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Heterogeneous salinity in the root system of bell pepper in greenhouse

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Key words:

Capsicum annuum L.
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ABSTRACT

The split-root technique was used as a strategy to reduce saline stress on pepper. A completely randomized design with six treatments and four replicates was used. The treatments consisted of six saline water application strategies (T1 - salinized nutrient solution ($S1 = 1.4 \text{ dS m}^{-1}$) during the whole cycle; T2 - salinized nutrient solution ($S2 = 4.5 \text{ dS m}^{-1}$) throughout the cycle, T3 - S1 and S2 throughout the cycle, using two emitters and without splitting the root system, T4 - S1 and S2, using two emitters and splitting the root system by a plastic film, T5 - S1 and S2, using two emitters and splitting the root system, alternating the solutions every 15 days, T6 - S1 and S2, using two emitters and without splitting the root system, alternating the solutions every 15 days). Five fruit harvests were performed, and the plants were harvested at 85 days after initiation of treatments and evaluated for the following variables: leaf number, leaf area, plant height, stem diameter, shoot dry matter (stem + leaves + fruits), root dry matter, number of fruits, fresh fruit weight and fruit production per plant. Most of the variables were reduced by the salinity of irrigation water. The highest fruit yields were obtained using low-salinity water, with the mixture of non-saline and saline waters, and alternating biweekly when the root system was split, demonstrating the viability of these three techniques.

Palavras-chave:

Capsicum annuum L.
água salina
fertilirrigação

Salinidade heterogênea no sistema radicular de pimentão em ambiente protegido

RESUMO

A técnica de divisão do sistema radicular foi utilizada como estratégia para reduzir o estresse salino em pimentão. Utilizou-se o delineamento inteiramente casualizado com seis tratamentos e quatro repetições. Os tratamentos foram constituídos por seis estratégias de aplicação de água salina (T1 - solução nutritiva não salinizada ($S1 = 1,4 \text{ dS m}^{-1}$) durante todo o ciclo; T2 - solução nutritiva salinizada ($S2 = 4,5 \text{ dS m}^{-1}$) durante todo o ciclo; T3 - S1 e S2 durante todo o ciclo, utilizando dois emissores e sem divisão do sistema radicular; T4 - S1 e S2, utilizando dois emissores e divisão do sistema radicular por um filme plástico; T5 - S1 e S2, utilizando dois emissores com divisão do sistema radicular, alternando-se as águas a cada 15 dias; T6 - S1 e S2, utilizando dois emissores sem divisão do sistema radicular, alternando-se as águas a cada 15 dias). Foram realizadas cinco colheitas de frutos e as plantas foram coletadas aos 85 dias após início dos tratamentos, e avaliadas quanto às seguintes variáveis: número de folhas, área foliar, altura da planta, diâmetro do caule, massa seca parte aérea (caule + folhas + frutos) e de raiz, número de frutos, massa fresca de frutos e produção de frutos por planta. A maioria das variáveis foi reduzida pela salinidade da água de irrigação. Os maiores rendimentos de frutos foram obtidos com uso de água de baixa salinidade, com a mistura de águas não salinas e salinas, e com alternância quinzenal quando utilizando a divisão do sistema radicular, demonstrando a viabilidade destas três técnicas.



INTRODUCTION

Bell pepper (*Capsicum annuum* L.) stands out among the most produced fruit vegetables in protected environment. The crop is classified as sensitive to salinity, showing significant reduction in fruit yield when irrigated using water with electrical conductivity above 1.0 dS m^{-1} (Ayers & Westcot, 1999), a fact already found by other researchers (Arruda et al., 2011; Hussein et al., 2012).

Thus, water with electrical conductivity above 1.0 dS m^{-1} should be used with caution, adopting practices and technologies that minimize the deleterious effect of salinity on plants.

