Agronomy Research **15**(5), 2183–2194, 2017
https://doi.org/10.15159/AR.17.041

Effects of Irrigation water salinity on evapotranspiration and spinach (*Spinacia oleracea* L. Matador) plant parameters in Greenhouse Indoor and Outdoor Conditions

A. Ünlükara[1,*], T. Yurtyeri[2] and B. Cemek[3]

[1]Department of Biosystem Engineering, Agricultural Faculty, Erciyes University, TR38039 Kayseri, Turkey
[2]Gazipaşa First School of National Educational Ministry of Turkey Republic, Tokat, Turkey
[3]Department of Agricultural Structures and Irrigation, Faculty of Agriculture, Ondokuz Mayıs University, TR55139 Samsun, Turkey
[*]Corresponce: unlukara@gmail.com

Abstract. Response of spinach to irrigation water salinity under greenhouse indoor and outdoor conditions was investigated in this study to reveal different weather conditions on salinity tolerance of the plant. For this purpose, saline waters at six different salinities (0.65, 2.0, 3.0, 4.0, 5.0 and 7.0 dS m^{-1}) were applied to spinach (*Spinacia oleracea* L. Matador) grown in pots. Soil salinity increased linearly with increasing salinity of irrigation water. Threshold salinity is 2.35 dS m^{-1} and yield lost slope after this threshold is 3.51% for indoor and threshold salinity is 2.83 dS m^{-1} and yield lost slope is 3.3% for outdoor. Salinity harmful effect on spinach yield is higher for indoor conditions than for outdoor conditions because of higher indoor temperatures. These results apparently showed that spinach salinity response could change with changing weather conditions especially for temperature. Yield response factors (k_y), which is the ratio of relative evapotranspiration decrease to relative yield decrease, were close in the cases of irrigation water salinity in greenhouse outdoor and indoor (k_y = 2.4 and 2.1), respectively. Considerable water consumption decreases because of salinity were determined. Every 1 dS m^{-1} increment in soil salinity caused about 1.35% water consumption decrease for spinach. Therefore, depressing effect of salinity on water consumption should be considered in irrigation and salinity management to prevent excess saline water application and to protect environment.

Key words: Irrigation water salinity, Spinach, Plant water consumption, Plant growth parameters.

INTRODUCTION

Using rural and agricultural waste water and poor quality water in agriculture increase as world population increase to supply food need. Irrigation is one of the most reliable ways to increase productivity from unit area. Water demand of industrial, rural and agricultural sectors and global warming force to use poor quality saline and waste water resources (Rhoades et al., 1992; Shalhevet, 1994).

Sustainable production in agricultural lands is essential. Using saline water cause salinization of agricultural land and decrease productivity. To keep productivity and prevent salinization and water logging, proper irrigation and salinity management measurement are accomplished. Knowledge on plant water need and salinity tolerance of agricultural plants are vital for these purposes (Ayers & Westcot, 1989; Hoffman et al., 1992; Rhoades et al., 1992). If salt accumulation in root zone due irrigation water applied or high water table reduce crop yield lost, a salinity problem exists. Yield lost begins salinity level that the crop no longer able to uptake sufficient from salty soil solution and the crop experience water stress (Ayers & Westcot, 1989).

Edible flowering spinach plant (*Spinacia oleracea* L.) belongs to the family *Amaranthacea*. Spinach originated from southwestern and central Asia (Avşar, 2011). Turkey is the fourth largest spinach producer with 225 thousand tons after China, United States and Japan (FAOSTAT, 2017). Spinach includes high levels of vitamins and minerals. Vitamin A, vitamin B, vitamin K, vitamin C, vitamin B2 and B6, phosphorus, iron, potassium, folate, betaine, copper, protein, manganese, zinc, niacin, selenium and omega-3 are the ingredient included by spinach (Avşar, 2011).

Spinach was characterized as moderately sensitive plant to salinity. Threshold soil salinity was 2.0 dS m^{-1} and yield lost slope was 7.6% after threshold (Ayers & Westcot, 1989; Hoffman et al., 1992; Grieve et al., 2012). Ors & Suarez (2016) found different threshold values associated with Racoon spinach cultivar as 4.2 dS m^{-1} or higher for late fall and early spring period, as 3.3–4.2 dS m^{-1} for spring period and as 1.9–3.3 dS m^{-1} for late spring period in Riverside/California. These researchers stated that cool season spinach grown under cool period was more salt tolerant than that grown under warmer spring season. Spinach was also reported as a very sensitive to water stress (Yurtyeri et al., 2014).

In this study, some growth, yield and water consumption responses of spinach exposed to salinity under greenhouse indoor and outdoor conditions in the same period were investigated to reveal effects of different weather conditions, especially temperature on the plant salinity response.

