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Effects of drip-irrigation regimes with saline water on pepper productivity and soil salinity under greenhouse conditions

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ABSTRACT

The aim of this study was to investigate the response of sweet pepper (*Capsicum annuum* L.) to saline irrigation water and various irrigation regimes. The experiments were conducted in a greenhouse with two sweet pepper varieties (ONUR F1 and ADA F1) over two cropping seasons: spring and autumn on the Mediterranean coast at Antalya, Turkey. The irrigation regimes comprised four levels of Class A pan-evaporation and were applied using a drip irrigation system when evaporation reached a target value of around 10 mm. These four levels represented 0.50, 0.75, 1.00 and 1.25 of Class A pan-evaporation. In each irrigation regime the sweet pepper plants were exposed to four salinity treatments with electrical conductivities of 1.0, 2.5, 3.5 and 6.0 dS m^{-1} respectively. The study showed that both pepper varieties generally performed in a similar manner (except in terms of vegetative biomass production). The amount of salt accumulation within the root-zone was higher in spring compared to autumn; and therefore related to the total amount of irrigated water usage between seasons due to climatic variability. Increased salinity induced higher levels of salt accumulation within the pepper plant's root-zone, while an increased amount of saline irrigation water increased the size of the affected layer within the root-zone. Overall, an increased level of salinity alongside increased irrigation considerably depressed both vegetative growth and yield. Higher irrigation water productivities were attained with a regime comprising 0.50 of Class A pan-evaporation and which appeared to fulfil crop water requirements. It was found that sweet pepper varieties ONUR F1 and ADA F1 are moderately sensitive to salinity with a threshold value of 1.43 dS m^{-1} and a decreasing slope value of 11.1%. Although both seasons revealed a single salinity response function, there were considerable differences in the actual fresh pepper yield. This study demonstrates that for pepper crops irrigated with saline water (or grown on salt-affected soils), pepper growers must consider the salinity response function and seasonal productivity alongside an appropriate irrigation regime.

1. Introduction

Pepper (*Capsicum annuum* L.) is a high-value crop cultivated in many parts of the world (DeWitt and Bosland, 1993). In the Mediterranean basin, pepper crops are grown in greenhouses and often irrigated in salt-affected soil with low quality water (i.e. brackish or reclaimed water) due to increasing demand (Chartzoulakis and Klapaki, 2000). Saline water combined with excessive fertilization only causes further problems. The use of poor quality water and over-fertilization can cause damage to the crop and soil—which in turn causes a reduction in the marketable yield if poorly managed.

Horticultural production is one of the main economic activities in Turkey, with Antalya province being a centre of protected cultivation (in greenhouses or plastic houses) due to the very sympathetic climatic conditions of the Mediterranean coast (e.g. Ozkan et al., 2004; Yilmaz et al., 2005). The most common vegetables produced under protected cultivation are tomato, pepper, cucumber, eggplant and squash (Yilmaz et al., 2005). Pepper is the second major vegetable crop produced in Antalya where it is grown twice a year (in spring and autumn) under protected cultivation. This production depends almost entirely on water management.

Pepper (*Capsicum annuum* L.) is normally classified as a moderately (or medium) sensitive crop to salt-stress and as being sensitive to water-stress (e.g. Allen et al., 1998; Aktas et al., 2006; Ayers and Westcot, 1985). It has been reported in several studies that water and salinity stresses can have a considerable effect on the production of field and greenhouse-grown pepper (e.g. AlHarbi

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Table 1
Soil properties of the experimental site before planting of pepper in spring 2011.

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH	EC_e ($dS\,m^{-1}$)
0–20	60	15	22	Sandy clay loam	7.8	0.42
20–40	62	16	23	Sandy clay loam	7.6	0.38
40–60	62	16	25	Sandy clay loam	7.8	0.36
60–80	59	15	25	Sandy clay loam	7.7	0.33

et al., 2014; Ben-Gal et al., 2008; Nagaz et al., 2012; Patil et al., 2014; Shao et al., 2010; Sezen et al., 2006; Ünlükara et al., 2015). Water and salt stresses restrain plant growth and affect crop yield (quality and quantity) as both reduce water uptake. The natural ability to tolerate or resist water-stress and root-zone salinity depends on crops and their varieties (e.g. Allen et al., 1998; Arslan et al., 2015; Maas and Hoffman, 1977; Rameshwaran et al., 2015a,b; Shannon and Grieve, 1999; Steppuhn et al., 2005a,b). The main objective of this paper, therefore, was to study the impact of water-use regimes and salt stresses on pepper crops (and their yield) grown in a greenhouse environment under a drip irrigation system. The two varieties of sweet pepper (ONUR F1 and ADA F1) were chosen because they are commonly grown in Antalya. The experiments were conducted in the spring and autumn of 2011. Four irrigation regimes were studied in which pepper plants were subjected to four differing salinity-level treatments. Mathematical modelling of the data was also performed using the SALTMED model. The impact of irrigation regimes and salinity treatments on greenhouse soil was also considered. Salinity response functions – the classical threshold-slope linear response function (Maas and Hoffman, 1977) and the sigmoidal-shape nonlinear response function (Steppuhn et al., 2005a) – were used to study the salinity response of pepper yields and also calibrate their indices.