The technique of splitting the root system into two or more parts has been studied in various crops, especially in other countries (Koushafar et al., 2011; Yang et al., 2012; Sun et al., 2013; Wang et al., 2013). In the Brazilian literature, there are few studies on this technique applied to the use of saline water (Guedes et al., 2015; Oliveira et al., 2017), which found that the adoption of this technique allows saline water to be used without reduction in yield. According to Kong et al. (2012), greater growth of plants subjected to heterogeneous salinity is due to the higher water use efficiency, reduction in the absorption and transport of Na^+ to the leaves and efflux of this ion when one part of the root system is kept under no saline stress.

Although this technique presents itself as promising, further research should be conducted for it to be passed on to the producers. Given the above, this study aimed to evaluate the effect of applying partial saline stress on the root system of bell pepper grown in protected environment.

MATERIAL AND METHODS

The experiment was carried out from July to October 2013, in a protected environment at the Department of Environmental and Technological Sciences of the Federal Rural University of the Semi-Arid Region (UFERSA), in Mossoró, RN, Brazil ($5^\circ 11' 31'' \text{ S}$; $37^\circ 20' 40'' \text{ W}$, $\sim 18 \text{ m}$).

The greenhouse used was 6.40 m wide and 22.5 m long, with a dome-like shape covered by 0.10-mm-thick low-density polyethylene, treated against the action of ultraviolet rays. Side and front walls consisted of anti-aphid screen, with a 0.30-m-high base wall made of reinforced concrete.

The soil used was classified as Red Yellow Argisol (EMBRAPA, 2013), collected in the 0-20 cm layer, in an uncultivated area located at the UFERSA campus. The collected material was air-dried, sieved through a 2.0-mm mesh and

subjected to physical and chemical analyses (EMBRAPA, 2011) (Table 1).

Bell pepper (*Capsicum annuum* L.) seedlings, cv. 'All Big', were produced on expanded polyethylene trays with capacity for 128 cells, containing substrate composed of coconut fiber and earthworm humus at 1:1 proportion. Transplanting was carried out approximately 25 days after sowing, using one seedling with four to five true leaves per pot, which contained the analyzed soil.

The experiment was set up in a completely randomized statistical design, with six treatments and four replicates, totaling 24 experimental units. The experimental unit was represented by one pot with capacity for 20 dm^3 of substrate, containing one plant each. The pots used had the following dimensions: 0.33 m of height; 0.30 m of upper diameter and 0.20 m of bottom diameter.

Treatments were obtained by the combination of two salinity levels in the water used to prepare the nutrient solution (S_1 -0.5 and S_2 -3.5 dS m^{-1}), with or without split root system, as described below:

T1 - Nutrient solution prepared using low-salinity water (S_1 -1.4 dS m^{-1}) during the entire cycle; T2 - Nutrient solution prepared using saline water (S_2 -4.5 dS m^{-1}) during the entire cycle; T3 - S_1 and S_2 during the entire cycle, using two emitters and without splitting the root system; T4 - S_1 and S_2 , using two emitters and splitting the root system with a plastic film; T5 - S_1 and S_2 , using two emitters and splitting the root system, alternating the solutions every 15 days; T6 - S_1 and S_2 , using two emitters and without splitting the root system, alternating the solutions every 15 days.

After preparing the nutrient solutions, their respective values of electrical conductivity were determined, 1.4 and 4.5 dS m^{-1} .

In the treatments T4 and T5, the root system was split by a plastic film and adhesive tape (Figure 1), so that each half of



Figure 1. Planting system in the pot using two plastic bags side by side to split the root system

Table 1. Chemical and physical characteristics of the soil used in the experiment

Chemical characteristics									
pH	EC _{se} dS m ⁻¹	OM (%)	P (mg dm ⁻³)	K ⁺	Na ⁺	Ca ⁺²	Mg ⁺²	Al ⁺³	H ⁺
				(cmol _c dm ⁻³)					
5.7	0.98	1.05	2.20	0.14	0.13	0.40	0.60	0.25	3.05
Physical characteristics									
Granulometric fraction (g kg ⁻¹)			Textural class	Moisture (g g ⁻¹)		Density (kg dm ³)			
Sand	Silt	Clay		FC	PWP	Ds	Dp		
707.2	172.2	120.6	SL	0.15	0.06	1.53	2.68		

EC_{se} - Electrical conductivity of the saturation extract; SL - Sandy loam; FC - Field capacity for $\psi_m = -10 \text{ kPa}$; PWP - Permanent wilting point for $\psi_m = -1500 \text{ kPa}$; Ds - Soil bulk density; DP - Soil particle density

the root system was exposed to the salinity according to the applied treatments. At transplantation, the soil clods of all seedlings were carefully crumbled to expose the root system, without damaging it. In the first five days after transplanting, irrigations were performed using only public-supply water and, after this period, the treatments began to be applied.

