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Gas exchange and growth of bell pepper grown in different substrates under salinity stress

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ABSTRACT

Physicochemical qualities of the substrate, such as moisture retention capacity and retention of exchangeable bases, enable better photosynthetic activity and plant growth gains in semi-hydroponic cultivation. The aim of this study was to evaluate the effect of different substrates on physiology and growth of bell peppers cultivated under salinity stress. The research was conducted in a greenhouse, in randomized block design, 3 x 4 factorial scheme, using three substrates [coconut fiber, sand, mixture (coconut fiber + sand (1:1)] and four electrical conductivity levels of the nutrient solution (2.2; 3.5; 4.5 and 5.5 dS/m), with three replications. At 72 days after transplanting, we evaluated gas exchanges in plants through stomatal conductance, transpiration rate, photosynthesis, water use efficiency and intrinsic water use efficiency. At 120 days after transplanting, the plants were collected and evaluated in relation to leaf dry mass, stem dry mass, fruit dry mass and total dry mass. Salinity stress affected gas exchange in bell pepper plants in all substrates, especially at higher salt levels. Coconut fiber provided better physiological and growth conditions for bell pepper grown under salinity stress. Bell pepper can be grown under salinity levels up to 3.5 dS/m using coconut fiber or the mixture of coconut fiber and sand (1:1) as substrates.

Keywords: *Capsicum annuum* L., salinity, semi-hydroponics, coconut fiber, sand.

RESUMO

Trocas gasosas e crescimento de pimentão cultivado em diferentes substratos sob estresse salino

Qualidades físico-químicas do substrato, como capacidade de manutenção de umidade e retenção de bases trocáveis possibilitam melhor atividade fotossintética e ganhos de crescimento de plantas em cultivo semi-hidropônico. O objetivo deste estudo foi avaliar o efeito de diferentes substratos na fisiologia e crescimento de pimentão cultivado sob estresse salino. O experimento foi conduzido em casa de vegetação, utilizando delineamento em blocos casualizados, em esquema fatorial 3 x 4, formado por três substratos [Fibra de coco, Areia, Mistura (Fibra de coco+Areia (1:1)] e quatro níveis de condutividade elétrica da solução nutritiva (2,2; 3,5; 4,5 e 5,5 dS/m), com três repetições. Aos 72 dias após o transplantio, as plantas foram avaliadas quanto às trocas gasosas por meio da condutância estomática, transpiração, fotossíntese, eficiência do uso da água e eficiência intrínseca do uso da água. Aos 120 dias após o transplantio as plantas foram coletadas e avaliadas quanto ao crescimento da massa seca de folhas, massa seca de caule, massa seca de frutos e massa seca total. O estresse salino afetou as trocas gasosas das plantas de pimentão em todos os substratos, especialmente nos níveis de condutividade elétrica maiores. O substrato fibra de coco proporcionou melhores condições fisiológicas e de crescimento para o pimentão cultivado sob estresse salino. É viável o cultivo de pimentão sob salinidade até 3,5 dS/m utilizando substrato fibra de coco ou a mistura de fibra de coco com areia (1:1).

Palavras-chave: *Capsicum annuum* L., salinidade, semi-hidroponia, fibra de coco, areia.

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Bell pepper (*Capsicum annuum* L.) is a member of *Solanaceae* family. The crop is one of the most consumed vegetables worldwide, being widely used in international cuisine (Lisboa *et al*., 2024). Its fruits are excellent source of minerals, vitamins and antioxidant, including carotenoids (β-carotenoids and lycopene) and vitamins (A, C and E) (Franczuk *et al*., 2023).

Bell pepper is a salt sensitive plant, showing a salinity threshold level of 1.5 dS/m, for soil saturation extract (Ayers & Westcot, 1999). Thus, the quality of water used in cultivation is extremely important, mainly in relation to dissolved salt concentration, considering that a high concentration of salts in the solution can cause nutritional imbalance, physiological problems and/or toxicity in plants (Taiz *et al*., 2017).

Given the above, the main

researches on bell pepper crop in a protected environment in this region focus mainly on the use of saline water in this plant production (Lima *et al*., 2016; Melo *et al*., 2017; Silva *et al*., 2020). Salinity stress causes metabolic and biochemical changes in plants, negatively affecting the leaf gas exchange, protein synthesis and enzymatic activity, intensifying chlorophyll degradation (Santos *et al*., 2022). These changes directly reflect in a reduced plant growth and development (Melo *et al*., 2017; Santos *et al*., 2022).

Considering the above, researches on technology and cultural management, aiming to enhance plant tolerance to salinity, are essential. One of the promising technologies is hydroponic cultivation using substrates, also called semi-hydroponic. In this cultivation system, plants are grown in inert or low ionic activity substrates, which are continuously supplied with nutrient solutions, making it possible to control the plant mineral nutrition in an appropriate way (Agius *et al*., 2022).

