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CROP PRODUCTION

Bell pepper production under saline stress and fertigation with different K^+/ Ca^{2+} ratios in a protected environment

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ABSTRACT. : Bell peppers are sensitive to salinity; therefore, it is necessary to find alternatives to reduce saline stress. An experiment was conducted in a greenhouse at Federal Rural University of the Semi-Arid Region, in Mossoró, Rio Grande do Norte State, Brazil, to evaluate the effects of salinity and K^+/Ca^{2+} ratios on bell pepper production. The experimental design consisted of randomized blocks in a 5 x 4 factorial scheme with four replicates, corresponding to five K^+/Ca^{2+} ratios (F1 = 3.3/1, F2 = 2.8/1, F3 = 2.2/1, F4 = 1.8/1, and F5 = 1.5/1) and four salinity levels in the nutrient solution using NaCl (1.75, 3.25, 4.75, and 6.25 dS m^{-1}). The following parameters were evaluated: the number of fruits (total, marketable and unmarketable), the mean weight of fruits (marketable and unmarketable), fruit production (total, marketable and percentage of marketable fruits) and a salinity tolerance index. Generally, nutrient solution enrichment with K^+ or Ca^{2+} did not cause significant increments in bell pepper yield. The fertigation treatments F2, F3, and F5 led to a higher bell pepper tolerance to salinity, allowing waters with higher salt concentrations to be used without causing a reduction in the yield.

Keywords: *Capsicum annuum* L., salinity, potassium, calcium, soilless culture.

Introduction

Bell peppers (*Capsicum annuum* L.) are one of the most consumed vegetables in Brazil. In the last ten years, their production has sharply increased due to better adaptation to protected environments than other crops (Leonardo, Broetto, Villas Bôas, Almeida, & Marchese, 2007).

Water stands out among the main natural resources needed for food production. However, due to an imminent water crisis, it has become necessary to use low quality water for irrigation, especially under arid and semiarid conditions. In several cases, the use of saline water has become inevitable.

The effects of salinity on plants include alterations in osmotic potential, ionic toxicity and nutritional imbalance, causing declines in plant growth and, consequently, serious losses in the agricultural industry (Ahmed & Montani, 2010).

In bell peppers, saline stress causes a reduction in photosynthetic activity, photosynthesis, transpiration, stomatal conductance, gas exchange and photosystem II efficiency, culminating in yield losses (Lima, Morais, Silva, Camara, & Willadino, 2017; Nunes, Dias, Moura, Souza Neto, & Costa, 2013; Amirinejad, Sayyari, Ghanbari, & Kordi, 2017).

The use of this water for irrigation is conditioned on strategies that minimize the deleterious effects of salinity on crop growth, allowing saline water to be used without causing significant losses in the yield and quality of the products (Oliveira, Medeiros, Cunha, Souza, & Lima, 2016).

The cultivation of vegetables and fruits on inert substrates has increased among rural producers, especially on coconut fiber (Charlo et al., 2012; Nunes et al., 2013). In comparison with cultivation on soil, this cultivation technique allows better nutritional management control. It also increases plant tolerance to salinity due to the smaller effect of the matric potential in raising the total water potential and reducing the difficulty of water absorption by plants (Santos et al., 2016).

In addition to cultivation on coconut fiber, nutrient solution management can contribute to increase crop tolerance to salinity, especially with respect to potassium and calcium concentrations, which stand out among the nutrients most required by the bell pepper, along with nitrogen (Charlo et al., 2012; Oliveira et al., 2015). Nonetheless, the absorption of these nutrients is affected more by the high Na^+ concentration in the root zone, increasing the Na^+/K^+ and N^+/Ca^{2+} ratios.

Thus, nutrient solution enrichment with K^+ and Ca^{2+} can be used as a strategy to reduce the effects of salinity on plants (Rubio, García-Sánchez, Rubio, García, & Martínez, 2010b; Rubio, García-Sanchez, Rubio, & Martínez, 2009; Rubio, García-Sánchez, Flores, Navarro, & Martínez 2010a). Nevertheless, the management of these nutrients must be conducted with caution because high K^+ concentrations can reduce Ca^{2+} absorption (and vice versa) and reduce Mg^{2+} absorption (Albuquerque, Silva, Bezerra Neto, Souza, & Santos, 2012).

In a study conducted with peppers, Kaya and Higgs (2003) observed that complementing fertilization with KNO_3 could overcome the effects of high salinity on fruit yield and biomass production. For the bell pepper crop in a hydroponic system, Rubio et al. (2009) evaluated the effect of K^+/Ca^{2+} ratios using a saline nutrient solution and observed that the increment in K^+ availability reduced fruit weight and increased the occurrence of fruits with blossom-end rot. On the other hand, these authors found that elevated Ca^{2+} concentrations increased the production of marketable fruits due to a reduced incidence of blossom-end rot. According to Rubio et al. (2010b), an adequate management of fertigation with K^+ and Ca^{2+} increased the yield of hydroponic bell peppers.