MATERIALS AND METHODS

Two experiment were conducted under greenhouse indoor and outdoor conditions in 2007 to determine response of spinach (*Spinacia oleracea* L. Matador) to salinity in Gaziosmanpaşa University Agricultural Faculty in Tokat/Turkey. Six different saline water treatments as $S_0 = 0.65$ dS m^{-1} (control), $S_1 = 2.0$ dS m^{-1}, $S_2 = 3.0$ dS m^{-1}, $S_3 = 4.0$ dS m^{-1}, $S_4 = 5.0$ dS m^{-1} and $S_5 = 7.0$ dS m^{-1} were used to irrigate the plants grown under two different weather conditions in the same growth period. The experiment was designed in completely randomized plots with 5 replications. Therefore, totally 60 number pots were used for which 30 one greenhouse indoor and 30 one outdoor conditions. To prevent leaching due to rainfall, the outdoor experiment was conducted under a rain shelter. Tokat province of Turkey had a step climate with warmer dry summers and cooler rainy winters. Mean annual temperature was 12.6 °C and mean annual rainfall was 423.7 mm. Long term averaged temperatures of March, April and May, spinach growth period of these experiments, were reported 7.4 °C, 12.5 °C and 16.5 °C by Turkish State Meteorological Service (Anonymous, 2017).

The pot height and diameter were 27 cm and included 18 kg soil sieved from a 4 mm-sieve. Unit weight was 1.25 g cm^3. Sandy loam textured soil had 60.5% sand, 26.3%silt and 13.2% clay. Water contents (w/w) were determined as 33.5% at saturation point, as 23.6% at field capacity and as 9.8% at wilting point. Sowing date was 12 march 2007 and 16 spinach seed were sown to the pots. After seedling emergence, only 6 seedlings were left in each pot. Tap water (S_0) was applied to seedling until the seedling reached to 10 cm height. Harvesting was carried out on 14 and 17 may 2007 for indoor and outdoor experiment, respectively. Fertilizer needs were 120 kg ha^{-1} nitrogen, 100 kg ha^{-1} phosphorous (P_2O_5) and 50 kg ha^{-1} potassium (K_2O). Half of the nitrogen needs applied at sowing and another half applied 20 days later after seedling emergence.

To prepare saline waters at different salinity levels, three salts ($CaCl_2$, $MgSO_4$ and NaCl) were used. Amount of these salt types in saline waters were determined by using constant 1/1 Ca/Mg ratio (me l^{-1}) and sodium adsorption ratio (SAR = 5) (Ünlükara et al., 2008a; Unlukara et al., 2008b; Kurunc et al., 2011). Salinity levels of saline waters were checked by an electrical conductivity device and the salt's amounts in the saline waters were adjusted before applicating to the spinaches in the pots. Soil salinity were determined by soil saturation paste extract method from soil samples taken at harvest (Richards, 1954; Rhoades et al., 1992; Carter, 2000).

Water amounts applied to the treatments were determined by the following equation (Ayers & Westcot, 1986; Ünlükara et al., 2008a):

$$\mathrm{I} = \mathrm{ET}/(1 - \mathrm{LF}) \tag{1}$$

where I was amount of water applied (l), ET was plant water consumption (I) and LF was leaching fraction. Plant water consumption from pot field capacity was determined by weighing the pots just before irrigation. Pot field capacity was determined by weighing the pot drained after saturation (Öztürk et al., 2004; Yurtseven et al., 2005; Ünlükara et al., 2010). To prevent higher salt accumulation in root zone and obtain different soil salinity levels, leaching was carried out at each irrigation at constant leaching ratio (LF = 0.30) (Maas & Hoffman, 1977; Ayers & Westcot, 1989). Leaching water drained from the underneath orifices of the pots to the drainage cups and then measured. Plant water consumption for whole season were determined according to soil water budget method. Meteorological data was derived from Weatherlink meteorological station at Gaziosmanpaşa experimental area.

Depressing effect of soil salinity on plant water consumption was determined as stress coefficient (K_s) (Allen at al., 1998; Ünlükara et al., 2015):

$$\mathrm{K_s} = \frac{\mathrm{ET_{c\,adj}}}{\mathrm{ET_c}} \tag{2}$$

where $K_s$was salinity stress coefficient; $ET_{c\,adj}$ was water consumptions in liter from the saline treatments; ET_c was water consumption in liter from the control treatment. Relative decrease in water consumption due to salinity stress was related to relative yield lost by the following equation (Doorenbos & Kassam, 1986):

$$\mathrm{K_y} = \frac{(\Delta \mathrm{Y}/\mathrm{Y_m})}{(\Delta \mathrm{ET}/\mathrm{ET_m})} \tag{3}$$

where K_y was yield response factor caused by water stress created by salinity.

Salinity tolerance model of spinach were obtained by Maas & Hoffman (1977) model:

$$\frac{Y_a}{Y_m} = 1 - (EC_e - EC_{e\ threshold}) \cdot \frac{b}{100} \quad (4)$$

where Y_m was maximum spinach fresh yield (g) obtained from the control treatment; Y_a was actual fresh spinach yield (g) obtained from saline treatments; EC_e soil salinity or soil saturation paste extract electrical conductivity (dS m^{-1}); $EC_{e\ threshold}$ was soil salinity (dS m^{-1}) at which spinach begins to lost yield and b was yield lost slope (%) after the threshold.

Spinach plant height was measured weekly and apparent physiological changes were recorded. Plant biomass, stem diameters, root lengths were also determined at the harvest. Plant growth, development and yield values were evaluated by means over 5 replications. Plant leaf number were countered and leaf areas were measured by a planimeter. Plant roots were get from the pots by careful washing. Quantitative analysis was carried out to assess plant growth parameters (see Table 1) (Cemek, 2002).

