CORE Metadata, citation and similar papers at core.ac.uk
Provided by NERC Open Research Archive

NERC Open Research Archive sharing our research

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Article (refereed) - postprint

Rameshwaran, Ponnambalam; Tepe, Akin; Yazar, Attila; Ragab, Ragab. 2016. **Effects of drip-irrigation regimes with saline water on pepper productivity and soil salinity under greenhouse conditions**.

© 2015 Elsevier B.V.
This manuscript version is made available under the CC-BY-NC-ND 4.0 license http://creativecommons.org/licenses/by-nc-nd/4.0/

This version available http://nora.nerc.ac.uk/512529/

NERC has developed NORA to enable users to access research outputs wholly or partially funded by NERC. Copyright and other rights for material on this site are retained by the rights owners. Users should read the terms and conditions of use of this material at http://nora.nerc.ac.uk/policies.html#access

NOTICE: this is the author's version of a work that was accepted for publication in *Scientia Horticulturae*. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in *Scientia Horticulturae* (2016), 199. 114-123. 10.1016/j.scienta.2015.12.007

www.elsevier.com/

Contact CEH NORA team at
noraceh@ceh.ac.uk

The NERC and CEH trademarks and logos ('the Trademarks') are registered trademarks of NERC in the UK and other countries, and may not be used without the prior written consent of the Trademark owner.

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

Ponnambalam Rameshwaran[a*], Akin Tepe[b], Attila Yazar[c] and Ragab Ragab[a]

[a]*Centre for Ecology & Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire, United Kingdom*

[*]*Corresponding author:* Dr P Rameshwaran, ponr@ceh.ac.uk

[b]*West Mediterranean Agricultural Research Institute, Antalya, Turkey*

[c]*Department of Irrigation and Agricultural Structures, Faculty of Agriculture, Cukurova University, Adana, Turkey*

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.

Keywords: Capsicum annuum L.; class A pan-evaporation, modelling; sweet pepper varieties; salinity response function; salinity tolerance index, season; irrigation water productivity; yield.

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 *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 meters long and 2.1 meters 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 meters and a 2.0 litre 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 litres of water were added over twenty-nine scheduled irrigations; while during the Autumn, 29.61, 44.42, 59.22 and 74.03 litres 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.

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 meters) 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 (Maas and Hoffman, 1977, Maas, 1993; Rameshwaran *et al*. 2015b, Shannon and Grieve 1999;

Steppuhn *et al*., 2005a,b). In order to scale and compare the salinity response of crops, root-zone soil salinity is commonly expressed on the basis of the electrical conductivity of the saturated soil-paste extracts (EC_e); while yields are expressed in terms of relative yield Y_r ($=Y/Y_{max}$ where Y is the absolute actual yield and Y_{max} is the maximum yield of the season and where salinity has a very minimal or zero effect on yield). The classical threshold-slope linear response function (Maas and Hoffman, 1977) and the sigmoidal-shape non-linear response function (Steppuhn *et al*. 2005a) were used and the indices calibrated.

4.1. Threshold-slope linear salinity response function

The threshold-slope linear response function of Maas and Hoffman (1977) is a three-piece linear function that measures the salinity response; maximum yield until the salinity threshold; rate of yield decline with increases in salinity beyond the threshold; and zero yield beyond a particular value of salinity (van Genuchten, 1983):

$$\begin{array}{ll} Y_r = 1 & 0 \leq EC_e \leq EC_t \\ Y_r = 1 - b(EC_e - EC_t) & EC_t < EC_e < EC_o \\ Y_r = 0 & EC_e \geq EC_o \end{array} \qquad (1)$$

where EC_e is the root-zone salinity during the growing season; EC_t is the maximum threshold for root-zone salinity without a yield reduction (Y_r=1); EC_o is the root-zone salinity beyond which the yield is zero (Y_r=0); and b is the absolute value of the declining slope in relative yield (Y_r).

4.2. Sigmoidal-shape salinity response function

The sigmoidal-shape salinity response function proposed by Steppuhn *et al*. (2005a, b) is given as:

$$Y_r = \frac{1}{\left[1+(EC_e/EC_{50})^{e^{(sEC_{50})}}\right]} \qquad (2)$$

where EC_{50} is the root-zone salinity at which yield is reduced by 50% and *s* represents response-curve steepness.

4.3. Salinity tolerance index

EC_{50} values are traditionally used as a salinity tolerance index (*ST Index*) for crops simply derived from experimental data or from the threshold-slope linear response function. These

EC_{50} values are used to assess the relative tolerance of an agricultural crop. For the sigmoidal-shape salinity response function, Steppuhn *et al*. (2005a) defined the salinity tolerance index (*ST Index*) as:

$$ST\ Index = EC_{50} + sEC_{50} \qquad (3)$$

More detailed discussion of the *ST Index* can be found in Steppuhn *et al*. (2005a, b) and Rameshwaran *et al*. (2015b).

5. Results and discussion

5.1. Root-zone soil moisture and salinity

Root-zone soil moisture and root-zone soil salinity (EC_e) measurements were taken periodically during the cropping season at three distinct soil layers: 0–20 cm; 20–40 cm; and 40–60 cm. These are shown in Figure 1 for ONUR F1 experimental Case 11 in Spring and Autumn respectively. The effects of pepper varieties ONUR F1 and ADA F1 on soil moisture and salinity were minimal. The amount of irrigation is also shown as litres per meter-length of dripper line. The variation of measured soil moisture and root-zone soil salinity (EC_e) for the 0–60 cm layer (i.e. calculated from 0-20 cm; 20-40 cm; and 40-60 cm layers) over the growing season for each experimental case in Spring and Autumn are summarised by box and whisker plots in Figure 2.

Figure 2 shows that soil moisture values are similar in both Spring and Autumn. This is because the irrigation carried out in each treatment was proportional to Class A pan-evaporation from the previous irrigation (with a threshold value of around 10 mm). Figures 2a and 2b clearly show irrigation regime effects on soil moisture where measured values were increasing as expected within the same salinity treatment. These figures also show that soil moisture values were increasing with salinity treatment for each irrigation regime (i.e. the same K_{cp} value experiments). In other words, soil moisture within the root-zone increases with increased irrigation or an increased level of salinity treatment. The average rate of increase in soil moisture was similar in both seasons. It is worth noting that the measured soil moisture at wilting point and field capacity for the greenhouse soil were 0.115 $m^3\ m^{-3}$ and 0.230 $m^3\ m^{-3}$ respectively while the measured root-zone soil moisture during the cropping season in Figures 2a and 2b were well above the wilting point and within field capacity except in the higher irrigation cases mainly in K_{cp}=1.25 experiments.

The root-zone soil salinity (EC_e) example – Experimental Case 11 in Figure 1 – shows that measured values were increasing over both cropping seasons (i.e. salt accumulation within the root-zone). Figures 2c and 2d also show that root-zone soil salinity increased with each level of salinity treatment. However, the average rate of increase and amount of variation were less in the Autumn than in the Spring, particularly in cases of higher salinity irrigation. This means that salt accumulation was also higher in the Spring.