Based on these antecedents, the present study aimed to evaluate the effects of fertigation with different K^+/Ca^{2+} ratios and saline stress on the production of bell peppers cultivated on a coconut fiber substrate.

Material and methods

The experiment was conducted from February to June 2015 in a protected environment at the Department of Agronomic and Forestry Sciences of the Federal Rural University of the Semi-Arid Region (UFERSA), in Mossoró, Rio Grande do Norte State, Brazil (5°12'02" S, 37°19'37" W; altitude of 18 m). According to Köppen's classification, the climate of the region is BSwh (i.e., hot and dry), with a mean air temperature of 27.6°C, a relative air humidity of 68.3%, rainfall of 756 mm, and winds with a mean speed of 2.3 m s^{-1} (Carmo Filho & Oliveira, 1995).

The greenhouse used in the experiment had a metal structure measuring 7.0 x 18.0 m (126 m^2 of total area), with a 4.0 m ceiling height and an arched frame. It was covered with a transparent plastic film against UV degradation and direct sunlight incidence on the plants and was protected with anti-aphid screens on the sides.

The experimental design consisted of randomized blocks in a 5 x 4 factorial scheme with four replicates. The experimental unit consisted of one 15-dm^3 pot containing one plant. The treatments consisted of the combination of five ionic K^+/Ca^{2+} ratios (F1 = 3.3/1, F2 = 2.8/1, F3 = 2.2/1, F4 = 1.8/1, and F5 = 1.5/1), among which the F3 ratio was equivalent to that recommended by Castellane and Araújo (1995) for hydroponic bell peppers, and four levels of irrigation water salinity (0.5, 2.0, 3.5, and 5.0 dS m^{-1}).

To obtain the different K^+/Ca^{2+} ratios, the following procedure was used: in fertigation treatments F1 and F2, the K^+ proportions were increased, while the Ca^{2+} concentrations remained constant in relation to the standard nutrient solution; in fertigation treatments F4 and F5, the Ca^{2+} proportions were increased, while the K^+ concentrations remained constant in relation to the standard nutrient solution.

After preparation, the nutrient solutions had the following values of electrical conductivity: 1.75, 3.25, 4.75, and 6.25 dS m^{-1}. The nutrient concentrations used in each fertigation treatment are presented in Table 1. Micronutrients were added in the following concentrations: 3.7, 0.3, 0.4, 0.3, 0.05, and 0.05 mg L^{-1} for Fe, Zn, Mn, B, Cu, and Mo, respectively (Castellane & Araújo, 1995).

Table 1

Nutrient concentrations used in the fertigation treatments.

Fertigation	K^+/Ca^{2+}	N	P	K	Ca	Mg	S
				mg L^{-1}			
F1	3.3/1	152.0	39.0	367.5	110.0	29.0	32.0
F2	2.8/1	152.0	39.0	306.3	110.0	29.0	32.0
F3*	2.2/1	152.0	39.0	245.0	110.0	29.0	32.0
F4	1.8/1	152.0	39.0	245.0	137.5	29.0	32.0
F5	1.5/1	152.0	39.0	245.0	165.0	29.0	32.0

Standard nutrient solution used according to the recommendation of Castellane and Araújo (1995).

The least saline water (0.5 dS m^{-1}) was collected from UFERSA's supply system; the other salinity levels (2.0, 3.5, and 5.0 dS m^{-1}) were obtained by adding sodium chloride (NaCl).

For each type of water, an independent irrigation system was used that was formed by a motor pump, a 500-L water tank, 16-mm-diameter lateral lines and 0.50-m-long microtubes (spaghetti) with a mean flow rate of 2.5 L h^{-1}. After the irrigation system was installed, the flow rate was tested to evaluate the distribution uniformity coefficient (DU). The uniformity varied from 90 to 95%, and all drippers were classified as excellent (DU > 84%).

Irrigation management was performed using a digital timer (TE-2, Decorlux®, Brazil) at a frequency of 6 irrigations per day, adjusting the time of each irrigation according to the crop's water needs. Water consumption by plants was not recorded; however, in all irrigations, the moisture content in the substrate was increased to the maximum water retention capacity, so that irrigation stopped when leaching occurred.

Bell pepper seedlings, Arcade F1 hybrid (Topseed Premium®), were produced on an expanded polystyrene tray using a coconut fiber substrate and fertigation by capillarity with a nutrient solution (Castellane & Araújo, 1995) diluted to 80%. Transplanting was performed 30 days after sowing, when seedlings had six true leaves, by planting one seedling in each pot containing 15 dm^3 of coconut fiber.

