*Journal of Plant Nutrition*, 37:595–610, 2014
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ISSN: 0190-4167 print / 1532-4087 online
DOI: 10.1080/01904167.2013.867985

# INTERACTIVE EFFECTS OF SALINITY AND N ON PEPPER (*CAPSICUM ANNUUM L.*) YIELD, WATER USE EFFICIENCY AND ROOT ZONE AND DRAINAGE SALINITY

**G. Duygu Semiz,[1] Donald L. Suarez,[2] Ali Ünlükara,[3] and Engin Yurtseven[1]**
[1]*Department of Farm Structures and Irrigation, Agricultural Faculty, Ankara University, Turkey*
[2]*USDA-ARS, U.S. Salinity Laboratory, Riverside, California*
[3]*Department of Biosystem Engineering, Agricultural Faculty, Erciyes University, Kayseri, Turkey*

□ *The aim of this study was to determine the salt tolerance of pepper (*Capsicum annuum *L.) under greenhouse conditions and to examine the interactive effects of salinity and nitrogen (N) fertilizer levels on yield. The present study shows the effects of optimal and suboptimal N fertilizer levels (270 kg ha*$^{-1}$ *and 135 kg ha*$^{-1}$*) in combination with five different irrigation waters of varying electrical conductivity (EC) (*$EC_{iw} = 0.25$, *1.0, 1.5, 2.0, 4.0, and 6.0 dS m*$^{-1}$*) and three replicates per treatment. At optimal N level, yield decreased when the irrigation water salinity was above* $EC_{iw}$ *2 dS m*$^{-1}$*. At the suboptimal N level, a significant decrease in yield occurred only above* $EC_{iw}$ *4 dS m*$^{-1}$*. At high salinity levels the salinity stress was dominant with respect to yield and response was similar for both N levels. Based on the results it can also be concluded that under saline conditions (higher than threshold salinity for a given crop) there is a lesser need for N fertilization relative to the optimal levels established in the absence of other significant stresses.*

**Keywords:** irrigation, water quality, soil salinity, pepper (*Capsicum annuum* L.), nitrogen fertilization, yield

## INTRODUCTION

One of the most important inputs for agricultural production under arid climates is irrigation water. Increasing urban water demands in arid

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Received 24 May 2011; accepted 2 January 2012.

Address correspondence to G. Duygu Semiz, Department of Farm Structures and Irrigation, Agricultural Faculty, Ankara University, Ziraat Fakültesi, Tarımsal Yapılar ve Sulama Bölümü, 06190 Ankara, Turkey. Email: kesmezduygu@gmail.com

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regions, due in part to increasing population, makes high quality water less available for irrigation (Suarez, 2001). Competitive demand for water among urban, industrial, and agricultural sectors leads researchers to focus on using marginal waters for agricultural production. Alternative cultural techniques are being developed to reduce the adverse effects of salinity on crop production, such as breeding salinity resistant plants (Yang et al., 2005; Zhu et al., 2000; Singla-Pareek et al., 2003), utilizing grafting techniques on vegetables (Estan et al., 2005; Santa-Cruz et al., 2002; Edelstein et al., 2005), applying growth regulators (Abd El-Samad Hamdi et al., 2004; Abraham et al., 2003; Sakamoto and Murata, 2001), and controlling soil salinity by more uniform applications of water.

There are numerous studies on the salt tolerance of pepper but the manner in which the experiments were conducted makes comparisons difficult. Bernstein and Pearson (1954) in a solution culture study reported that yield reduction of pepper occurred at a saturation extract electrical conductivity ($EC_e$) value of 3 dS $m^{-1}$, with the values calculated from the solution composition and an assumed fixed relation between $EC_e$ and solution EC. Forges (1970) reported a yield decline for $EC_e$ above 2 dS $m^{-1}$ and Fernandez et al. (1977) at a calculated EC of 1.3–2.9, depending on variety, however only sodium chloride (NaCl) was added to the salinizing solution, the treatments were not replicated, and the $EC_e$ was reported based on measurement of EC in 1:5 extract taken from the top 25 cm of soil.

Akaş et al. (2006) reported genotypic variation in the salt accumulation and leaf damage of peppers growth in 150 mM NaCl for 10 d, suggesting that yield differences would likely occur as well. In a hydroponic study with a control EC of 2 dS $m^{-1}$, Navarro et al. (2002) found reduced yield with addition of salt at the first salt addition level (3 dS $m^{-1}$) and with losses being greater with addition of NaCl as compared to sodium sulfate ($Na_2SO_4$) salts. Using a generalized relation of solution to saturation extract, these studies suggest that yield declines when the EC of the saturation extract is less than 1.5 dS $m^{-1}$. Similarly, Chartzoulakis and Klapaki (2000) obtained an intercept of EC = 1.8 dS $m^{-1}$ in solution using the Maas and Hoffman model (1977) in an experiment with two varieties of pepper in a greenhouse sand culture experiment with addition of NaCl salts. Converting these data to saturation extract values would result in an intercept of $EC_e$ = 0.9 dS $m^{-1}$.