Table 1. Plant Growth Parameters and Models Used for Quantitative Analysis (Cemek, 2002)

Growth parameters	Models
Leaf Area Ratio (LAR)	Total leaf area (cm^2) per Total Dry Biomass (g)
Specific Leaf Area (SLA)	Total leaf area (cm^2) per Total Dry Leaf Mass (g)
Leaf Mass Ratio (LMR)	Total Dry Leaf Mass (g) per Total Dry Biomass (g)
Root Mass Ratio (RMR)	Total Dry Root Mass (g) per Total Dry Biomass (g)

MS Excel 7.0 and SPSS 10 programs were used for statistical analysis of the results from spinach grown under indoor and outdoor greenhouse conditions to determine its salinity responses. Standard error bars were used to compare the results. Mean standard errors were obtained by Excel 7.0 and these standard error bars were installed mean values at $p < 0.05$ (Gomez & Gomez, 1984).

RESULTS AND DISCUSSIONS

Mean monthly temperatures, minimum and maximum temperatures, relative humidity of indoor and outdoor greenhouse conditions were presented in Table 2 for plant growth season. Indoor mean temperatures varied between 13.3 and 24.2 °C while mean relative humidity varied between 40.7% and 66.1%. Outdoor mean temperatures ranged from 12.7 °C to 21.2 °C while mean relative humidity ranged from 40.8% to 54.8%. Therefore, the indoor spinach was exposed to 1.7 °C higher temperatures than the outdoor spinach.

Table 2. Temperature and relative humidity values for greenhouse indoor and outdoor conditions

	Indoor						Outdoor					
	Temperature (°C)			Relative Humidity (%)			Temperature (°C)			Relative Humidity (%)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
March	13.1	11.4	16.0	50.5	46.0	54.3	12.1	10.7	13.7	55.4	54.1	56.5
April	16.2	9.20	23.7	54.4	39.0	74.0	14.5	8.75	21.7	53.4	47.7	58.0
May	25.8	19.4	32.8	50.7	37.0	70.0	23.5	18.8	28.3	46.2	42.4	50.0
Mean	18.4	13.3	24.2	51.9	40.7	66.1	16.7	12.7	21.2	51.6	48.0	54.8

Effects of irrigation water salinity on spinach growth parameter under greenhouse indoor and outdoor conditions

Growth parameters of spinach grown under outdoor and indoor conditions were presented in Tables 3 and 4. Salinity effect did not found significant on leaf number and stem diameter for both conditions. Mean plant leaf numbers were 12 and 11.85 for indoor and outdoor conditions and the same stem diameter for both experiments (0.6 cm) were determined. Ors & Suarez (2016) concluded that salinity reduces spinach leaf area rather than leaf number.

Salinity affected plant root length significantly ($p < 0.05$) and higher root lengths were obtained in saline treatments for the both experiments (Tables 3 and 4). The smallest roots were observed in the control treatment (S_0) under two conditions but the longest roots were observed in all salinity treatments for outdoor and only in severe saline treatments (S_4 and S_5) for indoor condition. The root length increased from 9.13 cm for control treatment to 11.52 cm for S_5 under outdoor and from 11.57 cm to 14.07 cm under indoor. It could be concluded that salinity and higher temperature raised root length.

Table 3. Some growth response parameters of spinach to salinity for outdoor conditions

	Irrigation Water Salinity Treatments (dS m^{-1})							
	S_o 0.65)	S_1 (2.0)	S_2 (3.0)	S_3 (4.0)	S_4 (5.0)	S_5 (7.0)	Mean	P > F
Number of leaves	11.4#	12.2	12.5	11.9	12.0	11.8	12.0	ns
Root length (cm)	9.13 bΨ	10.6 a	10.5 a	10.8 a	10.6 a	11.5 a	10.51	**
Stem diameter (cm)	0.58	0.59	0.65	0.60	0.58	0.60	0.60	ns
Leaf area (cm^2)	501 a	350 b	268 c	243 cd	236 cd	216 d	302	**
Leaf area index	0.87 a	0.61 b	0.47 c	0.42 c	0.41 c	0.38 c	0.53	**
Leaf area ratio (LAR)	79.5 a	61.3 b	55.9 b	47.6 c	52.4 c	55.36 b	58.66	**
Specific leaf area (SLA)	95.0 a	71.9 b	66.7 c	54.0 d	60.6 d	65.0 c	68.9	**
Leaf mass ratio (LMR)	0.84 c	0.85 b	0.84 c	0.88 a	0.86 b	0.85 c	0.85	**
Root mass ratio (RMR)	0.16 a	0.15 a	0.16 a	0.12 c	0.14 b	0.15 a	0.15	**

Each value is mean of five replications; Ψ Within rows, means followed by the same letter are not significantly different according to Duncan's multiple range test at 0.05 significance level; *, ** Significant at the 0.01 and 0.05 probability levels, respectively; ns is non-significant.

Leaf area was significantly affected at 0.05 probability by salinity under both experimental conditions. The highest leaf areas (500.7 cm^2 and 484.2 cm^2) were observed in control treatment (S_0) while the lowest one (215.9 cm^2 and 211.3 cm^2) were observed in S_5 treatment outdoor and indoor conditions, respectively (Tables 3 and 4). Plant leaf area was decreased with increasing salinity. Changes in leaf area index (LAI) due to salinity was similar to leaf area changes. Generally, smaller leaves, shorter plant height and sometimes fewer leaves were resulted from salinity (Shannon & Grieve, 1999). Contrary to these results Ors & Suarez (2016) obtained increasing leaf area with salinity for late fall and early spring period. Decreasing leaf area with irrigation water salinity above 7 dS m^{-1} was reported by Ors & Suarez (2016) under warmer spring and late spring growth periods for Racoon spinach cultivar. Differences in spinach leaf area to salinity may result from different cultivars, environmental conditions and cultivating.