The climatic parameters within the greenhouse (averaged over the cropping seasons) are given in Table 3. We can see that the climatic parameters were lower in the Autumn and therefore evaporation rates were also lower than during the Spring. The amount of total water added in the Autumn was 20% less than that for the Spring (although the cropping season was forty days longer). The reduced total amount of irrigated water usage in Autumn led to less salt accumulation within the root-zone and can be seen in Figures 2c and 2d.

5.2. Predicted soil moisture and salinity

Figure 3 shows the predicted soil moisture and salinity for ONUR F1 experimental Cases 9, 10, 11 and 12 with EC_{iw}=3.5 dS m^{-1} (i.e. a constant level of salinity treatment) and Cases 3, 7, 11 and 15 with K_{cp}=1.00 (i.e. a constant level of irrigation) for Spring at mid-season (the highlighted cases are in Table 2). It is worth noting that the dripper line and plant row are central on the soil's surface, while the salinity predicted by the model was the actual salinity in the soil at mid-season (rather than the electrical conductivity of saturated soil-paste extracts, EC_e). The plotted soil moisture and salinity profiles reflect the dripper-irrigation effect where the contour profiles display an arch-like shape. We can see that soil moisture levels increase considerably under an irrigation regime (Figure 3a) and also with a level of salinity (Figure 3b). Figure 3c shows that increasing amounts of irrigation water for a particular salinity level increases the area of the soil layer affected by salinity within the root-zone. It also moves the region of higher concentration downward. Figure 3d shows that increasing levels of salinity for a particular irrigation regime increases salt concentration considerably within the root-zone.

During the cropping season salts accumulate in the root-zone (Figure 1) due to the process of saline water irrigation. This rate of accumulation can be increased by increasing higher salinity levels in the irrigation water and/or increasing the amount of water used to irrigate. In these experiments, the amount of water added in the higher irrigation cases (K_{cp}=1.25) was still not enough to leach out regions of higher salt concentration from the root-zone (Figure 3c). As soil salinity increases within the root-zone, the osmotic potential level of soil water and plant water uptake both decrease. In other words, the plant leaves more water in the root-zone as its salinity increases. This process can be clearly seen in Figures 2a and 2b.

5.3. Plant growth and yield response

Figures 4a and 4b show plant heights and Leaf Area Indexes (LAI) in mid and late stages for both varieties in both seasons. Figures 4c and 4d show the dry biomass of the vegetative elements and roots (excluding pepper fruits) at their late stage, as well as fresh yields for both varieties in both seasons. Figures 4a to 4d show that increased levels of salinity decreased both growth and yield rates considerably. Apart from the control experiments (with 1.0 dS m^{-1}) increased irrigation decreased the growth rate more in higher salinity-level treatment cases than lower treatment cases. These rates of decrease were higher in the Spring than the Autumn. In both seasons, the greenhouse pepper varieties ONUR F1 and ADA F1 responded in a similar manner; except in terms of vegetative biomass production where the ADA F1 variety produced slightly more (Figures 4b and 4c). Hence, the predicted model results for soil moisture and salinity (Figure 3) were almost similar for both variety.

Whenever root-zone soil salinity is high the roots cannot absorb water alongside dissolved nutrients. In these experiments, then, salts continued accumulating in the root-zone over the entire cropping season (Figure 1); with the salt-affected layer becoming larger under an irrigation regime. It also grew larger and more concentrated with salinity treatment (Figures 3c and 3d). This in turn further affects plant growth by reducing the availability of water; i.e. the osmotic potential of soil water. This lesser water and nutrient uptake (or absorption) leads to a decline in the growth rate and therefore the yield production.

Although root-zone salt concentrations were less during Autumn (Figures 2c and 2d), plant growth and yield remained lower than in the Spring. This was mainly due to climatic variation between seasons (Table 3). Biomass productivity is proportional to the level of solar radiation the plant receives. Indeed, Table 3 shows that the level of radiation was considerably less in Autumn (almost half) than in the Spring. This accounts for lower rates of photosynthesis and development. In turn, this leads to a longer growth period with less irrigation water usage during the Autumn.

The ability to produce biomass and yield from pepper plants with higher salinity levels is connected to a marked inhibition of photosynthesis as shown by Chartzoulakis and Klapaki (2000); as well as Bethke and Drew (1992). Chartzoulakis and Klapaki (2000) demonstrated a partial closure of stomata (i.e. decline in stomata conductance measurements at higher salinity levels) which caused a reduction in photosynthesis at higher salinity levels. On the other hand, Bethke and Drew (1992) concluded that reductions in photosynthesis are connected with concentrations of both Na+ and Cl- (biochemical levels) in the leaf tissue.

When analysing variance in plant parameters – plant height; LAI; and dry biomass of vegetative elements and roots – there are indications of significant differences ($p<0.05$) as evidenced by the four salinity-level treatments. Likewise, when we analyse variance in the yield, there are indications of significant differences ($p<0.05$) across the four salinity-level treatments and irrigation regimes in both seasons (except for Autumnal cases with salinity treatments of 1.0 dS m^{-1} and 2.5 dS m^{-1}).

5.4. Irrigation water productivity

Irrigation water-productivity (IWP) was used to evaluate the effects of irrigation regimes and salinity treatments on the pepper crop. It is calculated by using the following equation:

$$IWP = \frac{Y}{IW} \qquad (4)$$

where Y is the absolute actual yield (kg m^{-2}) and IW is the irrigation water applied in different irrigation regimes (m^3 m^{-2}). The calculated water-productivity (IWP) is shown in Figure 4e. There are significant differences ($p<0.05$) in the irrigation water-productivity (IWP) due to the four salinity level treatments and irrigation regimes in both seasons. In all cases, the greatest productivity was achieved in Case 1 (K_{cp} = 0.50, 1.0 dS m^{-1}) control experiments, while the least productivity was exhibited in Case 16 (K_{cp} = 1.25, 6.0 dS m^{-1}) experiments – which had the greatest amount of water added and the highest level of salinity. It can be seen, therefore, that productivity was affected by salinity levels, irrigation regimes, and the season itself. In lower salinity cases, greater productivities were attained in Spring, while in higher salinity cases almost similer productivities were attained in both seasons. Among the experiments, irrigation cases with K_{cp} = 0.50 gave higher irrigation water-productivity due to optimum moisture in the soil. It can be seen from the yield and IWP results (Figures 4d and 4e) that the crop water requirement was possibly fulfilled in K_{cp} = 0.50 irrigation cases (50% of Class A pan-evaporation) – which cannot be considered a real deficit in terms of the irrigation level.

5.5. Salinity response function

Mean and median values for root-zone electrical conductivity of the saturated soil-paste extract (EC_e) over the two cropping seasons for ONUR F1 experimental cases for root-zone layer 0–60 cm are listed in Table 4. It can be seen that the median values and mid-season values are almost similar. Therefore, the mean or mid-season value of the soil salinity can be considered as the mean reflection of soil salinity for the entire cropping season.