Several studies on semi-hydroponic cultivation focusing on saline water use, such as the ones on mini watermelon (Silva *et al*., 2021) and bell pepper (Melo *et al*., 2017; Silva *et al*., 2020), have been developed recently. In most studies, this cultivation system has enabled greater plant tolerance to salinity, due to a high nutrient availability in the solution, as well as to the low influence of the matrix potential. (Camposeco-Montejo *et al*., 2018).

Despite the fact that all the essential nutrients were supplied via nutrient solution (Agius *et al*., 2022), choosing substrate is a primordial factor for plants to express their physiological, growth and productivity potential properly.

Velazquez-Gonzalez *et al*. (2022) highlighted five fundamental characteristics for a good substrate: a) porosity: influences the nutrient availability which allows the plant to perform metabolic processes, just like respiration, transpiration and photosynthesis; b) capillarity: characteristic related to the capacity of the substrate to absorb nutrients and distribute to plant root; c) oxygenation: characteristic in which the substrate structure allows oxygen intake by the roots while they are in contact with the nutrient solution; d) to be chemically inert: the substrate shall contain materials which are not able to react to chemical products of the nutrient solution in order to avoid any alteration in its composition; e) to be biologically inert: the substrate is not expected to favor any biological activity, since microorganisms can cause detrimental effect on crops, like diseases, malnutrition and other consequences.

Considering the mentioned above, despite the fact that several studies have showed salinity effect on bell pepper crop (Lima *et al*., 2016; Melo *et al*., 2017; Silva *et al*., 2020), studies comparing the effects and benefits of different substrates under gas exchanges and growth of this vegetable under salinity stress are rare.

This study aimed to evaluate the effect of different substrates on gas exchange and bell pepper growth, hybrid 'Gladiador', grown under salinity stress.

MATERIAL AND METHODS

The research was carried out from May to September, 2021, in a greenhouse at Departamento de Ciências Agronômicas e Florestais (DCAF), in Centro de Ciências Agrárias (CCA), at Universidade Federal Rural do Semi-Árido (UFERSA), in Mossoró, RN (5º12'4"S; 37º19'39"W, mean altitude 18 m).

During the research, the authors collected climatic data, such as maximum (Tmax), medium (Tave) and minimum (Tmin) temperatures, as well as maximum (RHmax), medium (RHave) and minimum (RHmin) relative air humidity, monitored by an automatic meteorological station (Campbell Scientific Inc. model CR1000), installed inside the greenhouse. We verified temperatures ranging from 27.99 to 38.14ºC for Tmax; 27.28 to 31.96ºC for TAve; 20.82 to 28.29ºC for Tmim. For RH, ranges from 56.17 to 100% for RHmax, 48.16 to 88.63 for RHave and 22.89 to 78.96% for RHmin were verified.

The experimental design used was randomized block (DBC), in a factorial scheme 3 × 4, with three replications. Each experimental unit consisted of four 10 dm^3-capacity pots, containing one plant in each pot, totalizing 144 plants. The treatments consisted of three substrates (Sb) [coconut fiber, washed sand and a mixture of coconut fiber + washed sand (1:1)], with four electrical conductivity levels of salinized nutrient solutions (CE1= 2.2 dS/m; CE2= 3.5 dS/m; CE3= 4.5 dS/m and CE4= 5.5 dS/m) applied via fertigation,

The standard nutrient solution used was recommended by Castellane & Araújo (1994). The authors used 650; 506; 170; 300 and 99.2 $Ca(NO_3)_2$; KNO_3; MAP; $MgSO_4$ and KCl, in g for 1000 liters, respectively. Micronutrients were supplied by two commercial products: one compost [Dripsol Micro Rexene Equilíbrio Micronutrientes Quelatados magnesium 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%)], and the other product was an extra source of iron (Quelato de Ferro Q48 Eddha 6%).

The authors used a hybrid bell pepper cultivar Gladiador F1 (Topseed®). The plant is compact and erect, with high leaf coverage, showing a 120-day cycle after sowing, squared fruits with about 5-mm wall thickness and green-to-red ripening stage.

The nutrient solutions were prepared using water from the supply system of the UFERSA Campus. The physical-chemical properties determined the following characteristics: pH= 7.57, EC= 0.54 dS/m, Ca^{2+}= 0.83, Mg^{2+}= 1.20, K^{+}= 0.31, Na^{+}= 3.79, Cl^{-}= 2.40, HCO_3= 3.20 and CO_3^{2}= 0.60 ($mmol_c$/L). In order to obtain the other solutions (EC_2, EC_3 and EC_4), non-iodized sodium chloride (NaCl) was added into the same water used for the standard nutrient solution (EC_1), in quantities of 306.4; 916.9 and 1527.4 g/1000 L, respectively, adjusting the salinities with the aid of a portable conductivity meter.