The pots had a drainage system formed by a 2-cm-thick layer of crushed stone and geotextile. They were arranged on 10-cm-high Dutch bricks, distributed in four rows separated 1.25 m apart, with a 50 cm spacing between plants, resulting in a population of 16,000 plants per hectare. Two pots placed at the end of each row were used as borders.

A staking system was installed inside the greenhouse that contained 2.00-m-high concrete posts and nº 14 wires. Bell pepper plants were trained using plastic ribbons, and the plants were thinned by removing side shoots below the bifurcation and selecting and eliminating stems above it, leaving four stems to be trained.

Seven harvests were conducted throughout the experiment: the first one at 65 days after transplanting, and the others at 5-day intervals, when the fruits showed a bright, dark green color. The harvested fruits were analyzed at UFERSA's Laboratory of Irrigation and Salinity, where they were selected, counted, visually assessed for injuries caused by biotic and abiotic agents, and then classified as marketable and unmarketable.

Crop yield was evaluated based on the following parameters: number of marketable and unmarketable fruits, obtained by counting all marketable and unmarketable fruits of all harvests, respectively; total number of fruits, obtained by the sum of all harvested fruits; mean weight of marketable and unmarketable fruits, obtained by dividing the production of marketable and unmarketable fruits by the number of marketable and unmarketable fruits, respectively; marketable fruit production, obtained by summing the fresh weights of all marketable fruits of all harvests, expressed in g plant^{-1}; total fruit production, obtained by summing the fresh weights of all harvested fruits, expressed in g plant^{-1}; and marketable percentage, obtained by multiplying the ratio between marketable and total production by 100.

In addition, crop tolerance to salinity was determined for each fertigation treatment through the salinity threshold (ST) and the coefficient of relative yield loss (b) per unit increase in electrical conductivity above the salinity threshold [(Y = 100 - b (ECse - ST)]. The salinity threshold was determined based on a reduction of up to 10% in the potential yield, i.e., the salinity level allowing for a minimum relative yield of 90% (Ayers & Westcot, 1999).

The obtained data were subjected to an analysis of variance. Quantitative factors associated with the salinity levels were analyzed by polynomial regression (linear and quadratic), whereas qualitative factors (K^+/Ca^{2+} ratios) were analyzed by means of comparison tests (Tukey, $p < 0.05$). All statistical analyses were conducted using the statistical program SISVAR (Ferreira, 2011).

Results and discussion

According to the statistical analyses, all parameters were affected by the interaction of fertigation and salinity level ($p < 0.01$), indicating that bell pepper response to salinity varied depending on the fertigation treatment.

The number of marketable fruits (NMF) was affected by the fertigation treatment only when plants were subjected to the highest salinity (6.25 dS m^{-1}), and only F4 differed from the other treatments, showing the lowest value. For the number of unmarketable fruits (NUF), significant differences occurred between fertigation treatments at salinity levels of 4.75 and 6.25 dS m^{-1}, and the highest Ca^{2+} concentrations of F4 at 4.75 dS m^{-1} and F5 at 6.25 dS m^{-1} led to the highest values (Table 2).

Regarding the total number of fruits (TNF), significant responses were observed only at the 6.25 dS m^{-1} salinity level, at which the F4 treatment was inferior to F5, although these treatments did not differ statistically from the others (Table 2).

Table 2

Mean values of the number of marketable fruits (NMF), the number of unmarketable fruits (NUF), the total number of fruits (TNF), the mean weight of marketable fruits (MWMF) and the mean weight of unmarketable fruits (MWUF) of bell peppers as a function of irrigation water salinity and fertigation with different K^+/Ca^{2+} ratios.

Salinity (dS m^{-1})	Fertigation	NMF	NUF	TNF	MWMF	MWUF
1.75	F1	21.50 a	7.25 a	28.75 a	88.06 a	33.98 a
	F2	19.75 a	5.75 a	25.00 a	83.45 a	23.82 b
	F3	21.75 a	8.00 a	29.75 a	74.97 ab	33.10 ab
	F4	21.25 a	8.15 a	31.00 a	66.25 b	24.46 ab
	F5	19.75 a	6.75 a	26.50 a	79.30 ab	25.82 ab
3.25	F1	20.50 a	9.25 a	29.75 a	80.03 ab	36.14 a
	F2	20.25 a	6.75 a	27.00 a	79.84 ab	28.51 ab
	F3	17.50 a	7.50 a	25.00 a	90.86 a	28.34 ab
	F4	21.50 a	10.25 a	30.75 a	65.79 b	22.82 b
	F5	21.00 a	9.75 a	30.75 a	78.23 ab	24.53 b
4.75	F1	17.50 a	11.00 ab	28.50 a	85.02 a	25.80 ab
	F2	18.00 a	11.50 ab	29.50 a	64.01 b	28.62 ab
	F3	17.25 a	10.00 b	27.25 a	73.76 ab	32.50 a
	F4	17.50 a	14.25 ab	31.75 a	63.05 b	22.34 b
	F5	17.50 a	15.25 a	32.75 a	64.23 b	23.48 ab
6.25	F1	12.25 a	10.50 b	22.75 ab	60.59 a	23.17 a
	F2	13.75 a	11.50 b	25.25 ab	83.45 a	23.98 a
	F3	13.00 a	10.00 b	23.00 ab	61.30 a	22.61 a
	F4	8.50 b	10.00 b	18.50 b	59.93 a	18.90 a
	F5	13.25 a	16.75 a	29.50 a	68.14 a	23.10 a

