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Interactions between salinity and irrigation frequency in greenhouse pepper grown in closed-cycle hydroponic systems

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ABSTRACT

Two different irrigation regimes with two different salinity levels were applied to peppers (*Capsicum annum* L.) grown in closed hydroponic systems in a glasshouse. The two salinity levels were attained by adding NaCl to the irrigation water used to prepare nutrient solution to obtain concentrations of 0.8 and 6 mol m^{-3}, and allowing the salts to progressively accumulate in the recycled nutrient solution. The two salinity levels were combined with two different levels of irrigation frequency in a two-factorial experimental design. Initially, the Na and Cl concentrations increased rapidly in the recycled effluents, but nearly three months after treatment initiation they converged gradually to maximal levels depending on the NaCl treatment. The low irrigation frequency imposed a more rapid salt accumulation in the root zone, which was ascribed to restriction of the volume of drainage solution. However, the maximal salt concentrations in the root zone were independent of the watering schedule. This finding agrees with previous research revealing that the maximal salt accumulation in the root zone of plants, grown in closed hydroponics, is dictated merely by the NaCl concentration in the irrigation water. Total and Class I yields were suppressed by salt accumulation but the high irrigation frequency significantly mitigated the deleterious salinity effects. At low salinity, the low irrigation frequency raised significantly the weight percentage of fruits with blossom-end rot (BER), whereas at high salinity the incidence of BER was further increased without significant differences due to the irrigation regime. Frequent irrigation resulting in high drainage fractions in closed hydroponic systems may delay the rate of salt accumulation in the root zone, thereby enhancing yield and improving fruit quality, without increasing the discharge of polluting fertigation effluents to the environment.

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1. Introduction

Agriculture is facing a major worldwide problem with lack of adequate water resources, forcing many growers to use water with relatively high salt concentration for crop irrigation (Reed, 1996). Therefore, a considerable percentage of the water supplied to plants via irrigation is aimed at leaching the excessive salts out of the root environment (Guitjens et al., 1997). Another reason forcing growers to provide more water than the estimated water consumption to drip and trickle irrigated crops is the variability in water supply between individual emitters of the irrigation system, as well as the variability in water demand among individual plants (Lieth, 1996; Sonneveld, 2002). However, in modern greenhouse horticulture, the plants are commonly supplied with nutrient solutions rather than raw irrigation water (Sonneveld, 1995; Bar-Yosef, 1999). Hence, the excess nutrient solution that drains out of the root zone after each irrigation cycle, henceforth termed interchangeably drainage water or drainage solution, contains considerable amounts of nutrients such as nitrates and phosphates and is, therefore, considered an environment pollutant (Wilkerson, 1996; Raviv et al., 1998; Incrocci et al., 2006).

Closed soilless growing systems may be employed in greenhouses to minimize environmental contamination stemming from fertigation runoff (Van Os, 1999; Savvas, 2002a; Rouphael et al., 2006). Hence, considerable savings of irrigation water and fertilizers may be reconciled with high yields, thereby appreciably increasing the water use efficiency by the crop (Schwarz et al., 1996; Zekki et al., 1996; Rouphael et al., 2005). Nevertheless, the accumulation of ions that are sparingly taken up by the plants may impose a partial discharge of drainage water aimed at controlling the root-zone salinity, thereby reducing the efficiency of closed-cycle systems to prevent groundwater contamination (Raviv et al., 1998; Carmassi et al., 2005). To minimize the need to discharge recycled drainage water, thereby reducing groundwater contamination, intelligent automation systems based on mass balance models may be used (Pardossi et al., 2004; Carmassi et al., 2005; Savvas et al., 2005a). However, the question is raised whether the manipulation of irrigation frequency might also contribute to a better control of salt accumulation in closed hydroponic systems, since under such growing conditions the increase of the drainage percentage does not aggravate environment pollution.

In open soilless culture systems, the drainage fraction should be maintained at a minimum, since the cultural need to leach excess salts out of the root environment contrasts with the environmental constraint for minimal discharge of fertilizer residues. In open cultivation systems, typically leaching fractions of 25–35% are recommended (Schröder and Lieth, 2002). Optimal irrigation scheduling is very important to water saving while efficient use of water by irrigation is becoming increasingly important. Accurate supply of water and nutrients will result in better water use efficiency, avoid stress situations, and control production (Raviv and Blom, 2001).

However, in closed-cycle cultivation systems, the drainage percentage is not restricted by environmental concerns and hence the irrigation frequency may be considerably higher than that resulting in leaching fractions recommended for open cultivation systems. Katsoulas et al. (2006) evaluated the effects of two irrigation frequencies on growth, flower yield, and quality in a rose crop grown on rockwool slabs in a closed hydroponic system. The higher irrigation frequency increased both the number and the fresh and dry weight of cut flowers per plant by about 30%, while the greenhouse water use efficiency was improved. According to Xu et al. (2004) and Silber et al. (2005), a high irrigation frequency may improve crop performance due to a higher availability of nutrients, specifically P and Mn. Furthermore, high irrigation frequency is associated with constantly elevated moisture levels in the root zone of substrate-grown plants. As a consequence, the hydraulic conductivity and the water availability are maintained for longer times at high levels (Raviv et al., 1999, 2002). The only precaution regarding the application of a frequent irrigation schedule is the possible creation of excessive moisture conditions in the root zone that might reduce oxygen availability (Schröder and Lieth, 2002). Nevertheless, this problem may be tackled by selecting growing media with optimal physical characteristics in combination with proper placement of the media in the hydroponic installation (Gizas and Savvas, in press).

In view of the above background, the present study was designed to test whether the increase of the irrigation frequency at levels resulting in a high drainage percentage ranging between 60 and 70% in closed-cycle hydroponic systems might: (a) contribute to a better control of NaCl accumulation in the recycled drainage solution; and (b) improve crop performance due to enhancement of the nutrient and water availability.

2. Materials and methods

The experiment was conducted in a fully automated experimental glasshouse, W-E oriented, located in Arta (latitude 39°7′N, longitude 20°56′E, altitude 7 m), near the coastal area of Western Greece. Pepper plants (*Capsicum annum* L., cv. 'Calyx' F_1) propagated in peat plugs were transferred to channels connected to 12 independent, fully automated hydroponic units (experimental plots), which enabled complete recycling of the drainage solution (Savvas, 2002b). Each of the 12 hydroponic units (Fig. 1) comprised two channels (5×0.25 m) placed on one bench (90 cm in height). One channel of each hydroponic installation accommodated 15 pots filled with pumice (particle size range 0–5 mm) up to a volume of 4 L, while the second one contained five bags ($100 \times 15 \times 8$ cm) filled with a porous polyurethane substrate up to a volume of 12 L per bag. One plant was planted in each pot and three plants in each bag. Thus, each channel accommodated 15 pepper plants. All channels were covered with black–white polyethylene sheets to reduce water evaporation to a negligible amount. Spacing along each channel was 33 cm, corresponding to a crop density of 1.8 plants m^{-2}. The plants were supported by plastic twine attached 2.2 m above the plant row on a horizontal wire and trained to two stems per plant by pruning all auxiliary shoots.

A drip irrigation system equipped with an individual emitter per plant was used in each experimental unit to