These published data sets are almost always with NaCl salts and were either solution culture or soil data reported for average root zone salinity. Information is lacking on the response of pepper yield to a mixed salt solution, mimicking natural systems, as well as determination of salinity in a soil system with response to salinity of the soil water weighted for plant water uptake (rather than average soil root zone salinity or irrigation water salinity).

There is an extensive number of plant nutrition studies from all over the world, but the studies were mostly conducted to determine best management practices under non-saline conditions. Some studies have been conducted to determine if certain nutrients have alleviative effects on salinity tolerance (Bernstein et al., 1974; Kafkafi et al., 1982; El-Sidding and Ludders, 1994). Some studies indicated a positive effect of fertility on salt tolerance while some reported that there was no alleviative effect on salt tolerance. Even studies of the grain crops have resulted in opposite conclusions. Soliman et al. (1994) reported that in saline soil, nitrogen (N) and phosphorus (P) have a positive effect on growth of wheat. However, in another similar study, Esmaili et al. (2008) did not find any positive effects of these two fertilizers on sorghum. Gomez et al. (1996) found a positive yield response for pepper at all three salinity levels by increasing nutrient N from 2 to 15 mM in a solution culture. However the effect of N on relative yield was not clear. The first salinity level above the control (25 mM NaCl) had a lower relative yield at lower N and with subsequent increases in salinity it had a higher relative yield.

Most salinity-fertilizer studies were conducted in soils that have insufficient nutrition (Grattan and Grieve, 1999). Inadequate N is often the growth-limiting nutritional stress factor in field soils. Consequently, addition of N usually improves plant growth and yield regardless of whether the crop is salt-stressed or not (Grattan and Grieve, 1999). Hence a positive yield response to addition of N to saline soils need not indicate an ameliorative response of N to salinity.

The relations between salinity and mineral nutrition are extremely complex and not well understood. Several studies on salinity and N nutrition aimed at clarifying these relationships have been conducted using sand or solution cultures which are simpler to interpret than soil salt systems (Irshad et al., 2002).

The objectives of this study are to; 1) Determine pepper (*Capsicum annuum* L.) salt tolerance based on water uptake weighted soil salinity data (rather than on irrigation water salinity or average soil salinity), 2) Evaluate the response of pepper to optimal and a reduced, suboptimal N fertilizer level under increasing saline conditions and 3) Examine the water use efficiency of pepper as related to salt stress. We examine the effect of salinity and N on mineral content, fruit yield, biomass production, ion composition in the plant, water consumption, and water use efficiency.

## MATERIALS AND METHODS

Containers were filled with 9 kg of air-dried and sieved (4 mm) soil. The experimental soils were obtained from the fields of the Agricultural Research Station of Ankara University. The soil texture is as follows; 47.3% sand, 17.5%

**TABLE 1** Chemical and physical properties of experimental soil

| Bulk density ($g\ cm^{-3}$) | pH | EC ($dS\ m^{-1}$) | P mmol ($kg^{-1}$) | K mmol ($kg^{-1}$) | N mmol ($kg^{-1}$) | Org. mat.(%) | Sat. per. (%) |
|---|---|---|---|---|---|---|---|
| 1.24 | 7.69 | 0.4 | 1.25 | 10.0 | 107 | 1.06 | 49.1 |
| Texture | Sand % | Clay % | Silt % | $CaCO_3$, % | Field Capacity % | Wilting point % | |
| Sandy Clay Loam | 47.3 | 35.2 | 17.5 | 10.69 | 24 | 19 | |

silt, and 35.2% clay, expressed as mass ($g\ g^{-1}$) (Table 1). The soil water contents at field capacity (i.e., at a pressure head of −33 kPa) and wilting point (i.e., a pressure head of -1500 kPa) were measured with a pressure plate apparatus (Soil Moisture Equipment Co., San Francisco, CA, USA) (Blake and Hartge, 1986). The particle-size distribution was determined by the hydrometer method (Gee and Bauder, 1986). The organic matter content was obtained by a modified method of Walkley and Black (Jackson, 1958). One plant was placed in each container (pot) in order to simulate a realistic field planting density and to avoid additional stress for plants. The experimental design was a randomized factorial with 3 replications in a greenhouse environment. Five different waters of varying EC were utilized ($S_0 = 0.25\ dS\ m^{-1}$, $S_1 = 1.0\ dS\ m^{-1}$, $S_{1.5} = 1.5\ dS\ m^{-1}$, $S_2 = 2.0\ dS\ m^{-1}$, $S_4 = 4.0\ dS\ m^{-1}$ and $S_6 = 6.0\ dS\ m^{-1}$) along with two N fertilizer levels ($N_{SO} = 135\ kg\ ha^{-1}$ and $N_O = 270\ kg\ ha^{-1}$). The reported recommendations of N level for optimal production of pepper vary. For example, 180 $kg\ ha^{-1}$ N (Hedge, 1989), 203 $kg\ ha^{-1}$ (Neary et al., 1995) and 252 $kg\ ha^{-1}$ (Hartz et al., 1993). Thus the present 135 $kg\ ha^{-1}$ N treatment is considered a suboptimal N level and 270 $kg\ ha^{-1}$ treatment optimal. Irrigations were performed at 3–4 day intervals. Evapotranspiration (ET) was determined by weighting each pot. At the beginning of the study, the weight of each pot at field capacity was known, thus we were able to calculate ET based on the weight lost between consecutive irrigations (Ünlükara et al., 2008a, 2008b). The amount of irrigation water to be applied was calculated as follows:

$$AW = \frac{\frac{(W_{FC} - W_{ac})}{\rho_w}}{1 - LF} \tag{1}$$

where, AW is applied water (L), $W_{fc}$ and $W_{ac}$ are the weight of each pot at field capacity and the weight of each pot just before irrigation (g), respectively, $\rho_w$ unit weight of water (1000 $g\ L^{-1}$) and LF is the leaching fraction, where LF is defined as the volume of water drained divided by the volume of water applied. We utilized a value of 0.3 as the LF target. Thus each pot received a different quantity of water based on actual water consumption during the previous time interval, in order to maintain the target LF.

Previous studies have demonstrated that the actual ET ($ET_a$) is dependent on salinity (Yurtseven et al. 2005, Ünlükara et al. 2008a, 2008b). Irrigations were performed manually. Drainage waters were collected for measurement of volume and electrical conductivity ($EC_d$).

Urea, potassium nitrate ($KNO_3$) (75 kg $ha^{-1}$), and triple-super-phosphate (37.5 kg $ha^{-1}$) were applied to each pot. The N source from the $KNO_3$ was taken into consideration and applied urea N levels were adjusted accordingly. Consequently, N application consisted of 0.73 g $pot^{-1}$ $KNO_3$ and 0.88 g $pot^{-1}$ urea for 135 kg $ha^{-1}$ ($N_{SO}$) treatment and 0.73 g $pot^{-1}$ $KNO_3$ and 1.76 g $pot^{-1}$ urea for 270 kg $ha^{-1}$ ($N_O$) treatment. Saline waters were prepared by mixing calcium chloride ($CaCl_2$) + NaCl with Ankara municipal tap water such that calcium (Ca) = magnesium (Mg) on a $mmol_c$ $L^{-1}$ basis. The sodium adsorption ratio {SAR; defined as $Na/[(Ca + Mg)/2)]^{0.5}$ where concentrations are expressed in $mmol_c$ $L^{-1}$} values of all treatments were less than 1.0. Irrigation waters were stored in 220 L containers. The 'Bağcı Çarliston' cultivar of pepper plant was used in this study. This is the most common pepper cultivar and is widely consumed as a fresh vegetable in Turkey.

At the end of the experiment fruit yield (fresh weight), total biomass and $ET_a$ (actual ET) were measured and recorded and leaves analyzed for ash percent, potassium (K), sodium (Na), chloride (Cl), Ca and Mg content. The $EC_e$, the EC of the saturated extract (U.S. Salinity Laboratory Staff, 1954) of the container soils, $EC_d$ the EC of the drainage water, and volume of the drainage water were also determined.

Dry (oven-dried at 70°C) weights were measured for harvested fruits. The dried fruit samples from each container were ground in a mill with a 0.5-mm sieve and then analyzed for mineral content. At the end of the experiment, the plants were cut at 1 cm above the soil surface. Vegetative fresh and dry weights (oven-dried at 70°C to a constant weight) were obtained for each replication. Soil samples taken from each pot were air dried and crushed to pass through a 2-mm screen. Saturated soil pastes were prepared, equilibrated in the laboratory for 24 hours, and then saturation extracts were taken and $EC_e$ measured. The EC of the drainage water was measured as soon as the drainage flow under the containers ceased.

To determine leaf ion composition, undamaged leaves were collected at harvest. These samples were washed first with tap water and then deionized water, then oven dried at 60°C and ground. The 0.500 g ground samples were ashed by heating in a muffle furnace at 500°C for 5 h, then dissolved in 5 mL of 2 M nitric acid ($HNO_3$), and finally diluted to 25 mL with deionized water (Kacar and İnal, 2008). Extracts were filtered and stored in plastic containers until analyzed. Potassium and Na were analyzed by flame photometry, Ca and Mg by ethylenediaminetetraacetic acid (EDTA) titration, and Cl by silver nitrate ($AgNO_3$) titration (US Salinity Laboratory Staff, 1954). Statistical analyses of the results were carried out with SPSS 9.05

(IBM, Armonk, NY, USA). One way analysis of variance (ANOVA) test for variance analyses and Duncan Multiple Range Test for testing of the means (Duncan, 1955).