Means followed by the same letters in a column did not differ among fertigation treatments with different K+/Ca2+ ratios for each salinity level according to Tukey's test ($p < 0.05$).

The mean weight of marketable fruits (MWMF) was affected by the fertigation treatments at salinity levels of 1.75, 3.25, and 4.75 dS m^{-1}. At 1.75 dS m^{-1}, the lowest values were obtained for F4, which did not differ significantly from F3 and F5. At 3.25 dS m^{-1}, the MWMF was higher for F3 than F4, and these two treatments did not differ significantly from the others. At 4.75 dS m^{-1}, plants showed a higher MWMF in treatments F1 and F3. As salinity increased, the nutrient solution with the highest Ca proportion reduced the fruit weight (Table 2).

For the mean weight of unmarketable fruits (MWUF), significant differences occurred at salinity levels of 1.75, 3.25, and 4.75 dS m^{-1}, as observed for the MWMF. At 1.75 dS m^{-1}, the highest MWUF occurred in treatments F1 and F3. At 3.25 dS m^{-1}, the heaviest fruits were obtained in treatments F1, F2, and F3. At 4.75 dS m^{-1}, significant differences were found between F3 and F4, with the highest and lowest MWUF, respectively, and these two treatments did not differ from the others (Table 2).

All fertigation treatments led to significant responses in the NMF as a function of salinity. For F1 and F3, increasing salinity led to a linear reduction in the NMF: the highest values of 22.5 and 21.3 fruits per plant in F1 and F3, respectively, were found at the lowest salinity level (1.75 dS m^{-1}); the lowest values of 13.2 and 13.4 fruits per plant in F1 and F3, respectively, occurred when plants were subjected to the highest salinity (6.25 dS m^{-1}), resulting in respective losses of 40.9 and 37.2%, respectively, compared with the NMF obtained at the lowest salinity level (Figure 1A).

For the fertigation treatments F2, F4 and F5, quadratic responses were found as salinity increased, with the highest NMF values of 20.5, 22.0, and 20.5 fruits per plant, respectively, at the salinity levels of 2.81, 2.63, and 2.74 dS m^{-1}, respectively. From these levels on, there was a reduction in the NMF, so that the lowest values of 12.3, 8.5, and 13.0 fruits per plant in F2, F4, and F5, respectively, were found at the highest salinity level (6.25 dS m^{-1}), leading to respective losses of 37.6, 59.6, and 34.6%, respectively, compared with those of the lowest salinity level (Figure 1A).

Although the data best fitted quadratic models, only small gains were observed compared with the values obtained at the lowest salinity level. Nonetheless, these results are important because the F2, F4, and F5 fertigation treatments led to a higher bell pepper tolerance to salinity for the NMF.

A reduction in the NMF of bell peppers due to water salinity has also been found by other authors (Arruda, Dias, Blanco, Sousa Neto, & Ferreira Neto, 2011; Furtado, Cavalcante, Chaves, Santos Júnior, & Gheyi, 2017).

This behavior can be attributed to the high rate of fruit abortion, resulting from some physiological and/or biochemical factor due to the elevated salt concentration, which may cause a physiological limitation in the plants under saline stress (Giuffrida et al., 2014). In this context, Ashraf (2004) reported that saline stress reduces the number of fruits by acting in the microsporogenesis and elongation of the stamen filaments, increasing cell death in some types of tissues, and causing the abortion of ovules and the senescence of fertilized embryos.

