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Effect of dynamic unequal distribution of salts in the root environment on performance and Crop Per Drop (CPD) of hydroponic-grown tomato

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ABSTRACT

Due to water shortage, application of saline water for irrigation is an urgent requirement in agriculture. The aim of this study was to investigate the effects of NaCl-induced salinity stress on the growth and Crop Per Drop (CPD) of tomato (*Lycopersicon esculentum* var. Falcato F1) in a dynamic split-root hydroponic system. Roots of tomato seedlings were separated into approximately two equal parts, half was grown in a box containing aerated nutrient solution (A-half), and the other half was grown in a similar box containing aerated saline water (B-half). Four salinity levels (0, 40, 80, and 120 mM NaCl) were applied at the B-half. At the static split-root hydroponic system, significant difference was found between the tomato roots supplied with the nutrient solution and those supplied with saline waters in the root volume and fresh and dry matter weight. By increasing NaCl concentration in the B-half, the root growth was decreased. At the dynamic split-root system, interchanging the split roots between the nutrient solution and the saline water at 3-day intervals resulted in significant reduction of tomato growth, fruit yield and CPD. The highest CPD was found at the treatment where in a 7-day dynamic split-root system, half of the roots were exposed to the nutrient solution and the other half was immersed in the 40 mM NaCl solution. At the 7-day intervals treatments, exposing the split root to 80 and 120 mM NaCl concentrations resulted in significant reduction of the plant growth, fruit yield and the CPD. The results showed that the dynamic split-root hydroponic system is an applicable technique for using saline waters; although the success of this system is strongly dependent on the salinity level and the exchange interval of root parts between the nutrient solution and saline water.

1. Introduction

Salinity is one the most abiotic stresses affecting plant growth and productivity worldwide. The salt stress problem becomes more acute due to irrigation with saline water and uses of uncultivable saline soils to meet the demand of the increasing population throughout the world (Munns, 2002).

Plants are suffered from salt stress in three ways: (i) the decrease in the osmotic potential in the rooting medium, (ii) the toxic effect of a high concentration of Na^+ and Cl^-, and (iii) impaired nutrients balance (Gama et al., 2007). Decreases in the osmotic potential might cause disturbances in the water balance in plants reducing turgid and photosynthesis (Koryo, 2006). On the other hand, high concentrations of Na^+ and Cl^- reduce the absorption of essential nutrients and additionally can be toxic by competing with K^+ and NO_3^- in biochemical processes (White, 1999).

Tomato is a plant 'moderately sensitive' to salinity that plays a significant role in agriculture section (Foolad, 2004). Diluted sea water can be used for the production of salt-tolerant tomato genotypes as a valid alternative to fresh irrigation water (Incerti et al., 2007). The response of tomato plants to uniform distribution of salt in the root media has been studied by several researchers (Katerji et al., 1998; Yaling and Stanghellini, 2001; Malash et al., 2005; Incerti et al., 2007; Tantawy et al., 2009), however the effect of unequal distribution of salt in the root zone on plant growth and particularly crop water productivity is still poorly understood. Surely, up to now the possibilities and consequences of an unequal distribution of nutrients and residual salts are insufficiently studied in greenhouse industry (Sonneveld and Voogt, 2009).

It seems that unequal distribution of salt in the root media using split-root technique can be an effective approach for using saline water to increase tomato yield and improve Crop Per Drop (CPD), where CPD is defined as the yield component per unit of applied water. The CPD can be improved through increasing yields and/or decreasing the amount of water used that means "more Crop Per Drop" (Seckler, 1996; Luquet et al., 2005). The limitation of water

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resources has resulted in shift of the overall focus in the agricultural sector from the traditional agronomic perspectives of higher yields and higher total production towards water productivity or producing higher yield from each unit of water used (Meredith et al., 2006).

Leo (1964) applied a split-root technique to investigate the effect of salinity on plant–water relationships and found that root elongation and growth and water uptake were greatly inhibited by increasing salinity level. Mulholland et al. (2002) reported that salt stress in a split-root system led to reduced leaf area and water uptake of tomato but it had no impact on the fruit yield. Flores et al. (2002) showed that saline treatment of the whole root system in split-root system on tomato caused a decline in water uptake. When half of the root system was treated with salinity, water uptake was reduced in the treated part, but a compensatory increase in water uptake through the untreated part was observed. Nakano (2007) showed stable growth of tomato plants in split-root systems between humid air and nutrient solution. Dara (2009) showed that in an unequal distribution of salt in hydroponic culture, increasing salinity level decreased tomato root growth and nutrient uptake while increased water use efficiency.

Split-root system seems to be a suitable technique for using saline water (Mulholland et al., 2002; Bazihizina et al., 2009). Although the effect of salt stress on performance and water use efficiency of some plants using split-root in hydroponic culture has been studied, dynamic system of local replacement of salinity on plants has less been studied.

Therefore, the aim of this study was to investigate the effects of NaCl stress on the growth and crop water productivity of tomato in a dynamic unequal distribution of salts in the root environment.