Water salinity of 3.5 dS m⁻¹ was obtained by adding sodium chloride (1.22 g L⁻¹) to water from the supply system of the UFERSA campus (S₁), adjusted using a benchtop conductivity meter, with automatic correction of temperature. The water used as control (0.5 dS m⁻¹) and to obtain the other saline treatments was analyzed according to the methodology recommended by Richards (1954) and had the following chemical characteristics: pH = 8.30; EC = 0.50 dS m⁻¹; Ca²⁺ = 3.10; Mg²⁺ = 1.10; K⁺ = 0.30; Na⁺ = 2.30; Cl⁻ = 1.80; HCO₃⁻ = 3.00; CO₃²⁻ = 0.20 (mmol L⁻¹).

The pots were irrigated by a drip system using two microtube emitters, which were previously evaluated under normal conditions of operation. The emitters were attached to 16-mm-diameter lateral lines (polyethylene pipes). Water consumption by plants was not taken into account; however, the irrigation system was turned off only when the water drained from all pots.

For each type of water, an independent irrigation system was used, formed by a motor pump, a 500-L tank, 16-mm-diameter lateral lines and 0.50-m-long microtubes (spaghetti), with mean flow rate of 2.5 L h⁻¹. For plants to receive the same volume of water, each pot contained two emitters, including the treatments in which the root system was not split.

The pots were arranged in 4 rows, at spacing of 1.50 m between rows and 0.70 m between plants in the row, adding one pot to each end as a border, in which plants were conducted according to the treatment T1.

Nutrients were supplied through fertigation at weekly intervals, using fertilizer solution at the following concentration: every 1000 L of solution was mixed with 650 g of calcium nitrate, 500 g of potassium nitrate, 170 g of monopotassium phosphate (MKP), 250 g of magnesium sulfate and 50 g of magnesium nitrate (Trani et al., 2011). As source of micronutrients, Quelatec[®] (solid mixture of EDTA-chelated nutrients, containing 0.28% Cu, 7.5% Fe, 3.5% Mn, 0.7% Zn, 0.65% B and 0.3% Mo) was applied at dose of 6 g 100L⁻¹ of solution.

Fruits were harvested four times, when they were at the commercial point of harvest. After each harvest, the fruits

were counted and weighed to obtain the number and weight of fruits per plant at each harvest and then the fruit production per plant.

At 90 days after transplantation (October 8, 2013), plants were harvested and evaluated with respect to the following variables: number of leaves, leaf area, plant height, stem diameter, shoot dry matter (stem + leaves + fruits), root dry matter and total dry matter. For the number of leaves, only green leaves were counted. Leaf area was determined using an area integrator (LI-COR, model LI-3100).

The fresh matter was placed in paper bags and dried in forced-air oven at temperature of 65 °C until constant weight, and the biomass was determined on a precision scale (0.01 g).

The data were subjected to analysis of variance and means were compared by Tukey test (p < 0.05) using the program Sisvar[®] (Ferreira, 2011).

RESULTS AND DISCUSSION

The statistical analysis of the data revealed that there was significant response of the plants to the treatments applied with respect to growth parameters, except stem diameter, which showed mean value of 10.6 mm (Table 2).

Exclusive use of saline water (T2) reduced plant height by approximately 41.5%, in comparison to plants irrigated only with low-salinity water (T1); however, when irrigations were performed using both types of water, with or without split root system, lower reductions were observed for this variable, with losses from 21.7% (T3) to 29.7% (T4), in comparison to plants in the treatment T1 (Table 2).