The relative yield data (Y_r) of all experiments across both seasons are plotted against the mean value of soil salinity (EC_e) in Figure 5. It shows that relative yield data decreases with soil salinity (EC_e) and that this data reasonably falls into a curve regardless of salinity treatments, irrigation regimes or season. The parameters b, EC_t, EC_o, s and EC_{50} of the crop-yield response function equations (1) and (2) are calibrated along with the salinity tolerance index (*ST Index*) in equation (3) and given at Table 5. The correlation coefficients (R^2) are also listed here. The fitted threshold-slope linear function and sigmoidal-shape function curve is also shown in Figure 5. Both functions fitted the data reasonably well with single representation and good correlation.

Table 6 lists literature parameter values for the threshold-slope linear response function for peppers developed using soil salinity (EC_e) as their function variable. The differences in the threshold-slope linear response function parameters between studies can be due to variety of pepper; growing environment (including soil properties); irrigation method/amount; fertilizer application; climatic variation between study regions; as well as season. Figure 5 shows that the calibrated threshold-slope linear response function placed the ONUR F1 and ADA F1 pepper varieties in the moderately salt-sensitive category along with other studies in Table 6. Although the measured fresh yield (Figure 4d) clearly shows considerable differences in salinity response between seasons, Figure 5 shows that the salinity response of pepper varieties ONUR F1 and ADA F1 can be well represented by a single threshold-slope linear function or sigmoidal-shape function in terms of soil salinity (EC_e) within our experimental range regardless of season.

6. Conclusions

In this study, the effects of different irrigation regimes and salinity treatments using a drip irrigation system on sweet pepper (Capsicum annuum L.) were investigated. Experiments were conducted in a greenhouse in the Mediterranean coast at Antalya, Turkey during the Spring and Autumn growing seasons. Two varieties of sweet pepper were used (ONUR F1 and ADA F1) with four irrigation regimes subjected to four salinity treatment levels. Four irrigation regimes were considered using Class A pan-evaporation data multiplied by the pan coefficient (K_{cp}) of 0.50, 0.75, 1.00 and 1.25 respectively – and subjected to four salinity treatments with irrigation water electrical conductivities (EC_{iw}) of 1.0, 2.5, 3.5 and 6.0 dS m^{-1}.

The study showed that increased levels of salinity induced a high level of salt accumulation within the pepper plants' root-zone, while increased saline irrigation increased the size of the affected layer within the root-zone. The total amount of irrigated water usage was higher in Spring than the Autumn. This was due to climatic variability and also reflected for salt accumulation within the root-zone. In all salinity treatment experiments, higher irrigation water-use productivities were achieved under irrigation regimes with a K_{cp} of 0.50. Here, the crop water requirements appeared to have been fulfilled. Both pepper varieties (ONUR F1 and ADA F1) largely performed in a similar manner throughout the season; except in terms of vegetative biomass production. Vegetative growth, biomass production and yield were all significantly lower in cases of higher level salinity treatment. This was true in both seasons. The study also highlighted considerable variations in fresh pepper productivity between the seasons: their rate of decrease corresponding with increases in salinity-stress due to climatic variation.

The calibrated threshold-slope linear salinity response function for both seasons (a threshold of 1.43 dS m^{-1} and a decreasing slope of 11.1%) showed that the ONUR F1 and ADA F1 sweet pepper varieties are moderately sensitive to salt and can be well represented by a single function in terms of soil salinity EC_e regardless of season. However, there are considerable differences in fresh yield from season to season. Salinity response can also be well represented by the sigmoidal-shape function within our experimental range regardless of season. Overall, this study demonstrates that for pepper crops irrigated with saline water, pepper growers must take into account both the salinity response function and productivity for the season with appropriate irrigation regime.

Acknowledgements

This research work was financially supported by the Scientific Research Fund of Cukurova University, Adana, Turkey (Project no: CUBAP-14), the European Commission under the Seventh Framework Programme (Project: Sustainable water use securing food production in dry areas of the Mediterranean region (SWUP-MED); Grant Agreement No. KBBE-2008-

212337) and the Centre for Ecology and Hydrology, Wallingford, UK.

References

Aktas H., Abak K., Cakmak I. 2006. Genotypic variation in the response of pepper to salinity. *Scientia Horticulturae*, **110**: 260–266.

AlHarbi A.R., Saleh A.M., Al-Omran A.M., Wahb-Allah M.A. 2014. Response of bell-pepper (*Capsicum annuum L*.) to salt stress and deficit irrigation strategy under greenhouse conditions. *Acta Horticulturae*, **1034**: 443-450.

Allen R.G., Pereira L.S., Raes D., Smith M. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements, *FAO Irrigation and Drain Paper No. 56*, Rome, Italy, 300pp.

Arslan A., Majid G.A., Abdallah K., Rameshwaran P., Ragab R., Singh M., Qadir M. 2015. Evaluating the productivity potential of chickpea, lentil, and faba bean under saline water irrigation systems. *Irrigation and Drainage*, doi: 10.1002/ird.1912.

Ayers R., Westcot W., 1985. Water quality for agriculture. *Irrigation and Drainage Paper No. 29*. FAO, Rome, Italy.

Ben-Gal A, Ityel E, Dudley L., Cohen S, Yermiyahu U, Presnov E, Zigmond L, Shani U. (2008) Effect of irrigation water salinity on transpiration and on leaching requirements: A case study for bell peppers. *Agricultural Water Management*, **95**, 587-597.

Bethke, P.C., Drew, M.C., 1992. Stomatal and nonstomatal components to inhibition of photosynthesis in leaves of Capsicum annuum during progressive exposure to NaCl salinity. *Plant Physiology*. 99, 219-226.

Chartzoulakis K, Klapaki G. 2000. Response of two greenhouse pepper hybrids to NaCl salinity during different growth stages, *Scientia Horticulturae*, **86**: 247-2600.

DeWitt D., Bosland P.W. 1993. *The Pepper Garden*. Ten Speed Press, Berkeley, CA.

Huez-López, M.A., A.L. Ulery, Z. Samani, G. Picchioni, R.P. Flynn. 2011. Response of Chile Pepper (Capsicum Annuum L.) to Salt Stress and Organic and Inorganic Nitrogen Sources: II. Nitrogen and Water Use Efficiencies, and Salt Tolerance. Tropical and Subtropical Agroecosystems. **14**:757-763.

Kurunc A., Unlukara A., Cemek B. 2011. Salinity and drought affect yield response of bell pepper similarly. *Acta Agriculturae Scandinavica, Section B – Plant Soil Science*, **61**: 514-522.

Maas E.V. 1993 Testing crops for salinity tolerance. In: Maranville, J.W., BaIigar, B.V., Duncan, R.R., Yohe, J.M. (Eds.), *Proceedings of a Workshop on Adaptation of Plants to Soil Stresses*, l–4 August 1993. INTSORMIL Publication No. 94-2. Univ. of Nebraska, Lincoln, NE, 234-247.

Maas E.V. and Hoffman G.J. 1977. Crop salt tolerance - current assessment. *Journal of Irrigation and Drainage Division*, ASCE, **103**: 115-134.