Leaf area ratio (LAR) was affected due to salinity for both conditions. The highest leaf area ratios (LAR) were 79.47 and 66.24 for controls of two experiments and the lowest LAR were 52.4 and 44.80 for S_4 under both conditions (Tables 3 and 4). LAR aligned in descendent order with increasing salinity except for S_5 under outdoor. It was concluded that matador spinach cultivar improved smaller leaf area per unit dry biomass due to salinity stress. Significant effect of salinity on specific leaf area (SLA) of spinach grown outdoor and indoor conditions, as similar as observed for LAR.

Table 4. Some growth response parameters of spinach to salinity for greenhouse indoor conditions

	Irrigation Water Salinity Treatments (dS m^{-1})							
	S_o (0.65)	S_1 (2.0)	S_2 (3.0)	S_3 (4.0)	S_4 (5.0)	S_5 (7.0)	Mean	P > F
Number of leaves	12.30$^{\#}$	12.10	11.23	11.20	11.60	12.67	11.85	ns
Root length (cm)	11.6 c$^{\Psi}$	12.2 bc	13.0 ab	12.4 bc	12.9 ab	14.1 a	12.7	**
Stem diameter (cm)	0.57	0.62	0.58	0.56	0.59	0.66	0.60	ns
Leaf area (cm^2)	484 a	376 b	253 c	241 c	233 c	211 d	300	**
Leaf area index	0.85 a	0.66 b	0.44 c	0.42 c	0.41 c	0.37 d	0.52	**
Leaf area ratio (LAR)	66.2 a	58.5 b	47.5 c	48.6 c	44.8 d	45.64 d	51.87	**
Specific leaf area (SLA)	78.1 a	67.2 b	52.6 d	54.8 c	50.6 d	55.6 c	59.8	**
Leaf mass ratio (LMR)	0.85 ab	0.87 a	0.90 a	0.89 a	0.88 a	0.82 b	0.87	**
Root mass ratio (RMR)	0.15 b	0.13 bc	0.10 c	0.11 c	0.12 c	0.18 a	0.13	**

Each value is mean of five replications; $^{\Psi}$ Within rows, means followed by the same letter are not significantly different according to Duncan's multiple range test at 0.05 significance level; *, ** Significant at the 0.01 and 0.05 probability levels, respectively; ns is non-significant.

Salinity caused significant differences in leaf mass ratio (LMR) and root mass ratio (RMR) under both of the conditions (Tables 3 and 4). The highest LMR for indoor grown spinach were observed in all of the treatments except in the severe saline treatment (S_5) while the highest LMR only observed in S_3 for outdoor grown spinach.

Root mass ratios (RMR) significantly varied between 0.12–0.16 for outdoor and between 0.11–0.18 for indoor conditions (Tables 3 and 4). The highest RMR in S_0, S_1, S_2 and S_5 but the lowest RMR in S_3 were observed under outdoor but the highest one only in S_5 under indoor conditions. Salinity effects on LMR and RMR occurred different manner for outdoor and indoor greenhouse conditions.

Robinson et al. (1983) applied irrigation water with 1,450 mg L^{-1} NaCl and nutrient to spinach every day. Soil salinity concentration reached to 11,600 mg L^{-1} and the spinach lost big than 50% biomass. Leaf thickness also increased by salinity but plant normally sustained development.

Effects of saline irrigation water on soil salinity and yield for greenhouse indoor and outdoor conditions

Soil salinity (EC_e), pH, spinach water consumption, spinach leaf fresh and dry weight caused by salinity were presented in Table 5 for outdoor conditions and in Table 6 for indoor conditions. Plant water consumption was significantly affected by salinity ($p < 0.01$) for both conditions. Plant water consumption decreases as irrigation water salinity increases. The highest water consumption (8.92 L per pot) occurred in S_0 while the lowest water consumption (7.90 L per pot) occurred in S_5 (Table 5) under outdoor. Therefore, the spinach exposed to salinity experienced water stress due decreased osmotic potential of the soil solution despite there was sufficient water in the root zone.

Similar water consumption trend was also determined for indoor conditions but higher water consumption of 36% was observed because of higher indoor temperature (Tables 2 and 6). Mean temperatures for the growth period were 18.39 °C and 16.71 °C for indoor and outdoor conditions, respectively. The highest water consumption was 12.23 L per pot for S_0 and the lowest water consumption was 10.7 L per pot for S_5. Although lower atmospheric evapotranspiration demand (ET_0) occurred during late fall and early spring growth period, higher spinach water consumption determined due to longer growth period than warmer spring growth season (Ors & Suarez, 2016).