## RESULTS

### Soil Water Salinity and Drainage Water

Plants respond to the salinity of the water taken up by the plant rather than irrigation water salinity. The soil water salinity depends on the irrigation water volume and salinity, volume of rain, and crop water uptake. Calculation of the soil water salinity is thus most relevant to plant response to salinity and salt tolerance data should be reported in these terms rather than irrigation water salinity.

Soil salinity has been reported in different ways with various assumptions. The method proposed by Ayers and Westcot (1985) to calculate soil water salinity consists of dividing the root zone into quarters and calculating the water composition at the bottom of each quarter from the irrigation water EC and a concentration factor based on the overall leaching fraction (assuming that the water uptake in the 4 quarters is 0.4, 0.3, 0.2, and 0.1, respectively, with depth) This method then utilizes the average of the estimated salinity in the 4 quarters to calculate an average root zone salinity, and assumes that plants respond to the average root zone salinity.

The Ayers and Westcot (1985) method is considered to overestimate salinity experienced by the plant since it considers average root zone salinity rather than the salinity of the water taken by the plant, and does not consider the change in ET with increasing salinity (Suarez, 2010). Alternatively, it can be considered that the plant responds to the salinity of the water extracted from the soil rather than average soil water salinity, so the soil salinity can be weighed according to the corresponding water uptake factors.

Figure 1 shows the EC of the soil water ($EC_{sw}$), average EC of the soil extracts at the end of the experiment ($EC_e$), and mean EC of the drainage water ($EC_d$) of the various treatments. The $EC_d$ is lower than $EC_{sw}$, for all treatments, suggesting that there was some macropore flow in the containers (in essence, the irrigation water flowing in large pores directly to the bottom of the container). It was considered be the most accurate representation of EC experienced by the plants is that calculated from the soil water salinity, based on irrigation water composition, quantities of water applied, and measured water consumption.

Shown in Table 2 are the estimates of the salinity related to plant response using different calculation methods. The first calculation [Ayers and Westcot (A&W) assuming constant ET] is based on the ET of the non-stressed plant water consumption and the actual water applications. We calculated the

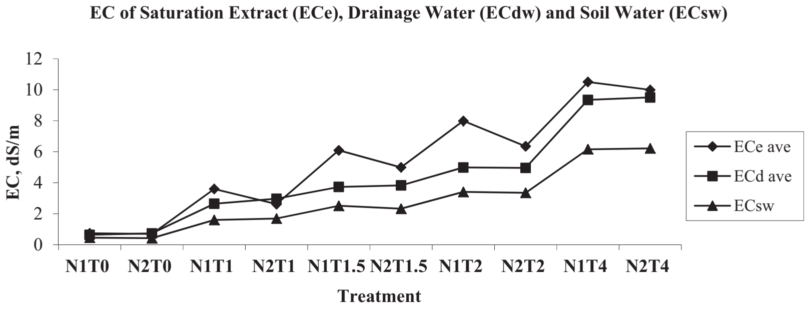

**FIGURE 1** Electrical conductivity of saturation extract, drainage water and soil water.

leaching fraction and average soil salinity using the method described by Ayers and Westcot (1985). The next method, labeled 'A&W with treatment ET', differs from traditional calculations in that we utilized the actual water budget data for each container, thus the applied water was adjusted for the reduction in ET due to plant stress. In this manner, an essentially constant leaching fraction (LF) could be achieved. This method still calculates average root zone salinity, similarly to Ayers and Westcot (1985). As expected 'A&W with treatment ET' with average root zone salinity calculated from column water budget data gives lower salinity values than the traditional average root zone method at higher salinity levels of irrigation water where reduction in ET occurs.

The salinity calculated with 'Water uptake weighted soil salinity with treatment ET' uses the actual water budget data and calculates a water uptake weighted salinity. In this manner the water uptake factors (0.4, 0.3, 0.2, and 0.1) are consistent with the values used to calculate the salinity with depth.

**TABLE 2** Soil water salinity, dS m$^{-1}$

| Treatment | A&W assuming constant ET | A&W with treatment ET | Water uptake weighted soil salinity with treatment ET |
|---|---|---|---|
| $N_{SO}S_0$ | 0.472 | 0.472 | 0.453 |
| $N_OS_0$ | 0.489 | 0.489 | 0.418 |
| $N_{SO}S_1$ | 1.80 | 1.83 | 1.60 |
| $N_OS_1$ | 1.96 | 1.98 | 1.69 |
| $N_{SO}S_{1.5}$ | 2.60 | 2.94 | 2.51 |
| $N_OS_{1.5}$ | 3.14 | 2.63 | 2.33 |
| $N_{SO}S_2$ | 3.76 | 4.00 | 3.41 |
| $N_OS_2$ | 4.76 | 3.91 | 3.35 |
| $N_{SO}S_4$ | 12.3 | 6.96 | 6.16 |
| $N_OS_4$ | 10.6 | 7.05 | 6.22 |
| $N_{SO}S_6$ | $\infty$ | 10.3 | 9.18 |
| $N_OS_6$ | $\infty$ | 10.3 | 9.16 |