Nagaz K., Masmoudi M.M., Mechlia N.B. 2012. Effects of deficit drip-irrigation scheduling regimes with saline water on pepper yield, water productivity and soil salinity under arid conditions of Tunisia. *Journal of Agriculture and Environment for International Development*, **106**: 85-103.

Ozkan, B., Kurklu, A., Akcaoz, H. 2004. An input–output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey, *Biomass and Bioenergy,* **26**: 89-95.

Patil, V.C.; Al-Gaadi, K.A.; Wahb-Allah, M.A.; Saleh, A.M.; Marey, S.A.; Samdani, M.S. and Abbas, M.E.; 2014. Use of saline water for greenhouse bell pepper (Capsicum annuum) production. *American Journal of Agricultural and Biological Sciences*, 9, 208-217.

Ragab R. 2015. Integrated Management Tool for Water, Crop, Soil and N Fertilizers: The SALTMED Model. J *Irrigation and Drainage*, **64**. 1-12.

Rameshwaran P., Tepe A., Yazar A., Ragab R. 2013. SALTMED 2013 model application using greenhouse experiment data from Turkey. In: *SWUP-MED Project Final Conference: Sustainable Water Use for Securing Food Production in the Mediterranean Region under Changing Climate*, Agadir, Morocco, 10–15 Mar 2013. 144-149.

Rameshwaran P., Tepe A., Yazar A., Ragab R. 2015a. The effect of saline irrigation water on the yield of pepper: experimental and modelling study. *Irrigation and Drainage*, **64**. 41-49.

Rameshwaran P., Qadir M., Ragab R., Arslan A., Majid G.A., Abdallah K. 2015b. Tolerance of faba bean, chickpea and lentil to salinity: accessions' salinity response functions. *Irrigation and Drainage*, doi: 10.1002/ird.1922.

Sezen S.M., Yazar A., Eker S., 2006. Effect of drip irrigation regimes on yield and quality of field grown bell pepper. *Agricultural Water Management*, **81**: 115-131.

Shannon, M.C. and Grieve, C.M. 1999. Tolerance of vegetable crops to salinity. *Scientia Horticulturae*, **78**, 5-38.

Shao, G.C., Liu, N., Zhang, Z.Y., Yu, S.E., Chen, C.R., 2010. Growth, yield and water use efficiency response of greenhouse-grown hot pepper under time-space deficit irrigation. *Scientia Horticulturae* **126**, 172–179.

Sonneveld C. 1988. The salt tolerance of greenhouse crops. *Netherlands Journal of Agricultural Science*. **36**: 63-73.

Steppuhn, H., van Genuchten, M.T. and Grieve, C.M. 2005a. Root-zone salinity: I. Selecting a product-yield index and response function for crop tolerance. *Crop Science*, **45**: 209-220.

Steppuhn, H., van Genuchten, M.T. and Grieve, C.M. 2005b. Root-zone salinity: II. Indices for tolerance in agricultural crops. *Crop Science*, **45**: 221-232.

Ünlükara, A., Kurunç, A., and Cemek, B. 2015. Green Long Pepper Growth under Different Saline and Water Regime Conditions and Usability of Water Consumption in Plant Salt Tolerance. *Tarım Bilimleri Dergisi*, **21**: 167-176.

van Genuchten, M.Th. 1983. Analyzing crop salt tolerance data: Model description and user’s manual. US Department of Agriculture, Agricultural research service, *US Salinity Laboratory. Research Report No. 120*, USDA-ARS, California, 50p.

Yilmaz, I., Sayin, C., Ozkan, B. 2005. Turkish greenhouse industry: Past, present, and future, *New Zealand Journal of Crop and Horticultural Science*, **33**, 233-240.

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

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

Table 3. Average climatic data over Spring and Autumn cropping seasons.

Parameters	Spring	Autumn
Minimum Temperature (°C)	16.2	9.3
Maximum Temperature (°C)	36.3	27.2
Sunshine (h)	9.4	6.6
Humidity (%)	68.3	53.8
Net Radiation (MJ m^{-2} day^{-1})	12.5	5.8

Table 4. Mean and median values of soil salinity (*EC_e*) over Spring and Autumn cropping seasons for ONUR F1 Experimental Case (number of measurements over Spring cropping season *n*=10; and over Autumn cropping season *n*=11).

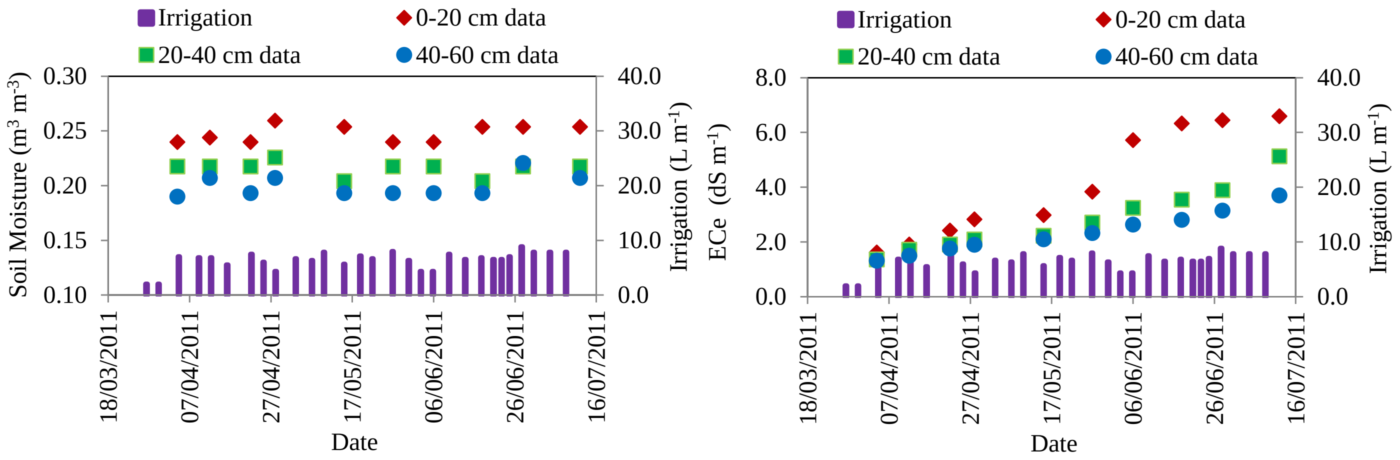
Salinity EC_{iw} (dS m^{-1})	K_{cp} = 0.50		K_{cp} = 0.75		K_{cp} = 1.00		K_{cp} = 1.25	
	Mean EC_e (dS m^{-1})	Median EC_e (dS m^{-1})	Mean EC_e (dS m^{-1})	Median EC_e (dS m^{-1})	Mean EC_e (dS m^{-1})	Median EC_e (dS m^{-1})	Mean EC_e (dS m^{-1})	Median EC_e (dS m^{-1})
Spring cropping season								
1.0	1.41	1.42	1.53	1.51	1.59	1.57	1.79	1.66
2.5	1.79	1.71	2.16	2.12	2.62	2.62	2.85	2.84
3.5	2.01	1.98	2.60	2.54	3.06	2.70	3.61	3.29
6.0	3.22	3.20	4.15	4.05	5.03	5.28	6.20	6.22
Autumn cropping season								
1.0	1.42	1.48	1.53	1.68	1.65	1.77	1.79	1.87
2.5	1.77	1.72	2.19	2.26	2.50	2.70	2.78	3.05
3.5	2.12	2.12	2.66	2.76	2.88	2.99	3.40	3.77
6.0	2.90	3.08	3.73	3.86	4.05	4.45	4.38	5.04

Table 5. The calibrated threshold-slope linear response function parameters b, EC_t and EC_o including salinity tolerance index (EC_{50}) and sigmoidal-shape function parameters s and EC_{50} including salinity tolerance index (*ST Index*).