Table 5. Irrigation water salinity effects on soil salinity and spinach yield for outdoor greenhouse conditions

	Treatments (dS.m^{-1})							
	S_o (0.65)	S_1 (2.0)	S_2 (3.0)	S_3 (4.0)	S_4 (5.0)	S_5 (7.0)	Mean	P > F
ET_c (l)	8.92 a	8.82 a	8.29 b	8.26 b	8.19 b	7.90 c	8.40	**
EC_e (dS.m^{-1})	2.36 f	4.29 e	6.96 d	8.25 c	8.78 b	11.73 a	7.06	**
pH	8.53 a	8.37 b	8.19 c	8.17 c	8.17 c	8.13 d	8.26	**
Leaf fresh weight (g pot^{-1})	129 a	126 a	111 b	109 b	101 b	91.2 c	110.9	**
Leaf dry weight (g pot^{-1})	5.3 a	4.9 ab	4.0 bc	4.5 b	3.9 c	3.3 d	4.31	**
Root dry weight	1.03 a	0.84 b	0.78 b	0.61 c	0.61 c	0.58 c	0.74	**
Total dry weight	6.3 a	5.7 a	4.8 b	5.1 ab	4.5 b	3.9 c	5.05	**

Each value is mean of five replications; $^{\Psi}$ Within rows, means followed by the same letter are not significantly different according to Duncan's multiple range test at 0.05 significance level; *, ** Significant at the 0.01 and 0.05 probability levels, respectively; ns is non-significant.

Soil salinity increased as irrigation water salinity increased in contrary to the water consumption trend for both outdoor and indoor conditions. Differences among soil salinity results were found significant at $p < 0.01$ for outdoor and at $p < 0.05$ for indoor conditions. The highest soil salinity resulted from application of the highest saline irrigation water for both of two conditions. Mean soil salinity of indoor experiment was found slightly higher than outdoor salinity (7.38 > 7.06 dS m^{-1}). Therefore, soil salinity over irrigation salinity ratios of S_0, S_1, S_2, S_3, S_4, S_5 treatments were 3.63, 2.15, 2.32, 2.06, 1.76 and 1.68 for outdoor and 2.95, 3.15, 2.34, 2.02, 1.84, and 1.68 for indoor conditions, respectively. Higher EC_e/EC_w ratios were obtained for lower EC_w application treatments due to depressing effects of salinity on water consumption. Plants extract nearly pure water from soil and left great amount of salt. More water consumption means relatively higher salt accumulation in soil and also in plant tissues.

Soil reaction (pH) varied between 8.53 and 8.13 for outdoor conditions and between 8.47 and 7.96 for indoor conditions. Soil pH decreased with increasing salinity (Tables 5 and 6).

Spinach fresh and dry leaf weight were significantly affected from salinity for indoor and outdoor conditions at $p < 0.01$. Mean fresh leaf weight were 110.9 g pot^{-1} and 95.7 g pot^{-1} for outdoor and indoor conditions, respectively (Tables 5 and 6). The highest fresh and dry leaf weight were observed from S_0 and S_1 treatments and the lowest one from S_5 for outdoor conditions. In indoor conditions, only S_0 treatment had the highest fresh leaf weight and S_4 and S_5 treatments had the lowest. Detrimental salinity effect on fresh leaf weight was more severe for indoor conditions than for outdoor conditions. Leaf dry weight decreased gradually with increasing salinity.

Detrimental effect of salinity on dry root weight was also observed for both indoor and outdoor conditions with one exception. Dry root weight gradually decreased with salinity until S_3 treatment and then stabilized for outdoor conditions (Table 5). Gradual decrease in root weight for indoor conditions was more steep until S_2 treatment and slight increase in root weight was occurred (Table 6).

Table 6. Irrigation water salinity effects on soil salinity and spinach yield for indoor greenhouse conditions

	Treatments (dS m^{-1})							
	S_o (0.65)	S_1 (2.0)	S_2 (3.0)	S_3 (4.0)	S_4 (5.0)	S_5 (7.0)	Mean	P > F
ET_c (l)	$12.2^{\#}$ a^{Ψ}	11.8 b	11.3 c	10.9 c	10.8 d	10.7 d	11.30	**
EC_e (dS m^{-1})	1.92 f	6.30 e	7.03 d	8.07 c	9.20 b	11.8 a	7.38	**
pH	8.47a	8.26 b	8.19 c	8.13 d	8.07 e	7.96 f	8.18	**
Leaf fresh weight (g pot^{-1})	114.6 a	104.5 b	94.3 c	90.8 c	85.4 d	84.9 d	95.7	**
Leaf dry weight (g.pot^{-1})	6.20 a	5.6 b	4.80 c	4.40 c	4.60 c	3.8 d	4.90	**
Root dry weight	1.11 a	0.83 b	0.52 c	0.57 c	0.60 c	0.83 b	0.74	**
Total dry weight	7.31 a	6.43 b	5.32 c	4.97 c	5.20 c	4.63 d	5.64	**

Each value is mean of five replications; $^{\Psi}$ Within rows, means followed by the same letter are not significantly different according to Duncan's multiple range test at 0.05 significance level; *, ** Significant at the 0.01 and 0.05 probability levels, respectively; ns is non-significant.

Total mean dry biomasses were 5.05 g and 5.64 g for outdoor and indoor, respectively. Dry mass differences among treatments were significant due to salinity for both conditions. Total dry biomass decreased from 6.3 g for S_0 to 3.9 g for S_5 under outdoor conditions. Similar dry biomass decreases were observed for indoor conditions but from 7.31 g for S_0 to 4.63 g for S_5. Shannon & Grieve (1999) stated that general effect of salinity in crops were depressed growth rate, shorter stature and sometimes fewer leaves.

