rate of the plants in the second harvest due to the accumulation of rainfall of 355 mm registered in the flowering phase and fruit growth. This situation associated with the sandy texture of the soil may have contributed to the leaching of salts from the root environment to the deeper layers.

The internal carbon concentration did not differ between the types of potassium chloride evaluated in the electrical conductivity of the irrigation water (Figure 4A). By correlating the values of the plants grown in the soil with potassium chloride coated with polymers, we verified that the higher water salinity inhibited the internal carbon concentration by 14.8% compared to those irrigated with non-saline water, with respective values of 148.90 and 174.67 µmol mol^{-1}.

Plants subjected to saline stress, according to Tatagiba *et al*. (2014), suffer a decrease in stomatal conductance, transpiration, and liquid photosynthesis but have elevated internal carbon concentration. This is because the carbon input to the substomatal chamber is dependent on the opening of the stomata (Parihar *et al*., 2015). The trend of the results correlated with Freire *et al*. (2014) for the same crop, but the values are lower than the amplitude of 229.4 to 259.7 µmol mol^{-1} registered in the treatments irrigated with water of low and high salinity.

The instantaneous water use efficiency by plants increased by 29.5% from the first to the second crop (Figure 4B). This variable, obtained by the ratio between photosynthesis and transpiration, indicates the amount of carbon the plant fixes by the amount of water lost during the transpiration process (Jákli *et al*., 2017). Thus, the lower values in the WUE are reflections of the increases in the transpiration rate of the plants in the first harvest (Figure 2A).

Productivity decreased from 20.35 to 18.63 t ha^{-1}, from the first to the second crop, resulting in a loss of 8.45% (Figure 4C). The greater stomatal opening (Figure 1B) and transpiration rate (Figure 2A) in the first crop associated with higher internal carbon concentration in the treatments with potassium chloride coated with polymers (Figure 4A) favored the entry and fixation of CO_2 in the leaf mesophyll, stimulating photosynthesis (Jákli *et al*., 2017) and in effect contributing to raise crop productivity in the first harvest.

The increase in the doses of the organic input raised the productivity of BRS Giant Yellow passion fruit plants (Figure 4D), and the highest yields of 21.82 and 20.60 t ha^{-1} in the soil without potassium and with the protected mineral fertilizer were obtained in the highest biofertilizer dose. Plants fertilized with conventional potassium chloride produced 20.95 t ha^{-1} at the maximum biofertilizer dose of 46.2% (Figure 4D). The application of bovine biofertilizer associated with potassium fertilization, even in soil with an initial K^+ content considered medium (Table 1), should have improved the physical (Mellek et al., 2010; Benbouali et al., 2013), chemical (Dias et al., 2015) and biological properties of the soil (Marrocos *et al*., 2012), contributing to plant growth (Mesquita *et al*., 2012; Souza *et al*., 2016) and the production of yellow passion fruit (Dias *et al*., 2011).

Considering that the data of Figure 4D represent the average values of productivity of the plants irrigated with water of low and high electrical conductivity, the addition of salts by the organic input, which is expressed by the increase of the electrical conductivity of the doses (Table 4), together with the conventional potassium chloride