**TABLE 3** Fresh fruit yield as related to salinity

| Treatment | $EC_{iw}$ | $EC_{sw}$ | Yield (g $plant^{-1}$) |
|---|---|---|---|
| $N_{so}$ (135 kg $ha^{-1}$) | 0.25 | 0.45 | 94.4 d[1] |
| | 1.00 | 1.60 | 82.0 d |
| | 1.50 | 2.51 | 86.8 d |
| | 2.00 | 3.41 | 85.8 d |
| | 4.00 | 6.16 | 54.6 f |
| | 6.00 | 9.18 | 0.00 g |
| $N_o$ (270 kg $ha^{-1}$) | 0.25 | 0.42 | 119. bc |
| | 1.00 | 1.69 | 143. a |
| | 1.50 | 2.33 | 135 ab |
| | 2.00 | 3.35 | 105 cd |
| | 4.00 | 6.22 | 61.0 ef |
| | 6.00 | 9.16 | 20.0 g |

[1] Where different letters state significant differences at $P < 0.05$.

This water uptake weighted soil salinity method was considered to be most representative for salt tolerance response. As expected, this calculation gives lower values than the average root zone salinity calculations.

The water uptake weighted values was used as a reference to plant salt response. Salt tolerance is generally reported as EC of the soil saturation extract ($EC_e$). The salt tolerance yield results was reported in terms of $EC_{sw}$, but they can be readily converted to $EC_e$, as have sand tank and hydroponic studies based on a conversion factor (Shannon and Grieve, 1999).

## Fresh Yield

The fresh fruit yields of the various treatments are listed in Table 3. The non-saline $N_O$ treatment had a yield of 119 g $plant^{-1}$, significantly greater than the non-saline $N_{SO}$ treatment (94 g $plant^{-1}$), confirming that the $N_{SO}$ concentration was not optimal. The maximum yield, 143.2 g $plant^{-1}$, was obtained from optimal N with 1.0 $dSm^{-1}$ irrigation water salinity ($N_OS_1$). Increasing salinity with optimal N led to a decrease in fresh yield (Figure 2). The sub-optimal N ($N_{SO}$) data showed a characteristic threshold- slope relationship as described by Maas and Hoffman (1977). The fresh yield for the $N_{SO}$ treatments was relatively constant until EC of the soil water exceeds 3.4 dS $m^{-1}$, then yield decreased with increasing salinity.

The optimal N ($N_O$) treatments had higher yields than the sub-optimal N ($N_{SO}$) treatments for every salinity levels considered. Optimal and suboptimal treatments with $EC_{iw} = 6$ dS $m^{-1}$ irrigation water (9.2 dS $m^{-1}$ soil water) resulted in 7% and zero relative yield, respectively (Table 3). The interaction of salinity and N fertilizer was found to be statistically significant, $P < 0.05$. According to Duncan statistical test results, the yield reduction due to salinity at the suboptimal N level was significant at $EC_{sw} = 6.2$dS $m^{-1}$ salinity level, while at optimal N level the decrease started at $EC_{sw} = 2.3$ dS $m^{-1}$.