Negative effect of saline water on bell pepper growth has been reported by other authors (Hussein et al., 2012); as well as in other species of the same family, such as tomato (Guedes et al., 2015). Reduction in plant height under saline stress is a typical behavior of glycophytes (Munns & Tester, 2008) and can be attributed to the increase in the osmotic pressure of the medium and the consequent reduction in the availability of the water to be consumed, affecting cell division and elongation (Martinez & Lauchli, 1994).

For number of leaves and leaf area, highest values were observed in the treatments T1, T3 and T5, which did not differ from one another. On the other hand, the treatments T2, T4 and T6 led to reduced values, especially T2 for leaf area, which decreased by 75.4% in comparison to the plants in the treatment T1 (Table 2).

Table 2. Plant height (PH), stem diameter (SD), number of leaves (NL), leaf area (LA), shoot dry matter (SDM), root dry matter (RDM) and total dry matter (TDM) of bell pepper plants subjected to partial saline stress of the root system

Treatments [#]	ECns (dS m ⁻¹)	PH (cm)	SD (mm)	NL (unit)	LA (cm ² plant ⁻¹)	SDM	RDM (g plant ⁻¹)	TDM
T1	1.45	59.3 a	12.2	136.0 a	9053.6 a	93.6 a	16.5 a	110.1 a
T2	4.45	34.7 b	9.7	53.1 b	2226.7 d	44.9 c	6.6 b	51.5 c
T3	1.45-4.45	46.4 ab	11.7	167.3 a	7215.0 ab	83.5 ab	17.1 a	100.6 a
T4	1.45/4.45	41.7 ab	9.3	63.0 b	3523.5 c	66.7 b	11.5 c	78.2 b
T5	1.45/4.45	43.3 ab	11.0	135.7 a	6762.5 ab	83.1 b	15.3 ab	98.4 ab
T6	1.45-4.45	45.0 ab	9.3	62.3 b	4434.1 bc	66.7 b	12.4 bc	79.1 b
F test		*	ns	**	**	**	**	**
CV (%)		17.5	12.2	15.6	19.6	16.5	16.4	15.8

ns, *, **Not significant, significant at 0.05 and 0.01 probability levels, respectively; Means followed by the same letter in the column do not differ by Tukey test at 0.05 probability level; ECns - Electrical conductivity of the nutrient solution (values separated by hyphen (-) or bar (/) indicate the two salinity levels applied without or with split root system, respectively

[#] Details of treatments are given in material and methods

These results indicate that the effect of salinity on bell pepper leaf development was more evident on leaf blade expansion than on the production and maintenance of new leaves.

The osmotic effects caused by the lower water potential in the root environment can reduce water availability to cell tissues, limiting cell growth and expansion (Munns & Tester, 2008). Consequently, the plant undergoes water stress, although the soil is moist, a process called physiological drought (Prisco & Gomes Filho, 2010).

This water stress can cause increase in the level of abscisic acid (ABA). In this context, various studies demonstrate that higher ABA concentration in the xylem sap of plants under treatments with partial stress of the root system induces partial stomatal closure, reducing the growth and expansion of the leaf blade, thus decreasing water use and increasing water use efficiency by the plants (Liu et al., 2009; Panigrahi et al., 2011; Yang et al., 2012).

Reduction in bell pepper leaf area due to increasing salinity of water or soil has also been observed by other authors (Arruda et al., 2011; Sá et al., 2016; Tehseen et al., 2016).

Regarding dry matter accumulation, a similar behavior was observed for shoot dry matter (SDM), root dry matter (RDM) and total dry matter (TDM), which showed highest values in the treatments T1, T3 and T5, and lowest values in the treatment T2 (Table 2).

The results obtained in the treatment T2 demonstrate the deleterious effect of salinity on bell pepper biomass production. Reduction in the production of photoassimilates in plants subjected to saline stress is mainly associated with the toxic effect of ions such as Na^+ and Cl^- on the net C fixation (Araújo et al., 2010). In addition, the data show that the split-root technique allows saline water to be used without significant losses in plant growth.