Salinity Tolerance Model for Spinach

Salinity tolerance model according to Maas & Hoffman (1977) for spinach fresh yield were presented in Fig. 1. The salinity model for indoor conditions and outdoor conditions, respectively:

$$Y = 100 - 3.51 \cdot (EC_e - 2.35)$$

$$Y = 100 - 3.30 \cdot (EC_e - 2.83)$$

Threshold salinity of Matador spinach cultivar was 2.35 dS m^{-1} and yield lost slope after this threshold was 3.51% for indoor and threshold salinity was 2.83 dS m^{-1} and yield lost slope was 3.3% for outdoor. Indoor salinity threshold value was less than outdoor value. In contrary to the thresholds, indoor yield lost slope was steeper than outdoor yield lost slope. These means that indoor spinach yield lost would be higher than outdoor at the same soil salinity after the threshold. Higher air temperatures for indoor caused changes in spinach response to salinity.

Different threshold value results were obtained Ors and Suarez (2016) for spinach grown under three different growth stages. They obtained 4.2 dS m^{-1} or higher threshold value for late fall-early spring period while they determined lower threshold values between 3.3–4.2 dS m^{-1} for spring period and between 1.9–3.3 dS m^{-1} for late spring period due to warmer conditions.

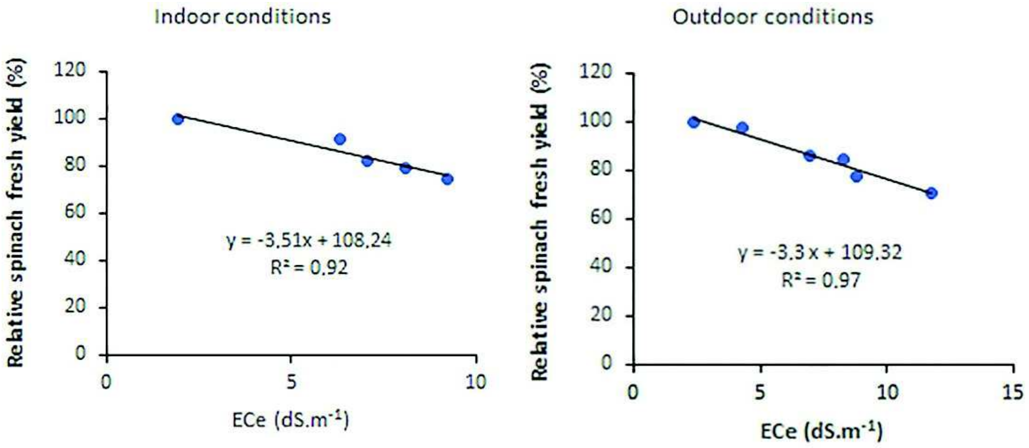

Figure 1. Spinach fresh yield salinity tolerance model for greenhouse indoor and outdoor conditions.

Spinach cultivar Matador was found moderately sensitive to salinity under both indoor and outdoor conditions. Long & Baker (1986) also reported that spinach had intermediate salt tolerance among herbaceous crops. Threshold soil salinity was 2.0 dS m^{-1} and yield lost slope was 7.6% after threshold (Ayers & Westcot 1989; Hoffman et al., 1992; Grieve et al., 2012). Spinach 50% yield lost occurred with watering 8.6 dS m^{-1} irrigation water (Maas & Hoffman, 1977; Shannon et al., 2000). Our both threshold values were higher than 2.0 dS m^{-1} but our outdoor and indoor yield lost slopes of 3.3 and 3.51% were not steeper than 7.6% (Fig. 1). In the past, NaCl salt often used to determine plant salt response to salinity. Besides of osmotic effect of Na and Cl ions were also reported toxic to cultivated plants and Na had detrimental effect to soil physical conditions (Hoffman et al., 1992; Rhoades et al., 1992). However, any water resource in nature is not consist of only NaCl. Perhaps, elimination of these more detrimental effect of NaCl by using three salts (NaCl, $MgSO_4$ and $CaCl_2$) in this experiment improved spinach salt response or using different cultivar under different conditions caused this result (Ünlükara et al., 2010; Kurunc et al., 2011).

Adjustment of Depressing Effect of Salinity on Plant Water Consumption and Yield Response Factor

Increasing salinity caused decreases in spinach water consumption under both indoor and outdoor conditions (Tables 5 and 6). This depressing effect of salinity on plant water consumption should be considered to manage irrigation and salinity, precisely. The relationship between soil salinity and relative plant water consumption is presented in Fig. 2. Very strong negative linear relationships were obtained between EC_e and ET_{adj}/ET for both conditions. Every 1 dS m^{-1} increment in soil salinity caused about 1.35% water consumption decrease for spinach.

Water deficiency caused plant yield lost. To evaluate plant tolerance to water stress, a yield response factor (k_y) often used (Katerji et al., 1998). K_y was used as a correlation coefficient between relative yield decreases and relative evapotranspiration decreases (Doorenbos & Kassam, 1986). Salinity also caused water stress because it decreased osmotic potential of soil water. The relationships between relative yield decreases and relative evapotranspiration decreases created by salinity were represented in Fig. 3 for Matador spinach cultivar. As seen in Fig. 3, $k_y = 2.1$ and $k_y = 2.42$ for indoor and outdoor conditions state that spinach was very sensitive to water stress created by salinity.