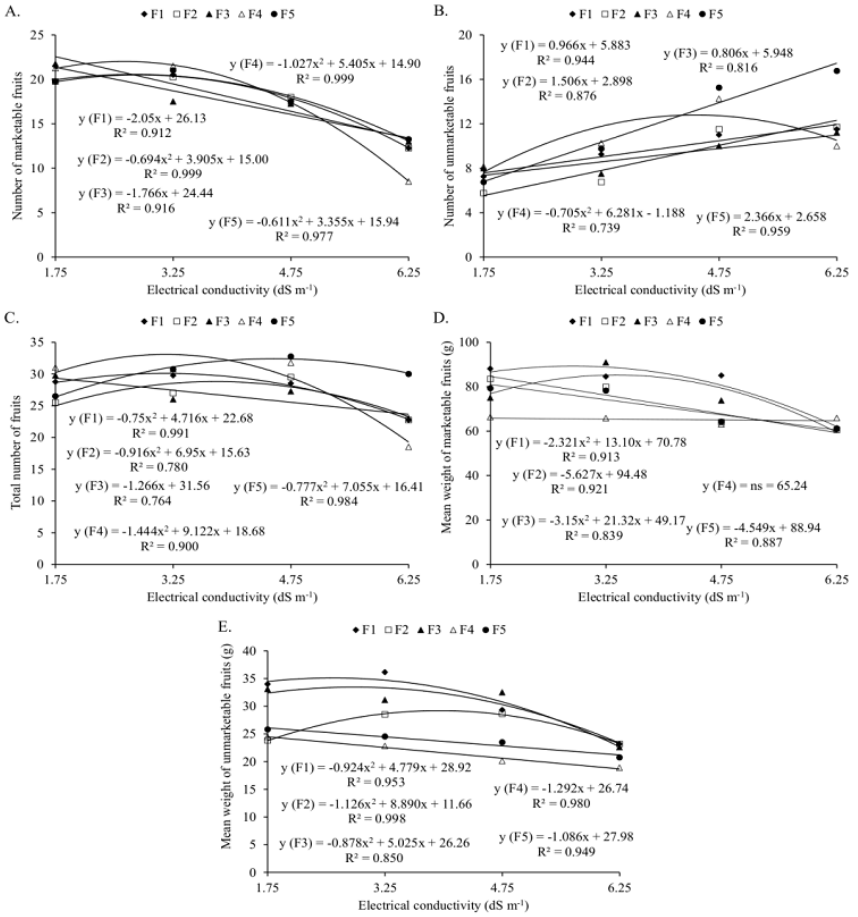

Figure 1

Number of marketable fruits (A), number of unmarketable fruits (B), total number of fruits (C), mean weight of marketable fruits (D), and mean weight of unmarketable fruits (E) of bell peppers as a function of irrigation water salinity and fertigation with different K^{+}/Ca^{2+} ratios.

For the NUF, increasing irrigation water salinity led to linear increments in the fertigation treatments F1, F2, F3, and F5, so that the highest values of 11.9, 12.3, 11.9, and 17.4 fruits per plants, respectively, occurred at a salinity of 6.25 dS m^{-1}. For the fertigation treatment F4, a quadratic response was observed as salinity levels increased, the highest NUF occurred at 4.45 dS m^{-1} (12.80 fruits per plant) and was 67.46% higher compared with the NUF found at 1.75 dS m^{-1} (7.64 fruits per plant) (Figure 1B). Water salinity caused larger increments in the NUF for the fertigation treatments F2 and F5, with values of 122.4 and 156.6%, respectively (Figure 1B).

The increase in the number of fruits without commercial quality in this experiment occurred for two reasons. The first one was the high number of fruits with blossom-end rot, especially in treatments F1 and F2, a typical symptom of Ca deficiency in the fruits resulting from high Na^{+} concentration, which was previously reported by various authors (Arruda et al., 2011; Nunes et al., 2013; Rubio et al., 2009). The second reason was the occurrence of small fruits in plants fertigated with nutrient solutions of higher salinity, confirming the results observed by other authors (Lima et al., 2016; Furtado et al., 2017).

A quadratic response was observed for the TNF with the increase in irrigation water salinity in the fertigation treatments F1, F2, F4, and F5, with the highest values of 30.09, 28.81, 33.09, and 31.14 fruits per plant, respectively, at salinity levels of 3.14, 3.79, 3.16, and 3.25 dS m^{-1}, respectively. For F4, the highest TNF was observed at a salinity of 1.75 dS m^{-1} (31.09 fruits per plant), decreasing linearly as salinity increased, so that the lowest TNF (23.64 fruits per plant) was found at 6.25 dS m^{-1}, representing a reduction of 19.41% (Figure 1C).

Based on Figure 1(A, B, and C), the nutrient solution with the highest Ca proportion (F5) favored fruit setting but increased the occurrence of small fruits, without commercial quality, when plants were subjected to higher salinities.

The MWMF was not affected by salinity when plants were subjected to the F4 treatment, and its mean value was 65.24 g. On the other hand, for treatments F1 and F3, the MWMF showed quadratic responses as salinity increased, reaching maximum values of 89.26 and 85.24 g, respectively, at salinity levels of 2.82 and 3.84 dS m^{-1}, respectively. For F2 and F5, increased salinity led to a linear reduction in the MWMF, so that the lowest values occurred at 6.25 dS m^{-1} (F2 = 59.31 g, F5 = 60.50 g), causing reductions of 29.92 and 25.28%, respectively, compared with the values of 84.63 and 80.98 g obtained at the lowest salinity for F2 and F5, respectively (Figure 1D).