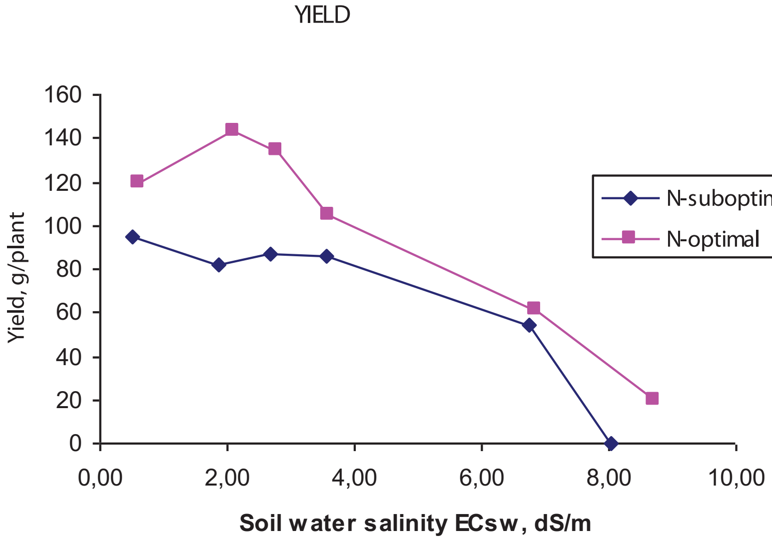

**FIGURE 2** Fresh fruit yield versus soil water salinity.

The yield response to salinity was more clearly observed at optimal N level than at suboptimal N level. Comparing the yields between $EC_{sw} = 2.5$ and at $EC_{sw} = 3.4$ dS $m^{-1}$ salinity levels, the decreases were 1.15% and 22.3% for $N_{SO}$ and $N_O$ fertilizer levels, respectively. The yield decrease for sub-optimal N level was much lower than for the optimal N level treatment, since the suboptimal treatment had already experienced N deficiency. The decrease in yield at the suboptimal N level was not severe and not significantly different from the low salinity until $EC_{sw} = 6.2$ dS $m^{-1}$, while at the optimal N level the yield significantly decreased above $EC_{sw} = 1.7$ dS $m^{-1}$.

It can be considered that the apparent increase in salt tolerance for the $N_{SO}$ treatments is due to the suboptimal fertilizer level (Figure 2). Under N stress, the plants already experienced a decrease in yield; hence a decreased response to moderate salinity levels. This study clearly demonstrates that when there is more than one stress factor, plants are affected primarily by the stress that has the highest impact. Above $EC_{sw} = 1.7$ dS $m^{-1}$ the salinity stress was dominant and caused a yield decrease at the optimal N level. Again, above $EC_{sw} = 1.6$ dS $m^{-1}$ at the suboptimal N treatment, the plants are still limited primarily from lack of N fertilizer in the soil media. Comparing the yields at only one or several salinity levels, one might incorrectly conclude that optimal fertilization leads to an increase in the salt tolerance of pepper. In this case, we conclude that the difference in yield between N fertilization levels is the consequence of N deficiency stress until $EC_{sw} = 3.4$ dS $m^{-1}$. Above $EC_{sw} = 3.4$ dS $m^{-1}$, salinity becomes the primarily limiting stress and the extra N applied with the $N_O$ treatment shows limited response.

**TABLE 4** Fruit and vegetative dry weight (g plant$^{-1}$) in respect to salinity and N levels

| Treatment | $EC_{iw}$ (dS m$^{-1}$) | $EC_{sw}$ (dS m$^{-1}$) | Fruit Dry weight (g plant$^{-1}$) | Vegetative dry weight (g plant$^{-1}$) |
|---|---|---|---|---|
| $N_{so}$ (135 kg ha$^{-1}$) | 0.25 | 0.45 | 5.73 c[1] | 6.80 b |
| | 1.00 | 1.60 | 5.17 cd | 6.53 b |
| | 1.50 | 2.51 | 5.91 c | 6.54 b |
| | 2.00 | 3.41 | 5.40 cd | 6.42 b |
| | 4.00 | 6.16 | 3.79 d | 6.81 b |
| | 6.00 | 9.18 | 0.00 e | 0.00 c |
| $N_o$ (270 kg ha$^{-1}$) | 0.25 | 0.42 | 7.68 b | 9.19 a |
| | 1.00 | 1.69 | 9.40 a | 9.92 a |
| | 1.50 | 2.33 | 8.99 ab | 9.72 a |
| | 2.00 | 3.35 | 5.03 cd | 9.29 a |
| | 4.00 | 6.22 | 4.38 cd | 4.01 c |
| | 6.00 | 9.16 | 1.24 e | 1.70 c |

[1] Where different letters state significant differences at $P < 0.05$.

The salt tolerance of pepper determined in this study was compared to literature values. For purposes of comparison the EC of the saturation extract was calculated using the soil water EC at field capacity and the ratio of water content at field capacity ($\theta_f$) and water content of the saturation extract ($\theta_e$), presented in Table 1. For the tested soil, the water content ratio was 2.0; thus the EC of the extract is calculated as $EC_{sw} \times 0.50$. Using the Maas-Hoffman salt tolerance model (Maas and Hoffman, 1977) the suboptimal N treatment had an intercept (EC at which yield starts to decline) of $EC_e = 1.7$ dS m$^{-1}$ and a slope of 34% (yield decline/dS m$^{-1}$). The optimal N treatment had a intercept at $EC_e = 1.16$ dS m$^{-1}$ and a slope of 25%.

## Biomass Production

Fruit and vegetative dry weights of pepper plants show a response to both salinity and N levels (Table 4). Salinity and fertilizer interaction was found to be statistically significant for fruit and vegetative dry weight at $P < 0.05$ significance level. The highest fruit dry weight was 9.40 g plant$^{-1}$ at $N_OS_1$. Comparing the treatments, the decrease in fruit and vegetative dry weight occurred statistically at 6.2 and 3.4 dS m$^{-1}$ salinity level for $N_{SO}$ and $N_O$, respectively. These results indicate that increasing salinity did not affect the fruit and vegetative dry weights adversely for the suboptimal N as much as it did at the optimal N level. At and above $EC_{sw} = 3.4$ dS m$^{-1}$ salinity level, $N_O$ treatments were statistically affected by increasing salinity and the response was almost the same as the response at the suboptimal N level. In summary, for the suboptimal N treatments the plants have already been affected by nutrient deficiency. This stress masks the effect of salt stress.

