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Effects of evapotranspiration and soil salinity on some growth parameters and yield of lettuce (*Lactuca sativa* var. *crispa*)

Bilal CEMEK[1], Ali ÜNLÜKARA[2], Sedat KARAMAN[3], Zeki GÖKALP[2]

[1]Ondokuz Mayis University
55139 Samsun, Turkey
E-mail: bcemek@omu.edu.tr

[2]Erciyes University
Kayseri, Turkey

[3]Gaziosmanpaşa University
Tokat, Turkey

Abstract

Salt tolerance of plants is evaluated by several models and most of them consider only soil salinity as the limiting criteria. In this study, impacts of climate over salt tolerance of plants were also considered and plant yield, plant height, number of leaves, amount of dry matter, soil salinity and plant water consumption were evaluated by using 3-D models. Therefore, relationships were established to express the combined effects of soil salinity and evapotranspiration on the yield and some growth parameters (plant height, number of leaves, dry matter content) of lettuce. The highest yield was obtained in low soil salinity and high evapotranspiration, whereas the lowest yield was obtained in high soil salinity and low evapotranspiration cases. The relationships between evapotranspiration–soil salinity and yield–some growth parameters were generally linear with increasing or decreasing tendencies. A wide range effect of evapotranspiration and soil salinity on the yield and some growth parameters of lettuce might be helpful for salinity management. In addition, the effects of salinity on growth, development and yield of lettuce can be used to derive some relationships between evapotranspiration and soil salinity.

Key words: *Lactuca sativa* var. *crispa*, soil salinity, evapotranspiration.

Introduction

All plants do not respond to salinity in a similar manner; some crops can produce acceptable yields at much greater soil salinity than others. This is because some are better able to make the needed osmotic adjustments enabling them to extract more water from a saline soil (Ayers, Westcot, 1989).

Ünlükara et al. (2010) investigated impacts of salinity on eggplant and found a threshold value lower than 1.5 dS m^{-1} and a slope value of 4.4%. Researchers also reported a decrease in plant water consumption due to salinity and a decrease slope of 2.1%. Again, Ünlükara et al. (2008 a) determined threshold value of 3.48 dS m^{-1} and slope value of 4.24% for okra and also reported a decreasing slope of 2.43% in plant water consumption against per unit increase in salinity. In another study, the same parameters were determined for lettuce (*Lactuca sativa* var. *crispa*) and found a threshold value of 1.1 dS m^{-1}, a slope value of 9.3% and a decreasing water consumption slope of 2.4% (Ünlükara et al., 2008 b).

Rhoades et al. (1992) proposed that excessive salinity reduced plant growth primarily because it increases the energy that must be expended to acquire water from the soil of the root zone and to make the biochemical adjustments necessary to survive under stress. This energy is diverted from the processes which lead to growth and yield. Also, plant water consumption increases at hot, dry and windy periods with higher atmospheric evaporative demands and decreases at cool, humid and steady periods. Taking into account plant water consumption and salinity for plant responses to salinity means considering the impacts of climate changes on plant salt tolerance.

Plant salt tolerances are generally evaluated by a model developed by Maas and Hoffman (1977). In this model, plants do not exhibit any yield decrease until a threshold value, then yield decreases linearly with values over threshold value. Whereas climate, plant species, plant growth stages and environmental conditions are effective in plant yield, only the salinity is considered as the limiting factor for yield in this model.

Based on the results of above mentioned studies, slope of decrease in relative yield for per unit increase in salinity is different from the decrease slope of plant water consumption. Plants are more tolerant to salinity in cool climates or cool periods of the year. Plant water consumption increases with increasing evaporative demand of atmosphere. Plant water consumption is a reflection of evaporative demand of atmosphere and therefore the climate. By using plant water consumption together with soil salinity, effects of climate will also be considered in evaluation of salinity over plant yield. In this study, both soil salinity and plant water consumption were taken into consideration to investigate the impacts of salinity on plant growth.