Similar results have been found by Attia et al. (2009), Guedes et al. (2015) and Oliveira et al. (2017), who worked with pea tomato and cucumber, respectively, under two salinity levels and using the split-root method. These authors observed that root exposure to salinity led to decrease in biomass production, and that the negative effect of salinity was mitigated when plants were cultivated with only half of the root system irrigated with saline water, whereas the other half was irrigated with the low-salinity control treatment.

Table 3 presents the effects of treatments on the fruit yield parameters, showing a significant response to the treatments by the number of fruits (NF), mean fruit weight (MFW) and fruit production (PROD), whose highest values were obtained in T1, T3 and T6, and lowest values were observed in plants irrigated exclusively with saline water (T2). When the effect of salinity on plants irrigated with only saline water (T2) were compared with the absence of salinity (T1), there were reductions of 40.6% in NF and 33.3% in MFW, resulting in losses of 60.3% in PROD (Table 3).

In general, the effect of salinity, regardless of the treatments using saline water, was more severe on NF than on MFW. This behavior can be attributed to the high fruit abortion due to some physiological and/or biochemical factor resulting from the high concentration of salts, which must have caused a

Table 3. Number of fruits (NF), mean fruit weight (MFW) and production (PROD) of bell pepper subjected to partial saline stress of the root system

Treatments	ECns (dS m^{-1})	NF unit	MFW g fruit^{-1}	PROD g plant^{-1}
T1	1.45	12.3 a	57.0 abc	700.7 ab
T2	4.45	7.3 b	38.0 d	278.3 c
T3	1.45-4.45	10.3 ab	73.3 a	757.7 a
T4	1.45/4.45	9.0 b	45.7 cd	407.7 c
T5	1.45/4.45	8.3 b	53.0 bcd	440.7 bc
T6	1.45-4.45	10.3 ab	68.3 ab	711.7 ab
F test		**	**	**
Mean		12.8	11.7	18.2

ns, *, **Not significant, significant at 0.05 and 0.01 probability levels, respectively; Means followed by the same letter in the column do not differ by Tukey test at 0.05 probability level; ECns - Electrical conductivity of the nutrient solution (values separated by hyphen (-) or bar (/) indicate the two salinity levels applied without or with split root system, respectively

physiological limitation on plants when subjected to saline stress (Giuffrida et al., 2014).

According to Ashraf (2004), saline stress reduces the number of fruits because it acts on the microsporogenesis and elongation of stamen filaments, increasing cell death in some types of tissues and causing abortion of ovules and senescence of fertilized embryos.

Studies conducted by various authors have demonstrated that the reduction in fruit yield in bell pepper subjected to saline stress results from the decrease in the mean fruit weight and/or reduction in the number of fruits per plant (Arruda et al., 2011; Rubio et al., 2011; Rameshwaran et al., 2015), because fruits are the most sensitive organs to salinity (Azuma et al., 2010) due to the deleterious effects of saline stress on the increase of abortion rate, caused by the reduction in the number and viability of pollen grains (Ghanem et al., 2009).

In general, the results presented in this study on the split-root technique as irrigation management to mitigate the effect of salinity on bell pepper growth and yield confirm those reported by other authors, in crops such as tomato (Koushafar et al., 2011; Guedes et al., 2015) and cucumber (Oliveira et al., 2017).

Although the split-root technique has potential to be adopted under conditions that require the use of saline water in bell pepper production, it is worth pointing out that the results obtained using such technique did not differ significantly from the treatment using both types of water (0.5 and 3.5 dS m^{-1}) simultaneously and without splitting the root system (T3). Thus, due to its greater practicality, the treatment T3 has higher viability of application, especially in situations with a large number of plants.

CONCLUSIONS

1. Exclusive use of saline water negatively affected the development of bell pepper plants.
2. The split-root technique allows saline water to be used in the bell pepper crop without significant loss in fruit production.
3. Irrigation management using the two types of water (0.5 and 3.5 dS m^{-1}) simultaneously and without splitting the root system is a viable alternative for the use of saline water, especially due to its greater practicality.

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