**TABLE 5** Water consumption (L $\text{plant}^{-1}$) as related to soil water salinity

| Treatment | $EC_{iw}$ (dS $m^{-1}$) | $EC_{sw}$ (dS $m^{-1}$) | Water consumption (L $\text{plant}^{-1}$) |
|---|---|---|---|
| $N_{SO}$ (135 kg $ha^{-1}$) | 0.25 | 0.45 | 34.7 bc[1] |
| | 1.00 | 1.60 | 36.3 abc |
| | 1.50 | 2.51 | 39.3 a |
| | 2.00 | 3.41 | 36.2 abc |
| | 4.00 | 6.16 | 30.2 de |
| | 6.00 | 9.18 | 16 g |
| $N_O$ (270 kg $ha^{-1}$) | 0.25 | 0.42 | 37.8 ab |
| | 1.00 | 1.69 | 38.0 ab |
| | 1.50 | 2.33 | 33.3 cd |
| | 2.00 | 3.35 | 36.8 abc |
| | 4.00 | 6.22 | 28.6 e |
| | 6.00 | 9.16 | 24.6 f |

[1] Where different letters state significant differences at $P < 0.05$.

At the higher salinity levels for both fertilizer treatments, the fruit biomass showed a similar response to salinity, so we it can be concluded that at these salinity levels there is no need to apply optimal N. It seems reasonable to consider that absolute N requirements would be related to plant biomass production, thus under salt stress with 50% of the optimal yield the N requirement might be expected to by 50% as well.

## Water Consumption

The cumulative water consumption values for the salinity and fertilizer treatments are presented in Table 5. The interaction between salinity and N is statistically significant, $P < 0.05$. The highest water consumption at suboptimal and optimal N level was observed at $EC_{sw} = 2.5$ $dSm^{-1}$ and $EC_{sw} = 1.7$ dS $m^{-1}$, respectively. Duncan test results indicated that water consumption significantly decreased above $EC_{sw} = 3.4$ dS $m^{-1}$ salinity level at both optimal and suboptimal N levels. These concentrations are similar to the concentration at which fruit yield significantly decreased for the $N_{SO}$ treatment, ($EC_{sw} =$ 3.4 dS $m^{-1}$) and greater than for the fruit yield of the $N_O$ treatment ($EC_{sw} =$ 2.3 dS $m^{-1}$).

The water applications were performed according to the target LF and the water consumed since the last irrigation. The ET data clearly represents the differences among the salinity treatments. The differences in ET clearly appeared at the $EC_{iw} = 4$ dS $m^{-1}$ salinity level $EC_{sw}$ 6.2 = dS $m^{-1}$. Increasing salinity caused a decrease in cumulative ET values. The highest water consumption was observed for the $N_OS_{1.5}$ (39.3 L $\text{plant}^{-1}$) treatment, and the lowest water use was the $N_OS_6$ treatment (24.6 L $\text{plant}^{-1}$).

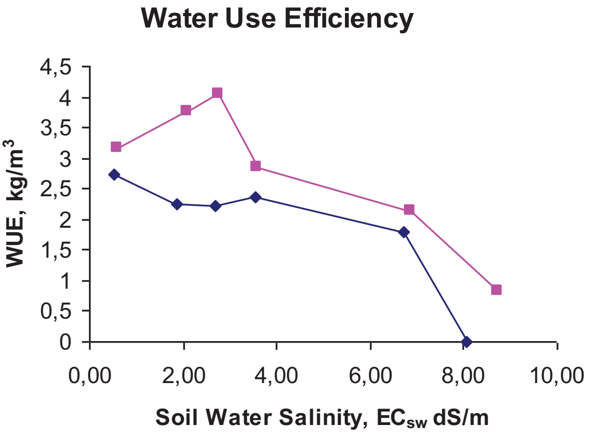

**FIGURE 3** Water use efficiency versus soil salinity.

## Water Use Efficiency (WUE)

The water use efficiency (WUE) is defined as yield per unit of water consumed. WUE response to salinity in Figure 3 is very similar to the fresh fruit yield response to salinity (Figure 2). At the optimal N level, WUE initially increased (yield increased with salinity and the total water consumption was constant) and then decreased above $EC_{sw} = 2.3$ dS $m^{-1}$. At suboptimal N level, WUE was initially almost constant then decreased at $EC_{sw} = 3.4$ dS $m^{-1}$ salinity level. When the soil water salinity was above EC = 6.2 dS $m^{-1}$ ($EC_{iw} =$ 4 dS $m^{-1}$), WUE was sharply reduced for both N levels, as shown in Figure 3. Between $EC_{sw} = 3.4$ dS $m^{-1}$ and $EC_{sw} = 6.2$ dS $m^{-1}$ salinity levels, the WUE was almost the same for both N levels. At the highest salinity, $N_{SO}$ treatment had 0 yields, hence WUE was 0.