These results agreed with those reported by various authors who studied the bell pepper crop under saline stress conditions, cultivated in either soil (Leonardo et al., 2007; Lima et al., 2016) or substrate (Arruda et al., 2011; Rubio et al., 2011; Nunes et al., 2013; Furtado et al., 2017; Lima et al., 2017). Reductions in fruit size and weight due to saline stress and, consequently, in the economic performance of the crop, are caused by physiological and biochemical changes in the cells or at the molecular level (Munns & Tester, 2008).

Regarding the MWUF, quadratic responses occurred in the fertigation treatments F1, F2, and F3, with the highest values of 35.08, 27.44, and 33.45 g, respectively, at salinity levels of 2.58, 3.95, and 2.86 dS m^{-1}, respectively. In the F4 and F5 treatments, increasing salinity led to a linear reduction in the MWUF, so that the nutrient solution of highest salinity yielded the minimum values of 18.67 and 21.19 g, respectively. Comparing the MWUF values obtained at the highest and lowest salinities (6.25 and 1.75 dS m^{-1}, respectively), greater reductions occurred in the F1 (34.20%), F3 (27.79%), and F4 (23.73%) treatments (Figure 1E).

As observed in Figure 1E, fruits classified as unmarketable in fertigation treatments F1, F2, and F3 were heavier at intermediate levels of salinity (3.25 and 4.75 dS m^{-1}). These fruits were not classified as marketable due to a high incidence of blossom-end rot, whereas in the other fertigation treatments the most noticeable reason was their size.

The marketable fruit production (MPROD) differed between fertigation treatments at all salinity levels. At the lowest salinity (1.75 dS m^{-1}), only F1 differed from the other treatments and led to the highest MPROD value that was 28.11% higher than the mean of the other treatments. At 3.25 dS m^{-1}, significant differences occurred only between F2 and F4, and the MPROD was 24.61% higher in F2 than in F4. In addition, these fertigation treatments did not differ from the others (Table 3).

When plants were subjected to 4.75 dS m^{-1}, the fertigation treatments F1, F2, and F3 led to the highest MPROD, although F2 and F3 did not differ from the others. At 6.26 dS m^{-1}, significant differences occurred only between F2 and F4, and the MPROD was 66.76% higher in F2 than in F4. These treatments did not differ from the others (Table 3).

The total fruit production (TPROD) was significantly affected by the fertigation treatments at most salinity levels, except 3.25 dS m^{-1}. At this level, there was no difference between treatments, and the mean TPROD was equal to 1,761.07 g $plant^{-1}$. At 1.75 dS m^{-1}, higher TPROD values were observed in F1 and F3 (the highest in F1), although F3 did not differ from the others.

At 4.75 dS m^{-1}, there was a significant difference in the TPROD only between fertigation treatments F1 and F4 (with a higher value for F1), which did not differ from the others. At 6.25 dS m^{-1}, the fertigation treatments F2 and F5 led to higher TPROD values comparison to those under F4, which caused lower TPROD values but did not differ from the others (Table 3).

Table 3

Mean values of marketable fruit production (MPROD), total fruit production (TPROD) and percentage of marketable fruits (%MF) of bell peppers as a function of irrigation water salinity and fertigation with different K^+/Ca^{2+} ratios.

Salinity (dS m^{-1})	Fertigation	MPROD	TPROD	%MF
1.75	F1	2,009.23 a	2,252.75 a	89.10 a
	F2	1,544.50 b	1,697.83 b	91.05 a
	F3	1,657.00 b	1,878.20 ab	85.97 a
	F4	1,552.75 b	1,791.83 b	86.69 a
	F5	1,519.00 b	1,693.33 b	89.69 a
3.25	F1	1,481.00 ab	1,817.83 a	81.62 a
	F2	1,654.25 a	1,855.08 a	89.23 a
	F3	1,477.25 ab	1,733.75 a	87.34 a
	F4	1,327.50 b	1,580.70 a	85.54 a
	F5	1,568.00 ab	1,818.00 a	86.06 a
4.75	F1	1,471.00 a	1,774.00 a	83.07 a
	F2	1,168.00 ab	1,514.50 ab	77.30 a
	F3	1,292.00 ab	1,673.41 ab	77.69 a
	F4	1,106.50 b	1,395.67 b	79.75 a
	F5	1,117.75 b	1,495.67 ab	74.86 a
6.25	F1	724.00 ab	955.83 ab	76.12 a
	F2	848.00 a	1,119.00 a	75.67 a
	F3	755.00 ab	981.33 ab	76.92 a
	F4	508.50 b	709.00 b	72.75 a
	F5	810.50 ab	1,198.83 a	67.75 a

Means followed by the same letters in a column did not differ among fertigation treatments with different K+/Ca2+ ratios for each salinity level according to Tukey's test ($p < 0.05$).