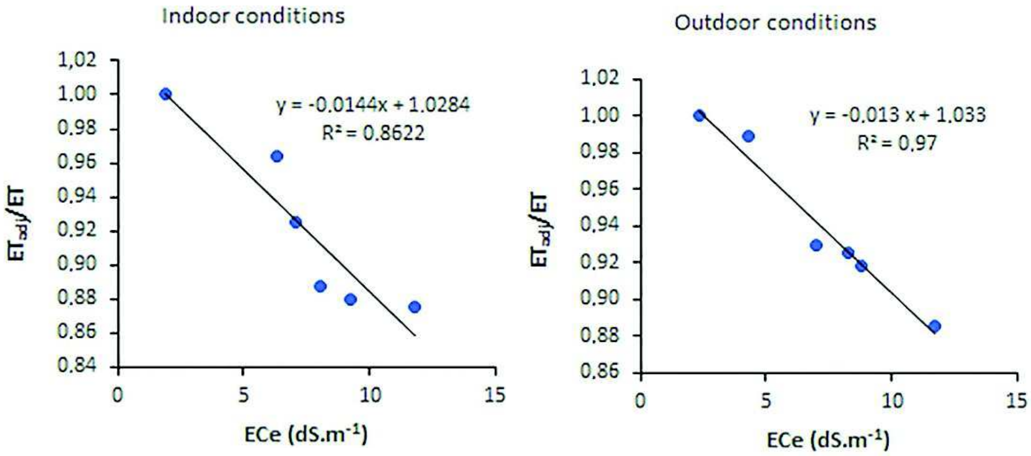

Figure 2. Soil salinity and spinach relative water consumption relationships for indoor and outdoor greenhouse conditions.

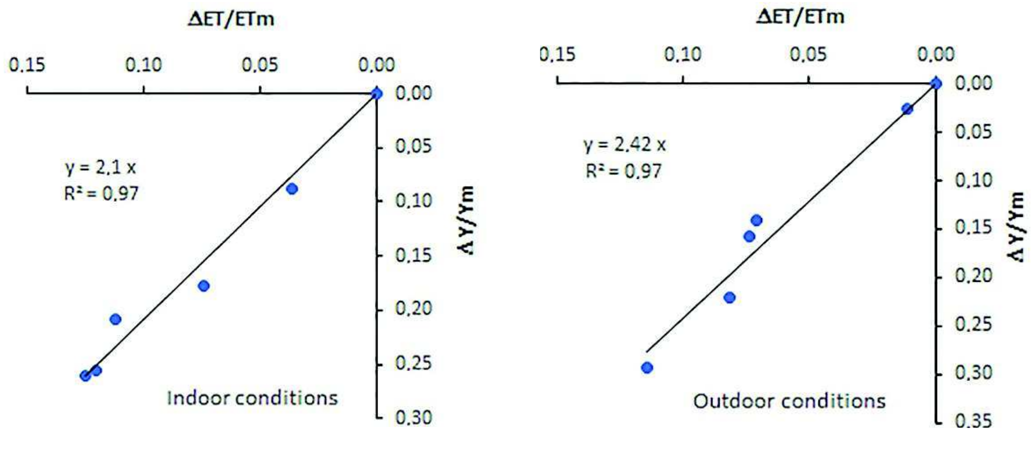

Figure 3. Relationships between relative yield decreases and relative evapotranspiration decreases created by salinity.

At the same time and same conditions, Yurtyeri et al. (2014) found Matador cultivar yield response factor created by water deficiency as 1.0 and 1.66 for the same indoor and outdoor greenhouse conditions, respectively. Spinach yield response factor was found higher under salinity conditions than reported ones under water deficiency conditions by Yuryeri et al. (2014).

CONCLUSION

Spinach responses to salinity investigated in this study under greenhouse indoor and outdoor conditions to reveal effect of different weather conditions on salinity tolerance. For this purpose, six different levels of saline waters (0.65, 2.0, 3.0, 4.0, 5.0 and 7.0 dS m^{-1}) were applied to spinach (*Spinacia oleracea* L. Matador). Spinach leaf number and stem diameter were not affected from salinity. Therefore, salinity promoted root length. Root mass ratio was found higher for non-saline and severe saline conditions. Medium salinity conditions negatively affected on root mass ratio. Severe saline conditions may cause spinach to develop more root to overcome salinity stress. Leaf area and leaf mass ratio decreased by increasing salinity.

Application of saline water increased soil salinity. Soil salinity to irrigation water salinity ratio was higher under relatively lower saline conditions due to more water consumption. Salinity had a depressing effect on spinach water consumption by causing osmotic potential decreases in soil water solution. This depressing effect should be considered to manage irrigation and salinity, precisely.

Spinach fresh yield was affected negatively from salinity. Matador spinach cultivar was found as a moderately sensitive plant to salinity. Warmer indoor greenhouse saline conditions caused higher yield decrease by a lower threshold value and steeper yield lost slope. Higher threshold value and smaller yield decrease slope were determined under cooler outdoor conditions. These results apparently showed that spinach salinity tolerance could change according to temperature.

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. 1998. *Crop Evapotranspiration (Guidelines for Computing Crop Water Requirements)*. Irrigation and Drainage Paper No: 56, Rome, 300 pp.

Anonymous, 2017. Turkish State Meteorological Service. https://mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=TOKAT

Avşar, B. 2011. *Genetic Diversity of Turkish Spinach Cultivars (Spinacia oleracea L.)*. The Graduate School of Engineering and Sciences of İzmir Institute of Technology, İzmir/Turkey, 27 pp, (in Turkish).