Season	Threshold-slope linear function					Sigmoidal-shape function			
	b	EC_t (dS m^{-1})	EC_o (dS m^{-1})	EC_{50} (dS m^{-1})	R^2	s	EC_{50} (dS m^{-1})	*ST Index*	R^2
Spring and Autumn	0.111 (11.1%)	1.43	10.41	5.92	0.84	0.16	5.60	6.50	0.82

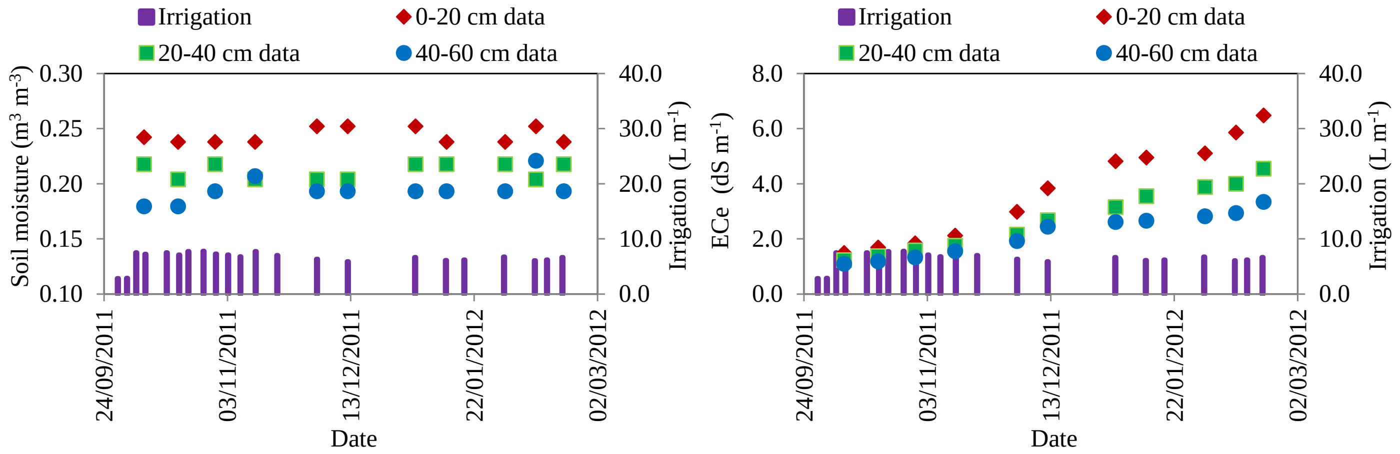
Table 6. Present and literature values for threshold-slope linear response function parameters b and EC_t for pepper based on soil salinity (EC_e).

Values based on soil salinity EC_e	b	EC_t (dS m^{-1})
Present study	0.111 (11.1%)	1.43
Allen *et al.*, (1998) (Upper limit of FAO-56 guideline)	0.120 (12.0%)	1.70
Maas and Hoffman (1977) (Lower limit of FAO-56 guideline)	0.140 (14.0%)	1.50
Sonneveld (1988) – Greenhouse Pepper (Addition of sodium chloride)	0.131 (13.1%)	3.40 - 4.00
Sonneveld (1988) – Greenhouse Pepper (Addition of various salts)	0.126 (12.6%)	3.40 - 4.00
Huez-López *et al.* (2011) – Greenhouse Chile Pepper (with inorganic fertilizer 120 kg ha^{-1})	0.120 (12.0%)	1.44
Huez-López *et al.* (2011) – Greenhouse Chile Pepper (with organic, plant-based fertilizer 120 kg ha^{-1})	0.160 (16.0%)	2.62
Huez-López *et al.* (2011) – Greenhouse Chile Pepper (with organic, plant-based fertilizer 200 kg ha^{-1})	0.100 (10.0%)	2.05
Kurunc *et al.* (2011) – Greenhouse Bell Pepper (with different saline and water regime conditions)	0.109 (10.9%)	1.20
Ünlükara, *et al.* (2015) – Greenhouse Green Long Pepper (with different saline and water regime conditions)	0.070 (7.0%)	1.20



Case 11 soil moisture (m^3 m^{-3}) Case 11 soil salinity EC_e (dS m^{-1})

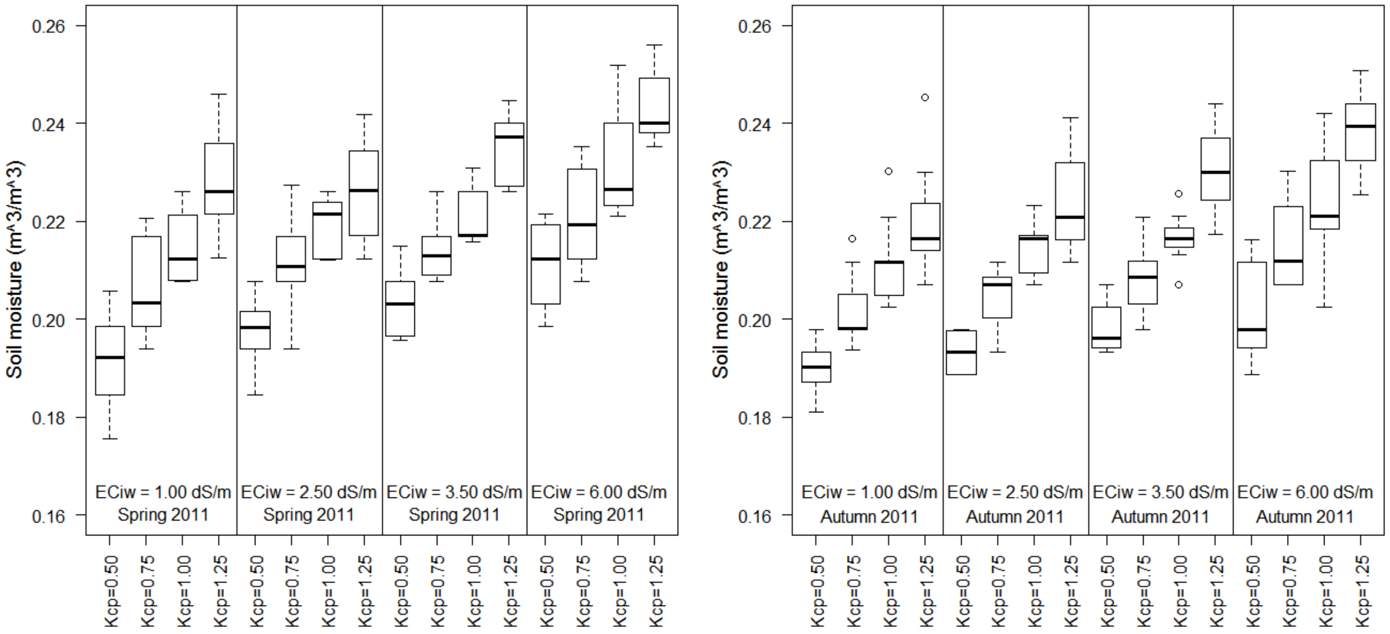
(a) Spring



Case 11 soil moisture (m^3 m^{-3}) Case 11 soil salinity EC_e (dS m^{-1})