In general, in comparison with plants with the standard nutrient solution (F3), in plants fertigated with salinized nutrient solutions, enrichment with K^+ or Ca^{2+} caused no significant alterations in fruit production. Rubio et al. (2009) observed that under moderate salinity conditions the highest MPROD for bell peppers occurred at low K^+ and high Ca^{2+} concentrations.

The fertigation treatments had no significant effect on the percentage of marketable fruits (%MF) regardless of the salinity level, and mean values of 88.50, 85.96, 78.53, and 73.84% were found at salinity levels of 1.75, 3.25, 4.75, and 6.35 dS m^{-1}, respectively (Table 3). These results partially agree with those reported by Rubio et al. (2010a), who studied K^+ and Ca^{2+} levels in hydroponic bell peppers cultivated on vermiculite and observed no significant response for this parameter.

The TPROD values were affected by salinity and differed between fertigation treatments. For F1 and F4, linear and negative responses were observed as irrigation water salinity increased. The highest TPROD values of 2,290.28 and 1,884.33 g $plant^{-1}$ occurred at the lowest salinity level and decreased to 1,109.89 and 854.28 g $plant^{-1}$ at the highest salinity level, resulting in losses of 51.54 and 54.66% for F1 and F4, respectively (Figure 2A).

In the fertigation treatments F2, F3, and F5, quadratic responses were observed with the increment in salinity, and the highest productions of 1,821.52, 1,875.99, and 1,760.58 g $plant^{-1}$ occurred at salinity levels of 2.92, 2.49, and 2.71 dS m^{-1}, respectively. Despite the fit to quadratic models, these values represented small increments of only 6.41, 1.82, and 2.87% compared with the values obtained at the lowest salinity for F2, F3, and F5, respectively. Nonetheless, using these treatments allowed waters with higher salt concentrations, up to approximately 3.0 dS m^{-1}, to be used without causing significant losses in the TPROD (Figure 2A).

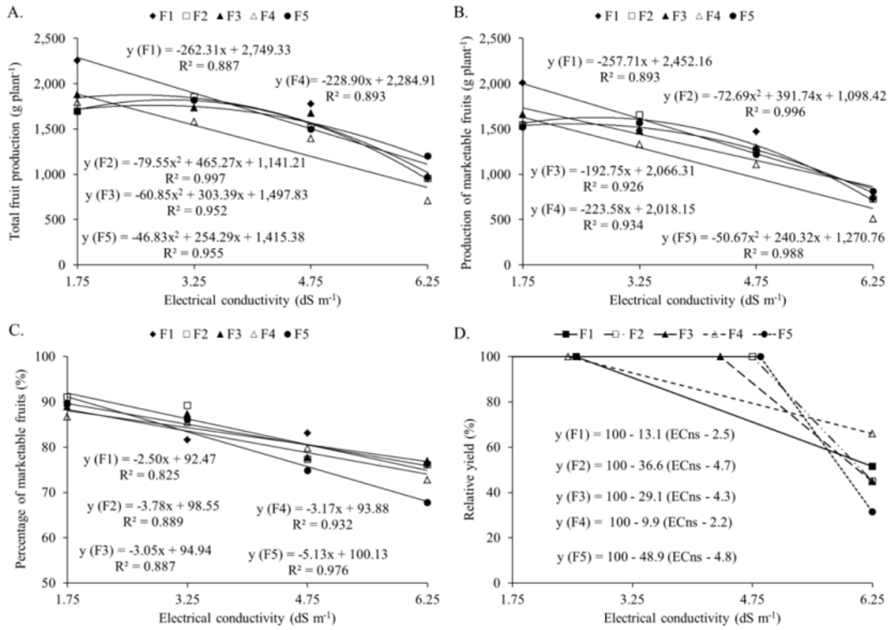

Figure 2

Total fruit production (A), marketable fruit production (B), percentage of marketable fruits (C) and relative yield (D) of bell peppers as a function of irrigation water salinity and fertigation with different K^+/Ca^{2+} ratios.

The MPROD also showed different responses to salinity depending on the fertigation treatment. Linear and negative responses occurred in fertigation treatments F1, F3, and F4, with the highest values of 2,001.16, 1,729.00, and 1,626.88 g plant^{-1}, respectively, at 1.75 dS m^{-1}, and respective reductions of 57.95, 50.16, and 61.84% when plants were subjected to 6.25 dS m^{-1} (Figure 2B).

For the fertigation treatments F2 and F5, quadratic responses occurred with the increment in irrigation water salinity, with maximum productions of 1,626.21 and 1,555.71 g plant^{-1} at salinity levels of 2.69 and 2.37 dS m^{-1}, respectively. These values represented increments of only 4.15 and 1.27% for F2 and F5, respectively, compared with the values obtained at the lowest salinity. Although fertigation treatments F2 and F5 led to only small gains, they allowed water with salinity of approximately 3.5 dS m^{-1} to be used without significant losses in the MPROD (Figure 2B).