Seedlings were grown in plastic trays containing coconut fiber, and one seedling per cell. Plants were transplanted at 35 days after emergence, using one plant in each pot. The pots were kept in the greenhouse, under 0.2 m-high concrete blocks, spacing 0.9 m between rows and 0.5 m between plants.

The crop was drip irrigated. The authors used microtubes emitters (spaghetti), 1.5-mm internal diameter, 10-cm long, mean flow of 18 L/h, coupled to the polyethylene pipe lateral lines (16 mm).

Each salinity treatment was irrigated independently. The system consisted of a reservoir (500-L capacity water tank) and a circulation pump Metalcorte/Eberle, self-ventilated model EBD250076, driven by a single-phase motor, 210 V voltage, 60 Hz frequency.

Fertigation system was controlled by a digital timer (model TE-2, Decorlux®), programmed for eight daily irrigations, according to the crop necessity throughout the development cycle (Table 1). The water consumption of the plants was not taken into account, however, in all irrigations the substrate moisture was increased to its maximum water retention capacity, based on the visualization of drainage in the pots.

Table 1. Irrigation time throughout the bell pepper cycle grown under salinity stress in different substrates. Mossoró, UFERSA, 2021**.**

Days after transplanting (DAT)	Average time in each irrigation	Daily irrigation time
1-17	1 min	8 min
18-25	1 min 12 s	8.5 min
26-29	1 min 15 s	10 min
30-49	1 min 30 s	10.30 min
50-99	2 min	14 min
100-Final	1 min 45 s	12.15 min

In each row, espaliers were built with wooden stakes and stainless steel wires were used on each side of the plants to induce them to grow vertically without bending.

Leaf gas exchanges were estimated at 72 DAT (fruiting), beginning at 9 a.m. until 11 a.m., considering the third leaf from the plant apex, with the aid of an infrared gas analyser (model "LCPro +" - ADC Bio Scientific Ltd.) operating at 25ºC, irradiation of 1200 µmol photons/m^2/s and air flow rate of 200 mL/min at atmospheric CO_2 level. We measured transpiration *(E)*; stomatal conductance (*gs*); photosynthesis (*A*); water use efficiency *(WUE)(A/E);* intrinsic water use efficiency (*iWUE*) (*A*/gs).

At 120 DAT, the plants were collected and divided into leaf, stalk and fruits. Then, each material was packed in paper bags labeled and placed in an oven with forced air, at 65ºC, for 72 hours, until reaching constant mass. After being dried, the materials were weighed individually, using a precision analytical scale (0.01 g), in order to obtain leaf dry mass (LDM), stem dry mass (SDM), fruit dry mass (FDM). The total dry mass (TDM) was obtained by the sum of different parts of the plant (TDM= LDM+SDM+FDM).

The obtained data were submitted to the analyses of variance, and unfolding analysis was performed, when a significant response related to the interaction between factors was verified. The effect of the substrates was evaluated using Tukey mean comparison test at 0.05. The effect of salinity levels was analyzed using regression, adjusting polynomial models. The statistical analyses were performed using the statistical software SISVAR (Ferreira, 2019).

RESULTS AND DISCUSSION

The authors verified significant effect in relation to the interaction between substrate and salinity for photosynthesis rate *(A)* at 5% probability, as well as for water use efficiency *(WUE)* and intrinsic water use efficiency (*iWUE*) at 1% probability. The variables stomatal conductance (*gs*) and transpiration rate *(E)* showed significant response to salinity, both at 1% probability.

No significant effect was noticed between stomatal conductance (*gs*) and transpiration rate *(E),* with averages of 103.69 mol $H_2O/m^2/s^1$ for *gs* and 1.58 mmol H_2O/m^2/s for *E*.

Stomatal conductance *(gs)* and transpiration rate *(E)* were quadratically affected by an increase in conductivity of the nutrient solution, regardless of the substrate used (Figure 1). Values of *gs* and *E* increased up to levels 3.64 and 3.83 dS/m, showing maximum values of 149.82 mol H_2O/m^2/s and 2.03 mmol H_2O/m^2/s, representing an increase of 69.83 and 67.09%, for *gs* and *E*, respectively, when comparing with values obtained in the lowest CE, 88.22 mol H_2O/m^2/s for *gs* and 1.24 mmol H_2O/m^2/s for *E*. The authors also verified that using a higher CE nutrient solution caused a reduction of these variables when compared with the highest values, showing losses of 67.39 and 41.26%, for *gs* and *E*, respectively (Figures 1A and 1B).