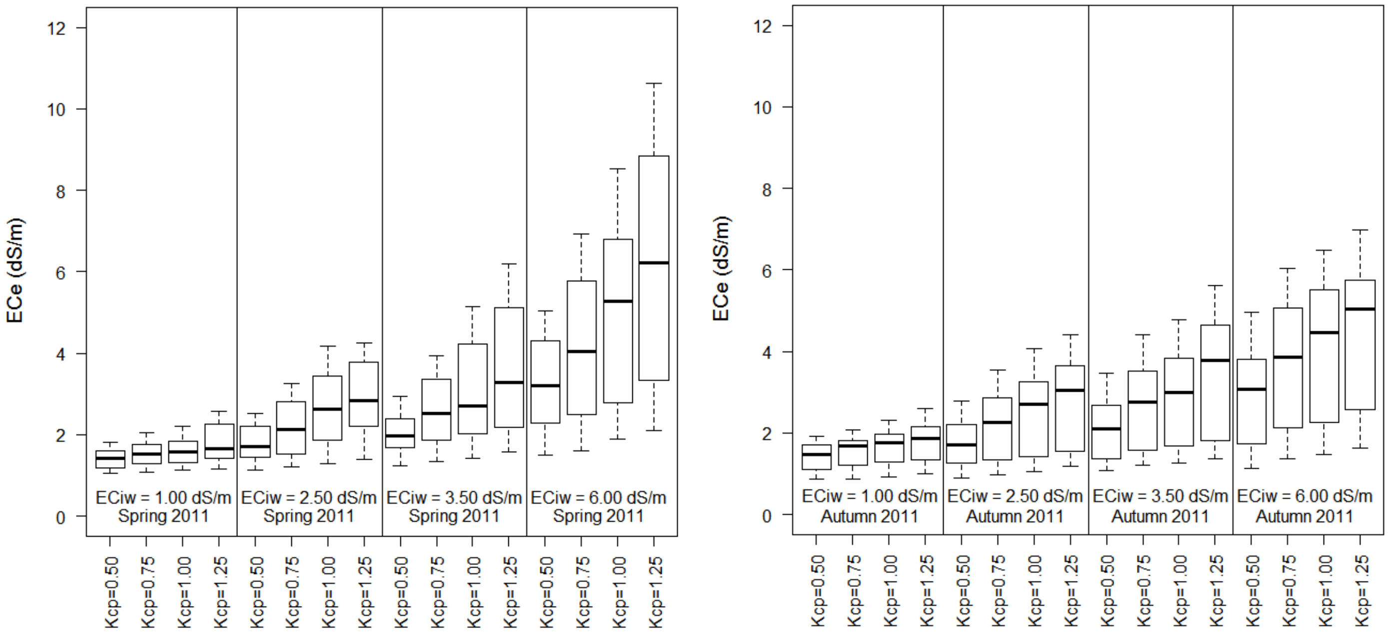
(b) Autumn

Figure 1 Measured root zone soil moisture and salinity (EC_e) at 0–20 cm, 20–40 cm and 40–60 cm layers during cropping seasons (a) Spring and (b) Autumn for ONUR F1 Experimental Case 11.



(a) Spring measured soil moisture during growing season

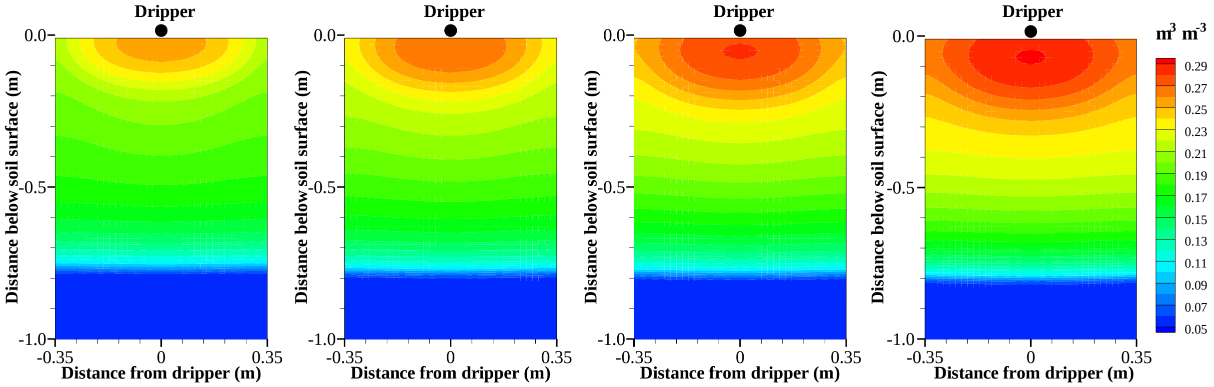
(b) Autumn measured soil moisture during growing season



(c) Spring measured root-zone soil salinity (EC_e) during growing season

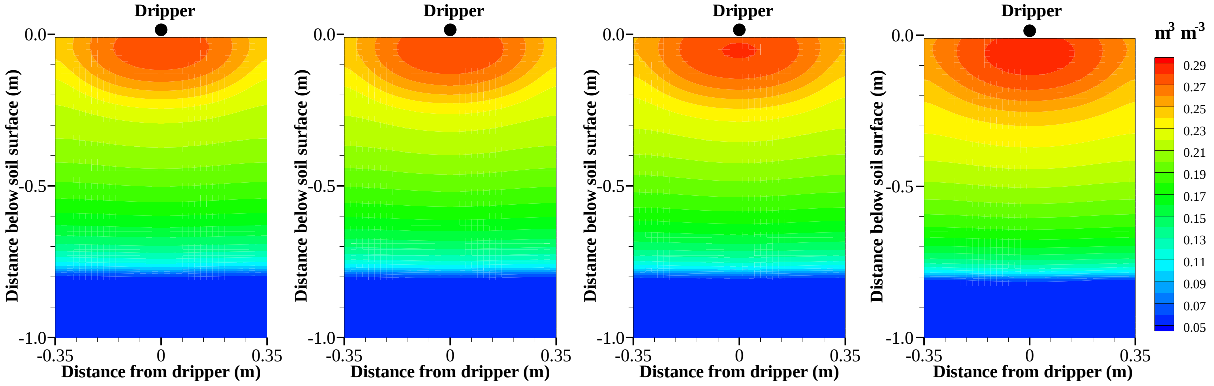
(d) Autumn measured root zone soil salinity EC_e during growing season