The reduction in fruit production is a common response in the bell pepper crop grown under saline conditions. It is usually caused by the decrease in both the number and the weight of the harvested fruits (Arruda et al., 2011; Rubio et al., 2011; Rameshwaran, Tepe, Yazar, & Ragab, 2015), because fruits are more sensitive to salinity (Azuma et al., 2010) due to the deleterious effect of saline stress on the abortion rate, caused by the reduction in the number and viability of pollen grains (Ghanem et al., 2009).

According to Figure 2C, increasing irrigation water salinity caused a linear reduction in the %MF, with bigger losses in plants subjected to fertigation treatment F5. These plants showed a 5.12% reduction in %MF per unit increase in water salinity, which resulted in a total loss of 25.33% in relation to the lowest salinity level.

In general, comparing TPROD and MPROD at salinity levels of 1.75 and 6.25 dS m^{-1}, respectively, larger losses occurred in the MPROD equivalent to 57.95, 56.50, 50.17, 61.84, and 49.00% for F1, F2, F3, F4, and F5, respectively. For TPROD, the reductions were 51.54, 44.99, 44.80, 54.66, and 31.54% for F1, F2, F3, F4, and F5, respectively, confirming the results reported by Navarro, Garrido, Flores, and Martínez (2010).

Saline stress induces cell growth inhibition, membrane permeability disorders and changes in stomatal conductance, photosynthesis and ionic balance (Aktas, Abak, & Cakmak, 2006). Saline stress on bell peppers leads to increased proline content and enzymatic activity of superoxide dismutase (SOD), catalase (CAT), and ascorbate peroxidase (APX), demonstrating the activation of the antioxidant defense mechanism, causing a reduction in the longitudinal fruit length and, consequently, in the production of fruits with a marketable size.

In addition, the reduction in the MPROD caused by salinity is due to the high incidence of blossom-end rot, a nutritional disorder directly caused by Ca deficiency in the fruits, resulting from the increase in the Na^{+}/Ca^{2+} ratio (Rubio et al., 2011; Manaa et al., 2014).

Analyzing the bell pepper relative yield as a function of nutrient solution salinity, the degree of tolerance varied according to the fertigation treatment. Plants subjected to the F1 and F4 treatments showed a lower tolerance to salinity, with salinity thresholds of 2.5 and 2.2 dS m^{-1}, respectively, and significant losses of 13.1 and 9.9%, respectively, per unit increase in salinity above these levels (Figure 2D).

The other fertigation treatments led to higher salinity thresholds of 4.7, 4.3, and 4.8 dS m^{-1} for F2, F3, and F5, respectively. These treatments caused relative yield reductions of approximately 36.7, 29.1, and 48.9% for F2, F3, and F5, respectively, per unit increase in salinity. Although these treatments led to a higher relative loss in yield, they allowed the use of water with higher salinity to prepare the nutrient solutions (Figure 2D).

Lower tolerance to salinity in plants subjected to the fertigation treatment F1 is due to the high proportion of K, causing inhibition in Ca absorption and translocation to the fruits (Shabani, Tabatabaei, Bolandnazar, & Ghasemi, 2012), favoring higher occurrence of fruits with blossom-end rot, consequently reducing the production of marketable fruits (Taylor & Locascio, 2007).

On the other hand, the lower tolerance of bell peppers to salinity observed in fertigation treatment F4 can be attributed to an inadequate Ca nutrition because salinity in the root zone reduces the translocation of water and Ca^{2+} to the fruits during the rapid fruit expansion phase (Rubio et al., 2009). Thus, an increase in Ca^{2+} proportion in the nutrient solution favors the production of marketable fruits (Rubio et al., 2011).

The bell pepper crop is classified as sensitive or moderately sensitive to water salinity (1.0 dS m^{-1}) or saturation extract (1.5 dS m^{-1}) (Ayers & Westcot, 1999). Thus, cultivation on coconut fiber allows the bell pepper crop to be grown using nutrient solutions with much higher salt concentrations than the limits suggested in the literature.

Other authors also observed a higher tolerance to salinity in hydroponic bell peppers, such as Arruda et al. (2011), who worked with the cv. 'Margarita' and found a salinity threshold of 2.6 dS m^{-1} and a relative reduction in marketable yield of approximately 6.3%. According to Santos et al. (2016), hydroponic systems allow for a higher tolerance to salinity in plants because of the higher availability of water and nutrients, resulting from the lower influence of the matric potential.

Conclusion

Nutrient solution enrichment with K^+ or Ca^{2+} did not cause a significant increase in the bell pepper crop yield.

The fertigation treatments F2, F3, and F5 led to higher bell pepper tolerance to salinity, allowing waters with higher salt concentrations to be used without causing a reduction in the crop yield.

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