2. Materials and methods

2.1. Plant material and culture conditions

Seeds of tomato (*Lycopersicon esculentum* var. Falcato F1) that is a commercial cultivar largely cultivated in Iran especially in greenhouses was surface sterilized with 2% (w/v) sodium hypochlorite for 10 min and then were germinated on perlite. The vigorous 5-leaf seedlings were selected and transferred to an aerated half strength Johnson nutrient solution for 9 days. Tomato seedlings were grown in a greenhouse with a temperature of 22–26 °C (day) and 18–20 °C (night), 80% relative humidity and 150 $\mu mol\ m^{-2}\ s^{-1}$ of light intensity with a 14-h photoperiod.

Therefore, a total of 48 boxes with 12 treatments and four replications were used in this experiment.

2.2. Treatments

The seedlings were removed from the half strength Johnson nutrient and then the roots of tomato seedlings (one seedling per box) were separated into approximately two equal parts, half was grown in an isolated water black box containing 2.7 l aerated Johnson nutrient solution, and the other half was grown in a similar box containing 2.7 l aerated saline water. The full-strength nutrient solution contained the following salts in mmol/l: KNO_3, 6; $Ca(NO_3)_2$, 4; $NH_4H_2PO_4$, 2; $MgSO_4$, 1; KCl, 0.050; H_3BO_3, 0.025; $MnSO_4$, 0.005; $ZnSO_4$, 0.002; $CuSO_4$, 0.0005; H_2MoO_3, 0.0001; Fe-EDTA, 0.050. Four salinity levels (0, 40, 80, and 120 mM NaCl) were applied. These levels were selected based on common water salinity levels in arid regions, especially in the studied area.

Treatments were distinguished according to the nature of the root medium as: J/0 (S0) plants supplied with Johnson nutrient solution in one box and distilled water in the other box, J/40 (S2) plants supplied with Johnson nutrient solution in one box and 40 mM NaCl in the other box, J/80 (S3) plants supplied with Johnson nutrient solution in one box and 80 mM NaCl in the other box, and J/120 (S4) plants supplied with Johnson nutrient solution in one box and 120 mM NaCl in the other box. Solutions and tap water in the boxes were renewed weekly. In all treatments, the box containing nutrient solution was called “A” and another side was called “B”.

Two parts of roots in each treatment were interchanged every 0 (T0), 3 (T3), or 7 (T7) days. The time interval was selected based on the preliminary experiment.

The plants were exposed to salinity in this split-root dynamic hydroponic system for 70 days and then the fruits were collected at the first harvest period.

2.3. Analyses

At harvest, plant height, stem diameter, number of expanded leaves, root volume, fresh and dry weight of root and shoots, and fruit yield were measured. The amount of water or solutions loss from each treatment was calculated daily by measuring the height of solution reduction in each box. Water boxes were isolated, so the amounts of evaporation and drainage were negligible. Crop Per Drop (CPD) was calculated by the following equation:

$$CPD = \frac{\text{fruit yield}}{\text{water consumption}}$$

2.4. Statistics

The experiment was set up in a split plot design with four replicates. Analysis of variance was carried out using the SAS program. All data were subjected to analysis of variance and means were compared using Fisher’s protected Least Significant Difference (LSD) method when the *F* test indicated significance difference at $P < 0.01$. The zero value was the effect of treatment.

3. Results

3.1. Fresh and dry weight of root

Plants grown at the T0 treatment had the highest fresh and dry weight of root at the A-half split supplied with the nutrient solution while they produced the lowest root in the B-half split supplied with saline water (Table 1). There was significant difference in root biomass between two parts of the roots at the T0 treatment, the A-half root that was set in the nutrient solution had higher biomass than the B-half root that was set in the saline solution.

Interaction of exchange interval and salinity treatment on root biomass was significant so that the plants at the T0S0, T0S1, T0S2, and T0S3 treatments had significantly higher root dry matter

Table 1
The effect of exchanging intervals of two parts of root between the nutrient solution (A-half) and saline water (B-half) on volume and dry and fresh weight of tomato root.

Treatment	Root volume (ml)		Root dry weight (g)		Root wet weight (g)	
	A-half	B-half	A-half	B-half	A-half	B-half
T0	71.31[a]	2.67[c]	4.61[a]	0.24[b]	62.44[a]	2.32[c]
T3	18.01[b]	11.52[b]	1.18[b]	0.92[a]	16.45[c]	10.62[b]
T7	24.75[b]	16.71[a]	1.61[b]	0.91[a]	23.23[b]	14.01[a]
$LSD_{(0.01)}$	6.8	1.84	1.09	0.61	4.34	2.49

In each column, means with the same letter are not significantly different. T0 represents the static split root system in which the root parts were not exchanged between the nutrient solution and saline water, and T3, and T7 represent dynamic split-root system in which the root parts were exchanged between the nutrient solution and saline water after 3 and 7 days, respectively.