Ayers, R.S. & Westcot, D.W. 1989. *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper No: 29, Rome, 174 pp.

Carter, M.R. 2000. *Soil Sampling and Methods of Analysis*. Lewis Publishers, Boca Raton, Florida, 823 pp.

Cemek, B. 2002. *Effects of Different Covering Materials on Growth, Development and Yield of Crop and Environmental Conditions Inside of Greenhouses*. 19 Mayıs University, Directory of Natural Sciences Institute, PhD. Thesis, 168 pp, (in Turkish).

Doorenbos, J. & Kassam, A.H. 1986. *Yield Response to Water*. FAO Irrigation and Drainage Paper No: 33, Rome, 193 pp.

FAOSTAT. 2017. http://www.fao.org/faostat/en/#data/QC

Gomez & Gomez, 1987. *Statistical Procedures for Agricultural Research*. John Wiley and Sons Ltd., Singapure, 657 pp.

Grieve, C.M., Grattan, S.R. & Maas, E.V. 2012. Plan Salt Tolerance. In: Wallender, W.W. & Tanji, K.K. (ed.): *Agricultural Salinity Assessment and Management.* ASCE, Virginia, pp. 405–459.

Hoffman, G.J., Rhoades, D.J. & Letey, J. 1992. Salinity Management. In: Hoffman, G.J., Howell, T.A. & Solomon, K.H. (ed.): *Management of Farm Irrigation Systems*. ASAE, St. Joseph, pp. 667–715.

Katerji, N., van Hoorn, J.W., Hamdy, A., Mastrorilli, M. & Karam, F. 1998. Salinity and drought, a comparison of their effects on the relationships between yield evapotranspiration. *Agric. Water Management* **36**, 45–54.

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

Long, S.P. & Baker, N.R. 1986. Saline Terrestrial Environments. In Baker, N.R. & Long, S.P. (ed.): *Photosynthesis in Contrasting*, Elsevier, New York. pp.63–102.

Maas, E.V. & Hoffman, G.J. 1977. Crop salt tolerance-Current assessment. *ASCE Journal of Irrigation and Drainage Division* **103**(IRZ), 115-134.

Ors, S. & Suarez, D.L. 2016. Salt tolerance of spinach as related to seasonal climate. *Hort. Sci.* **43**(1), 33–41.

Öztürk, A., Ünlükara, A., İpek, A. & Gürbüz, B. 2004. Effects of Salt Stress and Water Deficit on Plant Growth and Essential Oil Content of Lemon Balm (*Melissa officinalis* L.). Pakistan Journal of Botany **36**(4), 787–792.

Richards, L.A. 1954. Diagnosos and Improvement of Saline and Alkali Soils. USDA Handbook No: 60, Washington D.C. 160 pp.

Rhoades, J.D., Kandiah, A. & Mashali, A.M. 1992. *The Use of Saline Waters for Crop Production*. FAO Irrigation and Drainage Paper No: 48, Rome, 133 pp.

Robinson, P.S., Downton, W.J.S. & Millhouse, J.A. 1983. Photosynthesis and Ion Content of Leaves and Isolated Chloroplasts of Salt-Stressed Spinach. *Plant Physiology* **73**, 238–242.

Shalhevet, J. 1994. Using water of marginal quality for crop production: Major issues." *Agric. Water Management* **25**, 233–269.

Shannon, M.C., Grieve, C.M., Lesch, S.M. & Draper, J.H. 2000. Analysis of salt tolerance in nine leafy vegetables irrigated with saline drainage water. *J. of Amer. Soc. for Hort. Sci.* **125**, 658–664.

Ünlükara, A., Kurunç, A., Kesmez, G.D. & Yurtseven, E. 2008a. Growth and evapotranspiration of okra (*Abelmoschus esculentus L.*) as influenced by salinity of irrigation water. *J. of Irrigation and Drainage Engineering-ASCE* **134**(2), 160–166.

Unlukara, A., Cemek, B., Karaman, S. & Ersahin, S. 2008b. Response of lettuce (*Lactuca sativa* var. crispa) to salinity of irrigation water. *RSZN New Zealand J. of Crop and Hort. Sci*. **36**, 265–273.

Ünlükara, A., Kurunç, A., Kesmez, G.D., Yurtseven, E. & Suarez, D.L. 2010. Effects of Salinity on Eggplant *(Solanum melongena L.)* Growth and Evapotranspiration. *Irrigation and Drainage* **59**, 203–214.

Ünlükara, A., Kurunç, A. & Cemek, B. 2015. Green Long Pepper Growth under Different Saline and Water Regime Conditions and Usability of Water Consumption in Plant Salt Tolerance. *J. of Agric. Sci.* **21**, 167–176.

Yurtseven, E., Kesmez, G.D. & Ünlükara, A. 2005. The effects of water salinity and potassium levels on yield, fruit quality and water consumption of a native central anatolian tomato species (*Lycopersicon esculentum*). *Agric. Water Management* **78**, 128–135.

Yurtyeri, T., Cemek, B. & Ünlükara, A. 2014. Response of Spinach to Different Water Stress Conditions in Greenhouse Indoor and Outdoor Conditions. *12.Culturetechnique Symposium*, 21–23 May, Tekirdağ, Turkey, pp. 331–336, (in Turkish).