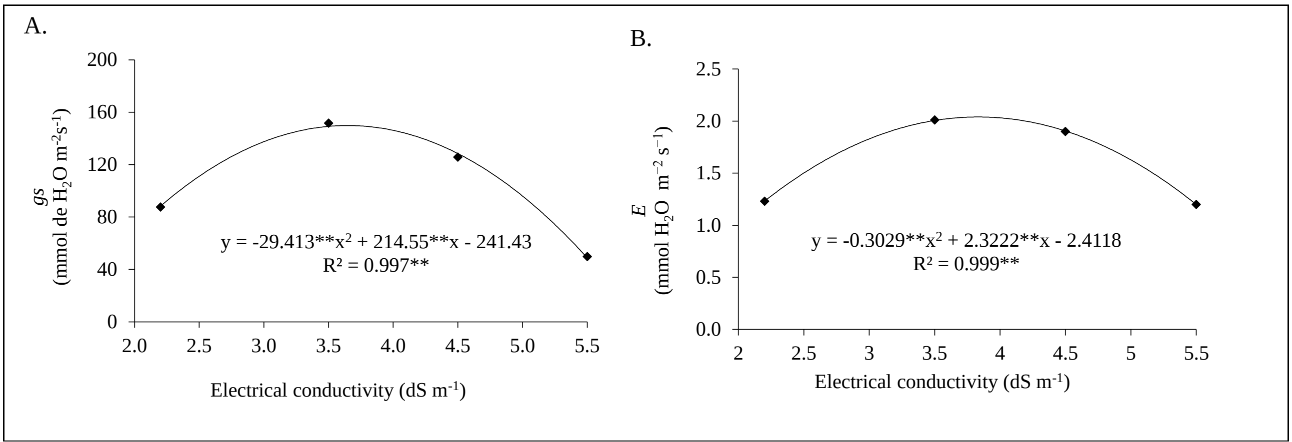

Figure 1. Stomatal conductance (*gs*) (A) and transpiration rate (*E*) (B) of bell pepper grown under salinity stress in different substrates. Mossoró, UFERSA, 2021.

In this study, we inferred that bell pepper plants adjusted themselves to salinity stress by increasing the stomatal conductance up to salinity 3.64 dS/m, showing that stomata were not closed and gas exchanges occurred normally. Consequently, transpiration rate increased up to 3.83 dS/m, showing that stomata were still open, resulting in an increase of transpiration and gas exchanges.

However, we noticed reductions in *gs* and in *E*, respectively, when using salinity levels of 3.64 and 3.83 dS/m, According to Gammoudi *et al.* (2016), this fact indicates that the plants showed a reduction in water uptake, resulting in stomatal closure and a decrease in transpiration as a strategy to adapt to salinity stress, limiting photosynthesis performance, though.

These results are similar to the ones showed by Orosco-Alcalá *et al.* (2021), which found a reduction in *E* in bell pepper submitted to salinity above 4.0 dS/m. Melo *et al.* (2017) also demonstrated quadratic behavior of *gs* of the bell pepper plants in relation to an increase of salinity levels, reaching the maximum in 1.0 dS/m and reducing from this level on.

One of the first warning signs that plants are under some stress condition, causing a decrease in water uptake, is stomatal closure. Thus, under these conditions, plants reduce *gs* and the quantity of CO_2 in leaves in order to avoid water loss to the atmosphere (Melo *et al.*, 2017). In this study, increases in *gs* and *E* up to CE 3.64 and 3.83 dS/m, respectively, were verified, these shall be signs of tolerance to salinity (Orosco-Alcalá *et al.*, 2021). Thus, bell pepper plants still perfom photosynthesis, since stomatal conductance and transpiration are functionally related to CO_2 assimilation (Melo *et al.*, 2017; Orosco-Alcalá *et al.*, 2021).

Photosynthesis (*A*) differed among the substrates for all electrical conductivities. In the lowest salinity level (2.2 dS/m) plants grown in sand substrate showed higher photosynthesis rate when compared to the ones grown in coconut fiber and mixture in 53.04 and 33.49%, respectively. In salinity levels 3.5 and 4.5 dS/m sand substrate provided higher *A* in relation to mixture, and both did not differ from the coconut fiber. In the salinity level 5.5 dS/m, sand and coconut fiber substrates produced plants with higher *A* in relation to mixture, surpassing in 44.97 and 34.01%, respectively (Figure 2A).

The plants grown in sand and mixture showed significant responses in relation to an increase in salinity levels for photosynthesis (Figure 2). For both substrates, higher values were obtained in the lowest CE (2.2 dS/m), being 33.68 and 25.34 µmol CO_2 m^2/s, respectively. The bell pepper plants showed linear reduction in photosynthesis in sand and mixture with an increase in CE of the nutrient solution, resulting in a reduction of 32.49% in sand and 36.03% in mixture. We verified no electrical conductivity effect on plants grown in coconut fiber, obtaining average photosynthesis rate of 23.04 µmol CO_2 m^2/s (Figure 2A).