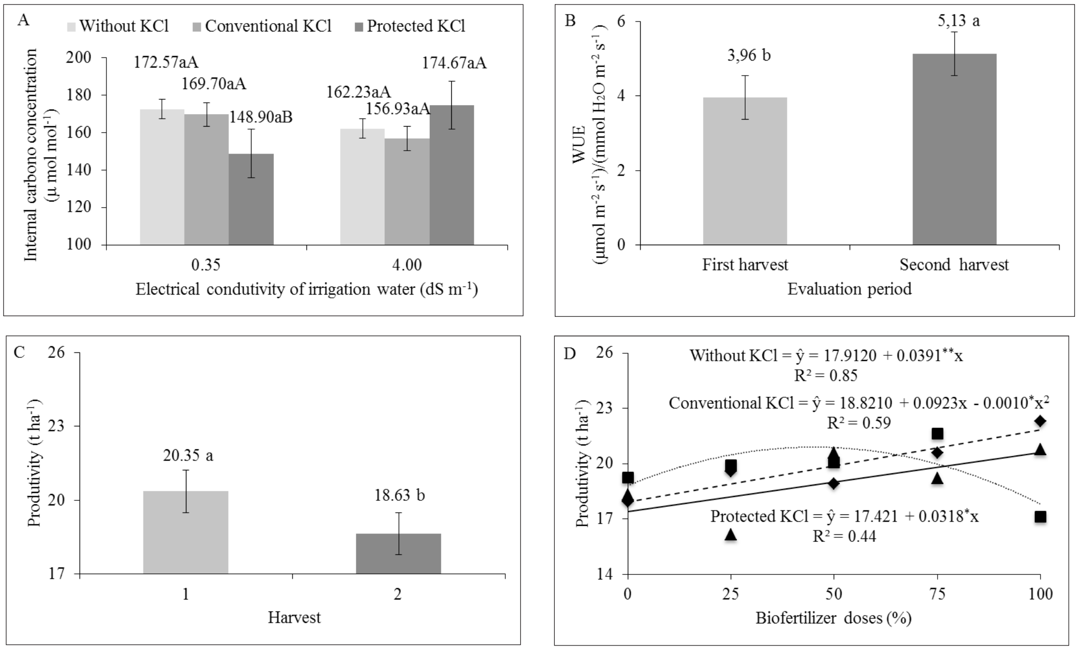

Figure 4. Internal carbon concentration - Ci (A), instantaneous in water use efficiency - WUE (B) and productivity (C, D) in passion fruit BRS Yellow Giant irrigated with non-saline water (0.35 dS m^{-1}) and salt (4.00 dS m^{-1}) in the soil with and without conventional and protected potassium chloride (A) at the beginning of the first and second harvests (B), as a function of the evaluation period (C) and biofertilizer doses in soil (D), without (----) and with conventional potassium chloride (·······) and protected with organic polymers (——).

p values of the equations: * and ** denote 0.05> p≥0.01 and 0.01>p≥0.001, respectively.

A - Means followed by the same lowercase letter under the same conditions of water salinity and different types of potassium chloride and the same uppercase letter in different conditions of water salinity and the same source of potassium chloride do not differ statistically from each other by the Tukey's test (P<0.05).

C - Means followed by the same letter do not differ by the F test (P<0.05).

saline index (116), possibly contributed to reduce plant productivity from the biofertilizer dose of 46.2% due to the lower photosynthetic rate in the plants irrigated with saline water (Figure 3B).

The absence of a significant effect of irrigation water salinity on productivity is a response of the sandy soil texture that contains more than 83% sand in the 0–40 cm layer (Table 2), contributing to the low adsorption of salts to the sorption complex and of the addition of 10% to the irrigation plate in the treatments with saline water (4.0 dS m^{-1}). This practice, according to Rhoades *et al*. (2000), promotes the leaching of the salts of the superficial layer to the depths beyond the radicular environment of the plants, keeps the soil more moist and in general exerts a diluting effect of the salts with less aggressive reflexes to the majority of the plants cultivated, including the yellow passion fruit which is sensitive to salinity.

Considering that the average productivity of Brazil is 14.5 t ha^{-1}, that of the northeast is 13.56 t ha^{-1} and that of the Paraiba is 8.88 t ha^{-1}, we verified that the total yield of 38.98 t ha^{-1} obtained in the two harvests exceeded the national, northeastern and Paraiban averages by 168.8; 186.7 and 337.9%, respectively. Considering that both harvests were harvested in the first year of planting, the average total productivity is the same as that presented by Embrapa (2008), who reported that the genotype BRS Giant Yellow reaches high yields ranging from 40 to 45 t ha^{-1} in the first year after planting and of 20 t ha^{-1} in the second year after planting.

Table 6. Pearson correlation coefficient between variables; stomatal conductance (gS), respiration (E), net photosynthesis (A), carbon internal concentration (Ci), instantaneous efficiency of water use (WUE), instantaneous carboxylation efficiency (EiC) and productivity (Product) of passion fruit plants BRS Giant Yellow.

Variáveis	gS	E	A	Ci	WUE	EiC	Product
gS	1	0.632^{**}	0.687^{**}	0.036^{ns}	0.114^{ns}	0.110^{ns}	0.173^{*}
E		1	0.557^{**}	-0.053^{ns}	-0.395^{**}	0.037^{ns}	0.273^{**}
A			1	-0.517^{**}	0.502^{**}	0.461^{**}	0.163^{*}
Ci				1	-0.494^{**}	-0.535^{**}	-0.052^{ns}
WUE					1	0.463^{**}	-0.152^{*}
EiC						1	0.015^{ns}
Product							1

* and ** denote significance at 5% and 1%, respectively; ^{ns}=not significant.