2. Materials and methods

The greenhouse experiment was conducted on the Mediterranean coast at Antalya, Turkey (Latitude: 36°12′, Longitude: 30°02′ and Elevation 19 m). The soil itself was a sandy clay loam and its properties (prior to planting of the peppers in spring 2011) are given in Table 1. The soil was of a slightly alkaline pH; its salinity varying from 0.42 to 0.33 $dS\,m^{-1}$ in a zero to 80 cm soil layer. The experiment was laid out using a design of sixteen subplots 8.0 m long and 2.1 m wide. In each subplot the pepper plants were transplanted in three rows (plant spacing 0.4 m and row spacing 0.7 m) with the top 4.0 m lengths with ONUR F1 variety and the rest 4.0 m with ADA F1 variety. In summary, each subplot contained two varieties with three replications. Transplanting from the seed bed during spring was carried out on 25th March 2011. The harvest ended on 12th July 2011 giving a growth period length of 110 days. Transplanting from the seed bed during Autumn was carried out on 26th September 2011. The harvest ended on 22nd February 2012 giving a growth period length of 150 days from transplanting. The soil was leached with fresh water before transplanting.

Class A evaporation-pan measured the water evaporation within the greenhouse. Four irrigation regimes were studied using Class A pan-evaporation data multiplied by a pan coefficient (K_{cp}) of 0.50, 0.75, 1.00 and 1.25 respectively. In each irrigation regime, pepper plants were subjected to four salinity-level treatments with irrigation water electrical conductivities (EC_{iw}) of 1.0, 2.5, 3.5 and 6.0 $dS\,m^{-1}$ respectively; and where the 1.0 $dS\,m^{-1}$ cases acted as a control. Salinity levels were attained by mixing fresh water with the concentrated saline water made with sodium chloride (NaCl).

A drip irrigation system was utilised with dripper spacing of 0.2 m and a 2.0 L per hour ($L\,h^{-1}$) discharge rate. The drippers were placed within 5 cm of the plant row. The threshold value (around 10 mm of Class A pan-evaporation from the previous irrigation) was used to initiate irrigation; except for the first two irrigations following transplanting, whereby a proportional amount of fresh water was added to each experimental treatment. The seasonal totals for each plant within the four irrigation regimes (i.e. K_{cp} of 0.50, 0.75, 1.00 and 1.25) were as follows: In the spring, 36.94, 55.41, 73.88 and 92.35 L of water were added over twenty-nine scheduled irrigations; while during the Autumn, 29.61, 44.42, 59.22 and 74.03 L of water were added over twenty-two scheduled irrigations per plant. Fertilizers were applied as 60% NO_3 and 40% NH_4. On average 0.70 $g\,m^{-2}$ NO_3 and 0.47 $g\,m^{-2}$ NH_4 were added per irrigation.

Table 2
Irrigation and salinity treatment experiments for ONUR F1 and ADA F1 varieties in both Spring and Autumn cropping seasons.

Salinity EC_{iw} ($dS\,m^{-1}$)	$K_{cp} = 0.50$	$K_{cp} = 0.75$	$K_{cp} = 1.00$	$K_{cp} = 1.25$
1.0	Case 1	Case 2	*Case 3*	Case 4
2.5	Case 5	Case 6	*Case 7*	Case 8
3.5	*Case 9*	*Case 10*	*Case 11*	*Case 12*
6.0	Case 13	Case 14	*Case 15*	Case 16

Various soil parameters were measured – such as saturated soil moisture content (0.410 $m^3\,m^{-3}$); soil moisture at wilting point (0.115 $m^3\,m^{-3}$) and field capacity (0.230 $m^3\,m^{-3}$); air entry value i.e. bubbling pressure (0.280 m); and saturated hydraulic conductivity (254.4 $mm\,day^{-1}$). The moisture and salinity of the saturated paste extract – EC_e at soil layers of 0–20 cm, 20–40 cm and 40–60 cm (i.e. within the root-zone) – were measured periodically during the cropping season at a central point between two plants along the row. Climatic parameters within the greenhouse were also measured; i.e. temperature, sunshine hours, relative humidity and radiation. The plant parameters such as crop height and leaf-area index were measured for mid and late growing stages for all sixteen experimental trials for each variety listed in Table 2. The dry biomass of the vegetative elements and roots (excluding pepper fruits) were measured for late growing stages. The total fresh pepper yields during the harvest period were also noted.

3. Mathematical modelling

In order to study the soil moisture and salinity distribution within root-zone soil we used a SALTMED model—a physical mathematical model that uses water and solute transport, evapotranspiration and water-uptake equations (Ragab 2015). The modelling was carried out using experimentally measured crop and soil parameters along with crop coefficients K_c and K_{cb} values from FAO-56 (Allen et al., 1998). A 'plane flow' model involving the Cartesian coordinates x and z was also utilised: namely, a set of dripper sources at an equal distance (0.2 m) and close enough to each other so that their wetting-fronts overlap shortly after starting the irrigation. Detailed procedures for this model set-up, calibration and validation are given in Rameshwaran et al. (2013, 2015a).

4. Salinity response functions and the salinity tolerance index

The salinity response function of a crop can be described by several forms of response functions where the yield is reduced by salinity of the irrigation water or soil; i.e. root-zone salinity