Some crops reduce photosynthesis under salinity stress, as observed by Melo *et al.* (2017) and Orosco-Alcalá *et al.* (2021). According to Orosco Alcalá *et al.* (2021), water deficiency caused by salinity stress results in stomatal closure and, consequently, reduction in CO_2 uptake. Reduction of photosynthesis in plants at higher salinity level occurred, probably, due to stomatal restrictions, which decreases the diffusion of CO_2 in the membranes.

Water use efficiency (*WUE*) differed among the substrates only when plants were fertigated with the lowest CE nutrient solution (2.2 dS/m), with better results obtained using sand substrate (37.02 µmol CO_2/mmol H_2O), being this substrate superior in 71.23 and 106.23%, comparing with coconut fiber and mixture, respectively. For the other electrical conductivities (3.5; 4.5 and 5.5 dS/m), we verified no significant differences among the substrates, with the average values of 12.94; 13.41 and 20.27 µmol CO_2/mmol H_2O, respectively (Figure 2B).

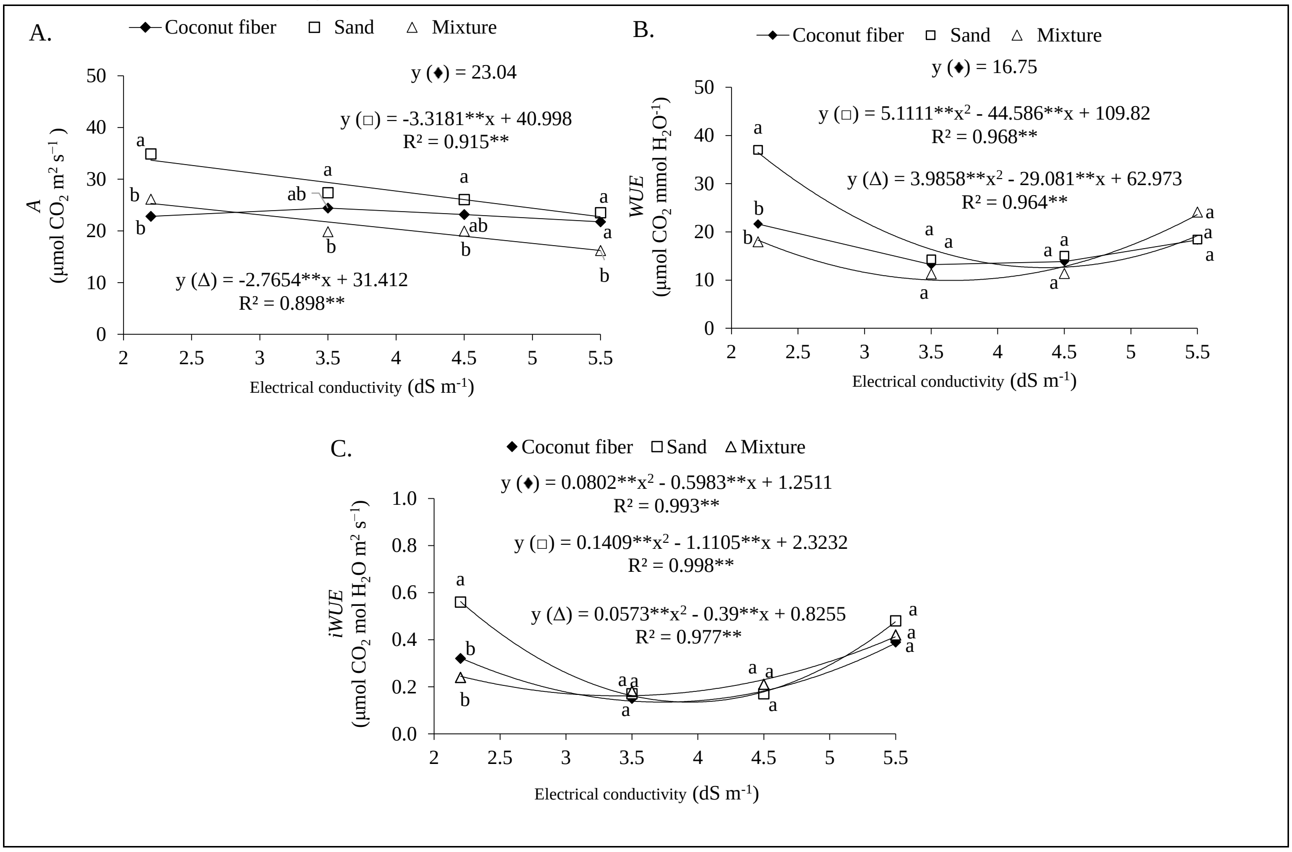

Figure 2. Photosynthesis (A), water use efficiency (B) and intrinsic water use efficiency (C) of bell peppers grown under salinity stress in different substrates (lowercase letters represent the effect of substrates at each salinity). Mossoró, UFERSA, 2021.