Figure 2. Variation of measured soil moisture and root-zone soil salinity (EC_e) for 0–60 cm layer over the growing season for each irrigation regime in Spring and Autumn are summarised by box and whisker plots showing median (thick horizontal line) and interquartile range (box) data spread up to 1.5 times the interquartile range beyond the box (dashed line) and outliers (empty circles – if any)



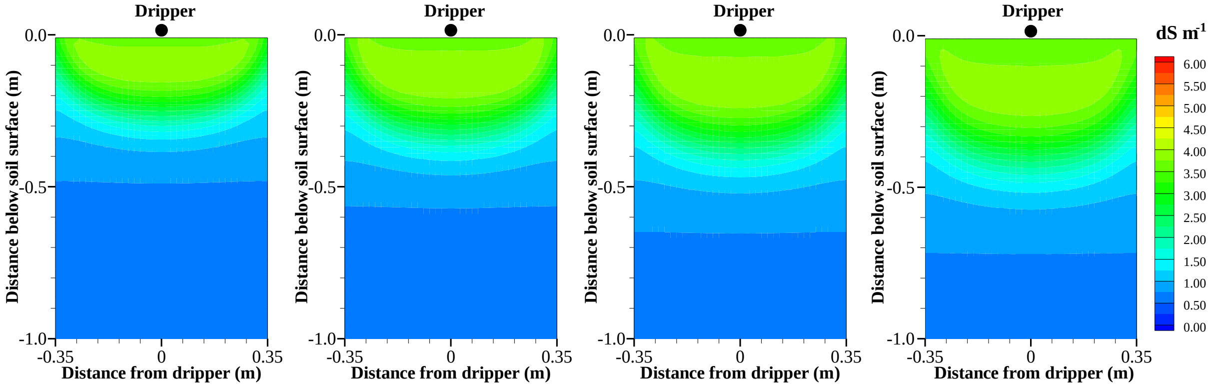
Case 9, K_{cp}=0.50 Case 10, K_{cp}=0.75 Case 11, K_{cp}=1.00 Case 12, K_{cp}=1.25

(a) Soil moisture (m^3 m^{-3}) with EC_{iw}=3.5 dS m^{-1}



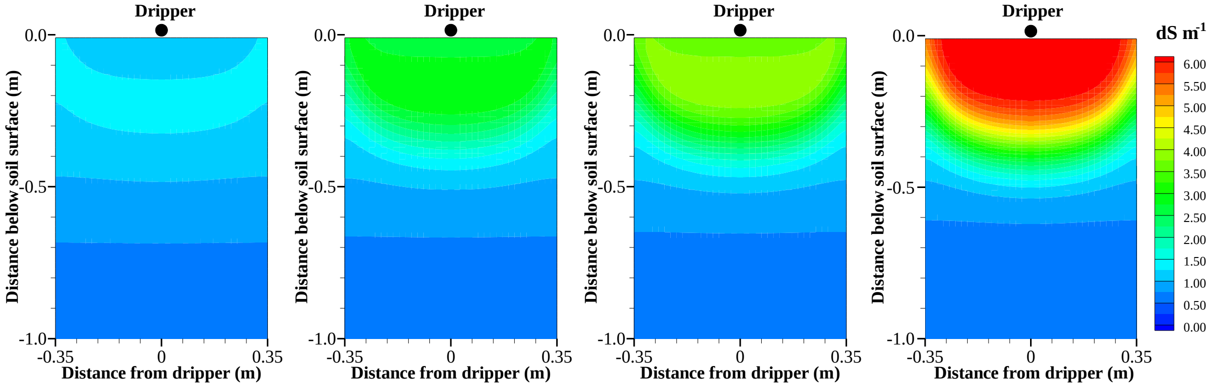
Case 3, EC_{iw}=1.0 dS m^{-1} Case 7, EC_{iw}=2.5 dS m^{-1} Case 11, EC_{iw}=3.5 dS m^{-1} Case 15, EC_{iw}=6.0 dS m^{-1}

(b) Soil moisture (m^3 m^{-3}) with K_{cp}=1.00



Case 9, K_{cp}=0.50 Case 10, K_{cp}=0.75 Case 11, K_{cp}=1.00 Case 12, K_{cp}=1.25

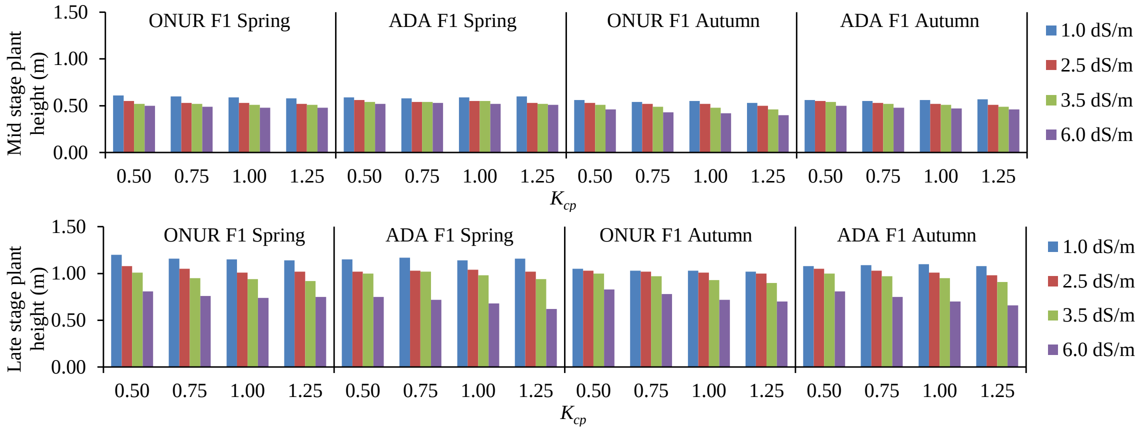
(c) Soil salinity with EC_{iw}=3.5 dS m^{-1}