## Mineral Content

Ash, Na and Ca percentage of the leaves are presented in Table 6. Statistical analysis indicated that salinity was the only factor affecting ash, Na and Ca percentage of the leaves ($P < 0.05$). Increasing water salinity caused an increase in ash percentage of pepper plant starting at $EC_{sw} = 3.4$ dS $m^{-1}$.

**TABLE 6** Ash percentage, Na and Ca content in leaves

| $EC_i$ $dSm^{-1}$ | 0.25 | 1.0 | 1.5 | 2.0 | 4.0 | 6.0 |
|---|---|---|---|---|---|---|
| Ash,% | 21.4 b[1] | 21.9 b | 23.3 b | 26.5 a | 26.5 a | 27.5 a |
| Na,% | 0.204 b | 0.19 b | 0.168 b | 0.158 b | 0.210 b | 0.65 a |
| Ca,% | 1.28 ab | 1.30 a | 1.24 ab | 1.08 bc | 1.16 bc | 0.99 c |

[1] Where different letters state significant differences at $P < 0.05$.

**TABLE 7** Chloride content in leaves,%

| Treatment | $EC_{iw}$ (dS $m^{-1}$) | $EC_{sw}$ (dS $m^{-1}$) | Cl (%) |
|---|---|---|---|
| $N_{SO}$ (135 kg $ha^{-1}$) | 0.25 | 0.45 | 0.285 e[1] |
| | 1.00 | 1.60 | 2.33 de |
| | 1.50 | 2.51 | 3.79 d |
| | 2.00 | 3.41 | 5.38 c |
| | 4.00 | 6.16 | 7.63 b |
| | 6.00 | 9.18 | 7.67 b |
| $N_O$ (270 kg $ha^{-1}$) | 0.25 | 0.42 | 0.473 e |
| | 1.00 | 1.69 | 2.96 de |
| | 1.50 | 2.33 | 3.54 d |
| | 2.00 | 3.35 | 3.79 d |
| | 4.00 | 6.22 | 8.38 ab |
| | 6.00 | 9.16 | 9.46 a |

[1] Where different letters state significant differences at $P < 0.05$.

The Na content in leaves was affected only by salinity level ($P < 0.05$). Increasing salinity level in the soil water led to an increase in the Na content of the leaves only at the highest salinity treatment (Table 6). Calcium accumulation in leaves was significantly affected by salinity ($P < 0.05$). Increasing water salinity had only a minor effect on Ca uptake, significantly decreasing only at the highest salinity level (Table 6). Magnesium and K concentrations in the leaves were not significantly affected by salinity nor by N fertilizer level, ($P > 0.05$).

Interaction of salinity and N fertilizer was found for the Cl content in leaves, ($P<0.05$). Increasing salinity caused an increase in leaf Cl content for both N levels (Table 7). At optimal N level, the leaf Cl concentration increased slightly until $EC_{sw} = 3.4$ dS $m^{-1}$, above this salinity level Cl concentration increased sharply.

## CONCLUSION

The biomass of the pepper plant showed a statistically significant decrease with increasing salinity. At optimal N level increasing salinity initially increased yield until $EC_{sw} = 2.4$ dS $m^{-1}$ in the soil water ($EC_{iw} = 1.5$ dS $m^{-1}$), which is the salinity threshold value of pepper. The differences between yield response at optimal and suboptimal N treatments was large at lower salinity levels and minor at high salinity levels, indicating that the pepper plants responded mostly to the stress limiting factor (initially N and subsequently salinity). Ash percentage increased with increasing salinity, calcium accumulation in leaves decreased above the $EC_{sw} = 3.4$ dS $m^{-1}$ salinity level. Chloride accumulation in the leaves increased with increasing salinity level but again mostly above the $EC_{sw} = 3.4$ dS $m^{-1}$ salinity level with optimal fertilizer. The Mg and K concentrations did not show statistically significant differences in leaves either with N or salinity. The WUE decreased dramatically with increasing salinity consistent with the fact that the fruit yields decreased faster than the total biomass as salinity increased. Biomass decreases would be expected to show smaller differences in WUE.

The results clearly show that if there is salinity and N stress, the larger stress tends to mask the effect of the other stress factor. At higher salinity levels the plant yields tend to decrease because of the salinity stress and response was almost the same at optimal and suboptimal N levels. It can be concluded that under two stress factors, plant responded primarily to the most limiting yield reduction factor. Under saline conditions, the N requirement for pepper can be greatly reduced with minimal further yield loss, as the main stress factor would be salinity. Future studies can provide more detailed information on yield response to salinity and fertilizer so that both environmental and economic factors can be optimized for growers when deciding on fertilizer application rates and water requirements under salt affected conditions.

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