For the effect of salinities on *WUE*, a significant quadratic effect was verified in sand and mixture. In sand, the highest *WUE* occurred at salinity level 2.2 dS/m (36.46 µmol CO_2/mmol H_2O) and the lowest at salinity 4.36 dS/m (12.58 µmol CO_2/mmol H_2O), reducing 65.49% between them. For mixture, the lowest *WUE* occurred in plants submitted to salinity 3.64 dS/m (9.92 µmol CO_2/mmol H_2O) and the highest was noticed in plants submitted to the highest salinity (5.5 dS/m), being 23.59 µmol CO_2/mmol H_2O, related to an increase of 137.80%. The plants grown in coconut fiber substrate showed no significant response for *WUE* in relation to the increase in salinity, the average *WUE* was 16 µmol CO_2/mmol H_2O (Figure 2B).

Differing from the results in this study, Melo *et al*. (2017) verified an increase of *WUE* in relation to an increase in the salinity levels. However, other studies showed a reduction in *WUE* as a result of an increased salinity in the nutrient solution (Carvalho *et al*., 2019; Orosco Alcalá *et al*., 2021).

WUE expresses the ratio between photosynthesis (*A*) and transpiration (*E*) of the plants, being inversely proportional to stomatal conductance. Accumulation of large quantities of Na^+ and Cl^- in leaf tissues causes water loss from the guard cells and, therefore, changes in morphology, activity and/or density number of guard cells and stomata, which may reduce or prevent the entry of CO_2 and limit normal photosynthesis (Ben Amor *et al*., 2020), resulting in a reduction in *WUE*.

Thus, in the present study, we can infer that an increase in salinity of nutrient solution resulted in the lowest water use efficiency by bell pepper plants in all substrates, showing that up to a certain salinity level (≈ 4,0 dS/m) plants lost more water through the process of transpiration than they were able to assimilate carbon, not being so efficient in carrying out photosynthesis.

The intrinsic water-use efficiency (*iWUE*) was affected by the substrates only in plants fertigated with the lowest CE nutrient solution (2.2 dS/m), in which sand substrate was superior at 75 and 133.33% in relation to coconut fiber and mixture, respectively. For the other salinities (3.5; 4.5 and 5.5 dS/m), the authors noticed no significant differences among the substrates, obtaining average values of 0.16; 0.18 and 0.43 µmol CO_2 mol $H_2O/m^2/s$, respectively (Figure 2C).

In relation to the effect of salinity levels on *iWUE*, significant quadratic response was verified on all substrates. In coconut fiber, at first, we verified a reduction in *iWUE*, showing an increase of CE up to3.73 dS/m (0.13 μmol CO_2 mol $H_2O/m^2/s$) followed by an increase from this level on, reaching the highest salinity value of 5.5 dS/m (0.38 μmol CO_2 mol $H_2O/m^2/s$), representing an increase of 185.75% in relation to the lowest *iWUE*. For sand substrate, the highest *iWUE* was verified in plants grown in salinity 2.2 dS/m (0.56 μmol CO_2 mol $H_2O/m^2/s$) and the lowest (0.13 μmol CO_2 mol $H_2O/m^2/s$) in CE 3.94 dS/m, reducing 75.96% among them. For the mixture, behavior similar to coconut fiber was verified, with the highest *iWUE* (0.41 μmol CO_2 mol $H_2O/m^2/s$) in plants grown in the highest salinity level (5.5 dS/m) and the lowest level 3.40 dS/m (0.16 μmol CO_2 mol $H_2O/m^2/s$) (Figure 2C).

In general, we noticed that intrinsic water use efficiency (*iWUE*) and water use efficiency (*WUE*) showed similar quadratic behavior, corroborating the results presented by Orosco Alcalá *et al*. (2021). *iWUE* expresses the relationship between water consumption and photosynthetic rates. Thus, an increase of *iWUE* in the highest salinities reflects tolerance mechanisms such as reduced transpiration, minimizing the entry of water and salts without compromising photosynthetic activity, reducing the toxic effects of specific ions (Flowers & Flowers, 2005). According to Wang *et al*. (2020), the increase in *iWUE* is an important characteristic which may increase plant tolerance to stress.

Fruit dry mass (FDM) and total dry mass (TDM) showed significant response in relation to the interaction between substrate and salinity at 5% probability significant level. Leaf dry mass (LDM) and stem dry mass (SDM) obtained isolated response for both factors, substrate and salinity, both showing significance at 1% probability.

For leaf dry mass (LDM) and stem dry mass (SDM), significant responses in relation to substrates were noticed. The highest values were verified in coconut fiber and the lowest values in sand and mixture, which did not differ significantly from each other (Figures 3B and 3D).