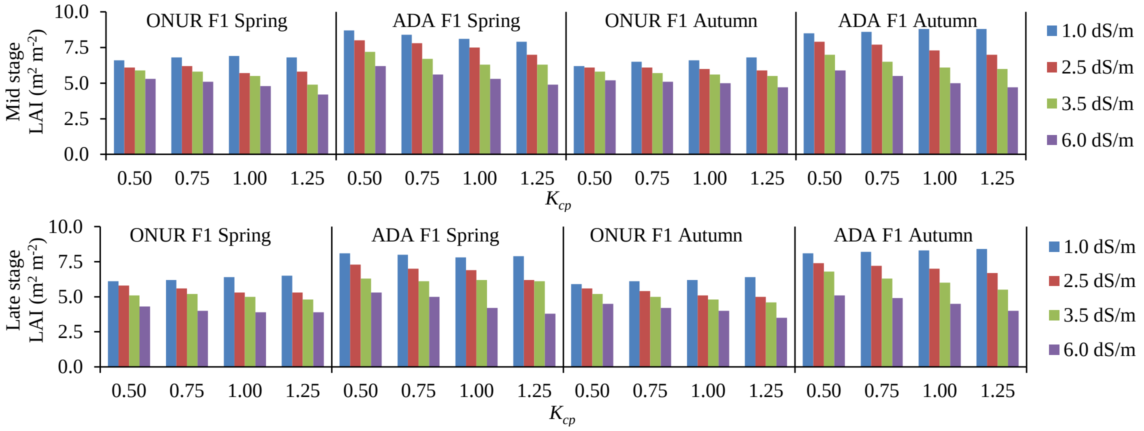
Case 3, EC_{iw}=1.0 dS m^{-1} Case 7, EC_{iw}=2.5 dS m^{-1} Case 11, EC_{iw}=3.5 dS m^{-1} Case 15, EC_{iw}=6.0 dS m^{-1}

(d) Soil salinity with K_{cp}=1.00

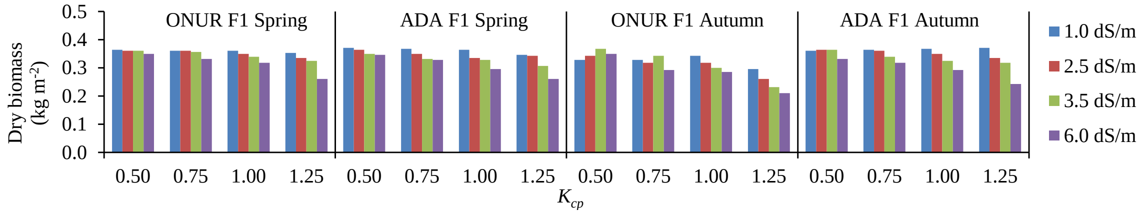
Figure 3 Contour plots showing the modelled soil moisture and soil salinity at mid-season of the Spring cropping season (55th day) for ONUR F1 Experimental Cases 9, 10, 11 and 12 with ECiw=3.5 dS m^{-1} and Cases 3, 7, 11 and 15 with K_{cp}=1.00.



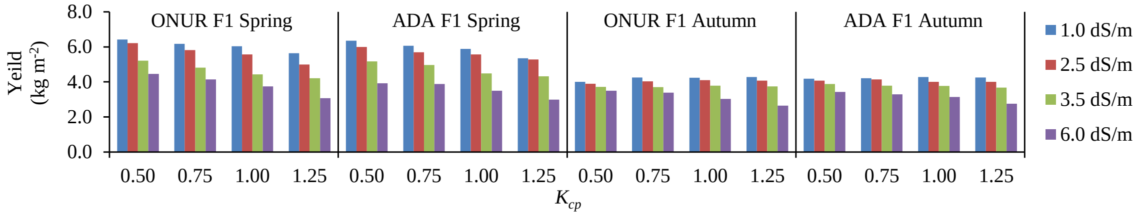
(a) Plant heights in mid and late stages



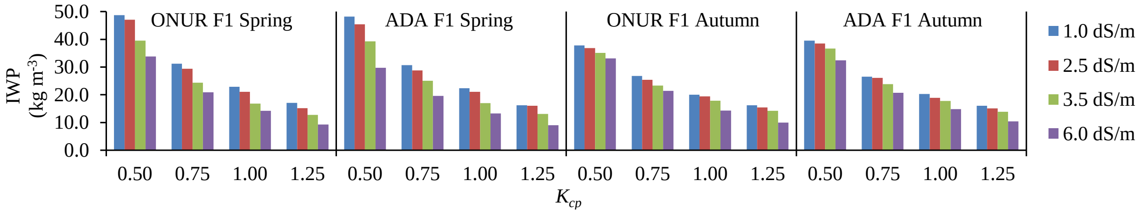
(b) Leaf Area Index (LAI) in mid and late stages



(c) Dry biomass of vegetative elements and roots (excluding pepper fruits)

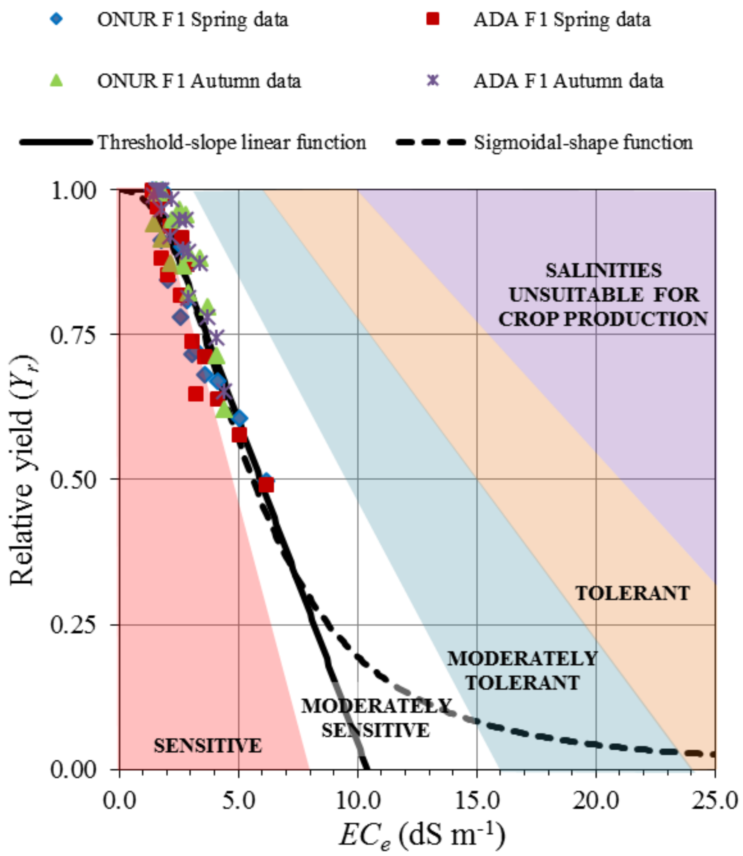


(d) Fresh pepper yield



(e) Irrigation water productivity (IWP)

Figure 4. Measured (a) plant heights in mid and late stages, (b) (Leaf Area Index (LAI) in mid and late stages, (c) dry biomass of vegetative elements and roots (excluding pepper fruits), (d) fresh pepper yield and (e) Irrigation water productivity (IWP) for the spring and autumn cropping seasons with ONUR F1 and ADA F1 varieties.



Threshold-slope linear function: $Y_r = 1 - 0.111(EC_e - 1.43)$

Sigmoidal-shape function: $Y_r = \frac{1}{\left[1+(EC_e/5.60)^{e^{(0.16\times5.60)}}\right]}$

Figure 5. Calibrated threshold-slope linear salinity response function and sigmoidal-shape salinity response function.