The productivity of the passion fruit 'BRS Giant Yellow' irrigated with saline water at the level of electrical conductivity not tolerated by most cultivated plants of commercial importance is promising and allows the use of saline waters in soils with sandy texture.

All physiological variables showed significant correlations with yellow passion fruit productivity except the internal carbon concentration and the instantaneous carboxylation efficiency (Table 6). Despite the significance of coefficients, the scores are considered low (Callegari-Jacques, 2003). The transpiration rate was the variable that best correlated with productivity (0.273), followed by stomatal conductance and net photosynthesis (0.173 and 0.163, respectively). The correlation between the instantaneous efficiency of water use and the production variable was negative (-0.152). When evaluating Pearson's correlations between the transpiration of plants with stomatal conductance and net photosynthesis, strong correlations were found between the variables, with values of 0.632 and 0.677, respectively. This situation indicates that the higher productivity is related to greater stomatal opening, which is expressed by the transpiration rate and results in greater stomatal conductance that stimulates photosynthesis and exerts a positive effect on the productive capacity of the plants (Parihar *et al*., 2015; Jákli *et al*., 2017).

Based on the initial hypotheses, we conclude that (i) the application of bovine biofertilizer and potassium in sandy soil irrigated with saline water did not inhibit the degenerative effect of the salts on the photosynthetic rates of the plants; (ii) the salinity of the irrigation water reduced stomatal conductance, transpiration and liquid photosynthesis of plants, but in the second harvest, the instantaneous water use efficiency was higher; and (iii) despite the decrease in productivity from the first to the second harvest, the bovine biofertilizer associated with potassium fertilization increased crop yield, which exceeded the Brazilian average, the average of the Brazilian Northeast and the average of the State of Paraíba, Brazil.

Resumen

J.C. Nunes, L.F. Cavalcante, W.E. Pereira, J.T.A. Souza, D.J. Almeida, D. Oresca, y P.D. Fernandes. 2017. Intercambio de gas y productividad de maracuyá amarillo irrigado bajo salinidad y fertilizado con potasio y biofertilizante. Cien. Inv. Agr. 44(2): 168-183. La salinidad del agua de riego puede afectar el crecimiento y desarrollo de la mayoría de las plantas de interés comercial. Con el objetivo de estudiar estos aspectos en el cultivo de la maracuyá, se realizó un experimento para evaluar los efectos del biofertilizante bovino y la fertilización potásica sobre el intercambio gaseoso y la producción de frutos de maracuyá, BRS Giant Yellow irrigado con agua salina y no salina. Los tratamientos se realizaron en bloques al azar con parcelas sub-subdivididas, utilizando el esquema fatorial 2×(3×5), haciendo referencia a dos niveles de conductividad eléctrica del agua de riego como parcela principal (0,35 y 4,00 dS m^{-1}), y en las subparcelas la combinación de tres prácticas de fertilización potásica (sin fertilización, fertilizada con KCl convencional y de liberación lenta) con cinco dosis de biofertilizante bovino (0, 25, 50, 75 y 100% de dosis de 15 L m^{-2}), con tres repeticiones y 12 plantas por parcela. Se evaluaron la conductividad estomática, transpiración, fotosíntesis líquida, concentración interna de carbono, eficiencia en el uso del agua, eficiencia instantánea de la carboxilación y productividad de plantas de maracuyá en dos cosechas, por lo que los datos fueron sometidos a la evaluación estadística de muestras repetidas en el tiempo. La aplicación de biofertilizante bovino y potasio en suelo de textura arenosa irrigada con agua salina no inhibió la acción degenerativa de las sales a las tasas fotosintéticas de las plantas. La salinidad del agua de riego redujo la conductividad estomática, la transpiración y la fotosíntesis líquida de las plantas, pero en la segunda cosecha, la eficiencia en el uso instantáneo del agua fue superior. A pesar de la productividad decreciente de la primera para la segunda cosecha, el biofertilizante bovino asociado a la fertilización potásica elevó el rendimiento de la cultura, que superó la media de Brasil, del Nordeste brasileño y del Estado de Paraíba, Brasil.

Palabras clave: Eficiencia fotosintética, estiércol líquido fermentado, *Passiflora edulis* Sims, salinidad.

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