Charlo *et al*. (2012) reported that the coconut fiber is a substrate which provides greater nutrient utilization efficiency by bell pepper plants. This is due to a greater ability to maintain moisture and keep nutrients available to plants for longer. Sand is a substrate which presents good aeration and drainage conditions (Fachinello *et al*., 1994), however, this substrate cannot retain moisture for a long time, providing a smaller volume of water to the plants. This implies a reduction in growth and dry mass production.

For salinity levels, we noticed a quadratic response for LDM and SDM. Greater LDM occurred at CE of 3.13 dS/m (25.57 g/plant), reducing 37.97% when compared with the LDM obtained using CE of 5.5 dS/m (15.86 g/plant) (Figure 3A). For SDM, CE of 2.65 dS/m provided better result (20.48 g/plant), reduced 41.99% at higher salinity level (5.5 dS/m) (Figure 3B).

The reduction of LDM related to salinity was also observed in other studies about bell peppers (Lima *et al*., 2016; Akhtar *et al*., 2020). The reduction of leaf dry mass under salinity conditions occurs since high salt concentrations in the roots, especially Na^+ and Cl^-, results in a greater accumulation of these ions in the plant tissue to the detriment of absorption of other essential elements, such as K^+, Ca^{2+} and Mg^{2+}, causing a nutritional unbalance. Thus, the osmotic potential of the leaves is reduced due to the presence of Na^+ and Cl^-, decreasing water uptake (Taiz *et al*., 2017).

Evaluating the effect of salinity water irrigation on bell pepper crop, cv. ‘All Big’, Lima *et al*. (2016) also reported reduction in SDM due to an increase in salinity, showing that SDM is the most salinity sensitive variable when comparing with leaf dry mass, plant height and stem diameter.

Among the substrates, fruit dry mass (FDM) showed, at salinity 2.2 dS/m, higher results when plants were grown in coconut fiber and mixture, being superior in 88.68 and 66.89%, respectively, in relation to sand. At salinity 3.5 dS/m, coconut fiber and mixture did not differ from each other. Sand obtained the lowest FDM in 57.13% when compared with coconut fiber and in 48.28% in relation to mixture. At higher salinities, higher FDM values were found in the mixture and in coconut fiber and the lowest in sand, which was 50.94% lower at CE of 5.5 dS/m in relation to the mixture substrate (Figure 3C).

Evaluating the effect of salinity on each substrate, we noticed significant and quadratic response for coconut fiber and mixture substrates. In coconut fiber, higher FDM at salinity 3.25 dS/m was verified (238.72 g/plant). In mixture substrate, higher FDM occurred at CE 3.69 dS/m (212.55 g/plant). The authors verified no salinity effect on FDM in plants grown in sand substrate, which showed an average of 98.89 g/plant (Figure 3C).

According to Azuma *et al*. (2010), fruits are more sensitive to salinity than leaves and stem. However, comparing FDM using the lowest and the highest studied salinity, the authors noticed no reduction in biomass accumulation in fruits for any substrates. This behavior highlighted the efficiency of the cultivation in substrate provides higher plant tolerance to salinity stress.

For TDM, coconut fiber substrate was superior in 106.84% in comparison with sand, and both substrates did not differ from mixture at the lowest salt level (2.2 dS/m). For salinity 3.5 dS/m, no significant difference in TDM of plants grown in coconut fiber and mixture was verified. Both TDM showed values superior in 127.39 and 78.52%, respectively, to the one found in sand. For the other CEs (4.5 and 5.5 dS/m), plants grown in coconut fiber and in mixture did not differ from each other, being superior in relation to sand at two salinity levels (Figure 3D).

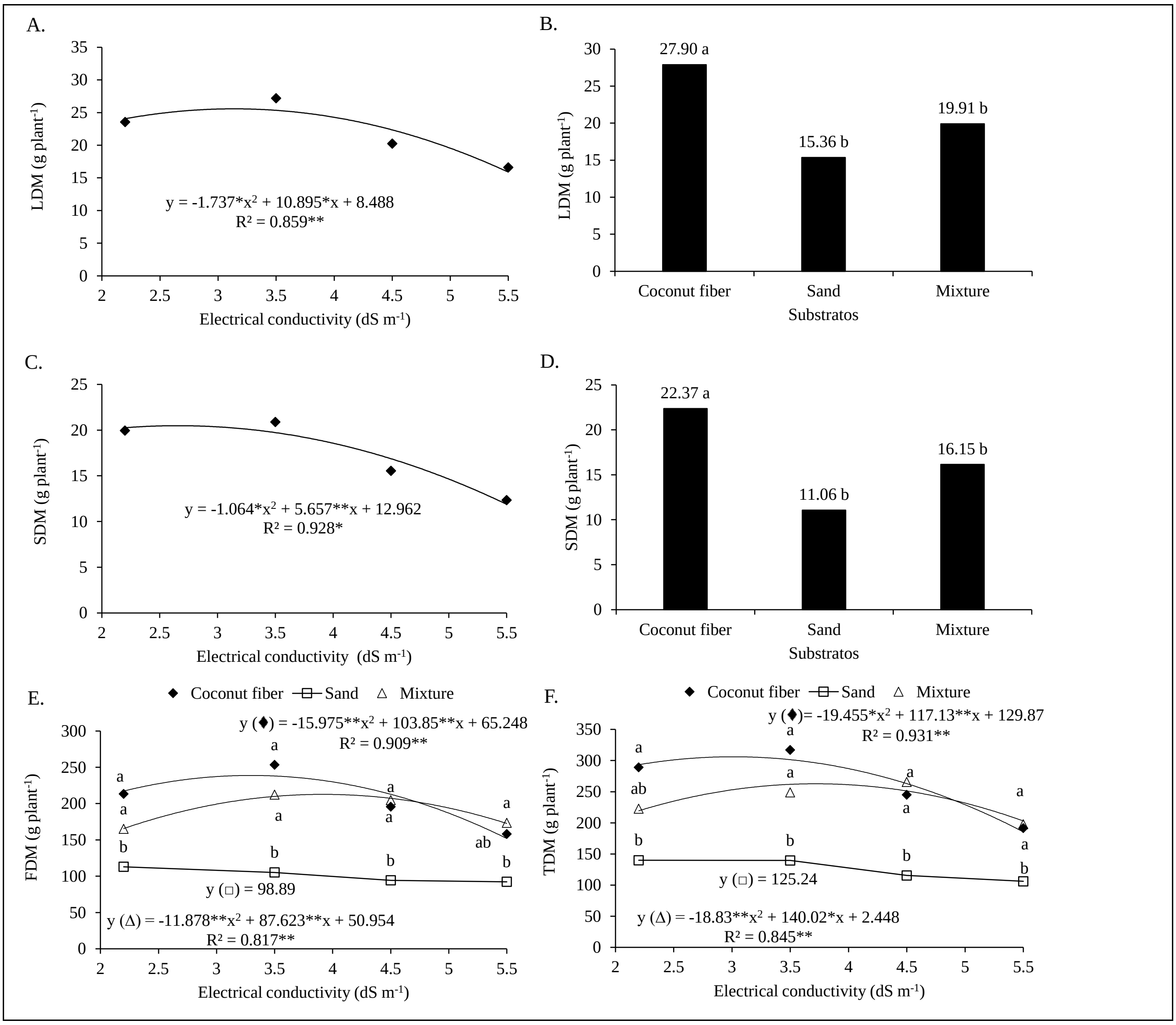

Figure 3. Leaf dry mass (A and B), stem dry mass (C and D), fruit dry mass (E) and total dry mass (F) in bell pepper plants grown in different substrates and fertigated with salinized nutrient solutions (lowercase letters represent the effect of substrates at each salinity). Mossoró, UFERSA, 2021.

Salinity showed a significant quadratic effect on TDM for coconut fiber and mixture substrates. The highest TDM in coconut fiber occurred at a salinity of 3.01 dS/m (306.16 g/plant), reducing 39.38% at the highest saline level in relation to the lowest level. In the mixture substrate, the highest TDM occurred at salinity 3.71 dS/m (262.74 g/plant), reducing 22.75% compared with CE 5.5 dS/m. For sand substrate, no significant response was verified; the research showed an average TDM value of 125.24 g/plant (Figure 3D).

Santos *et al.* (2020) reported a reduction in shoot dry mass in bell pepper seedlings submitted to increasing salinity levels in the water used for irrigation. For these authors, salinity stress reduced production, distribution and accumulation of photoassimilates, resulting in a lower production of plant biomass at higher salt levels.

The decrease in plant biomass submitted to high salt concentrations is the result of several physiological processes and mechanisms which are altered by salinity stress. Reduced photosynthetic activity, lower chlorophyll content in leaves, lower accumulation of photoassimilates and protein biosynthesis are examples of processes in which the presence of NaCl significantly alters plant growth, yield and quality (Ahmadi & Souri, 2020). According to Taiz *et al.* (2017), the reduction in osmotic potential caused by excessive salt induced dehydration and decreased cell expansion, which may have contributed to the reduction in dry mass of bell pepper plants.

In conclusion, the results obtained showed that coconut fiber substrate provided the best physiological and growth conditions for bell pepper plants grown under salinity stress and that sand was not a suitable substrate for bell pepper growth. The authors also observed that growing bell peppers under salinity up to 3.5 dS/m, using coconut fiber or the mixture of coconut fiber with sand (1:1), is a viable alternative.

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