He et al. (2010) investigated the effects of elevated root zone carbon dioxide and air temperature on photosynthesis, productivity, nitrate, and total reduced nitrogen content in aeroponically grown lettuce plants and observed significant impacts of both elevated CO_2 and higher temperature over the growth of lettuce plants. Researchers stated that elevated CO_2 had a greater effect in the higher air temperature regime and it also had a considerable impact on photosynthetic gas exchange, water relations, and N metabolism at lower air temperatures. Tzortzakis (2009) searched the effects of NaCl salinity and potassium level on the plant growth and severity of gray mold [*Botrytis cinerea* (De Bary) Whetzel] in lettuce (*Lactuca sativa* L. cvs. 'Beta' and 'Paris Island') grown with the NFT under greenhouse conditions during early spring. Researcher applied nutrient solutions containing 40 mM of sodium chloride (NaCl) and/or 10 mM potassium sulphate (K_2SO_4) and observed that salinity or K-enrichment mainly affected the upper part of lettuce plants and reduced leaf fresh weight and leaf area, and their combination reversed the negative impact of salinity on plant growth. It was also observed in this study that salinized and/or potassium-enriched plants did not differ in root length, leaf dry weight, leaf length, or numbers of leaves produced.

Al-Maskri et al. (2010) conducted an experiment to investigate the effects of salinity stress (NaCl) on growth of lettuce (*Lactuca sativa* L.) cv. 'Paris Islands' Cos under closed-recycled NFT. Different salinity levels of 50 mM and 100 mM along with control (0 mM) were used in the experiment and it was observed that number of leaves, plant fresh weight, shoot fresh weight, shoot dry weight, shoot dry matter percentage, root fresh weight, root dry weight, root dry weight percentage, leaf area and leaf area index were significantly affected by salinity levels, while shoot and root water contents percentage, ratio of the shoot to root fresh weight and ratio of the shoot to root dry weight showed insignificant effect in response to salinity. Mahmoudi et al. (2010) investigated the impact of genotype and salinity on physiological function, secondary metabolite accumulation, and antioxidative responses in lettuce and evaluated two lettuce types, 'Verte' (NaCl tolerant) and 'Romaine' (NaCl sensitive), under iso-osmotic 100 mM NaCl and 77 mM Na_2SO_4 treatments. Researchers observed that 'Romaine', NaCl-treated 'Verte' displayed better growth, contained lower levels of inorganic cations in leaves, and possessed superior antioxidative capacity due to enhanced carotenoid and phenolics biosynthesis and more active antioxidative enzymes resulting in reduced membrane damage. It was also observed in this study that both genotypes had relatively similar growth patterns under Na_2SO_4 treatment, but 'Romaine' showed enhanced root lignification, greater malondialdehyde formation, and suppressed Fe-superoxide dismutase expression in roots as compared with 'Verte'. Several other researchers carried out investigations on lettuce by using various parameters (Scorer et al., 1985; Yasseen et al., 2010; Zorrig et al., 2010). In this study, impacts of evapotranspiration and soil salinity over some growth parameters and yield of lettuce (*Lactuca sativa* var. *crispa*) were investigated and plant yield, plant height, number of leaves, amount of dry matter, soil salinity and plant water consumption were evaluated by using 3-D models.

Material and methods

In this study, results of a research carried out by Ünlükara et al. (2008 b) to investigate the response of lettuce (*Lactuca sativa* var. *crispa*) against irrigation water salinity were used. The study was carried out in a Venlo greenhouse with 4 sections. Each section is 3.35 m wide and 10.05 long with 2.4 m high side walls and 3.45 m high ridge. Experiments were conducted in completely randomised block design with six treatments and eight replications (T 0 = 0.75 dS m^{-1}, T 1.5 = 1.5 dS m^{-1}, T 2.5 = 2.5 dS m^{-1}, T 3.5 = 3.5 dS m^{-1}, T 5 = 5.0 dS m^{-1}, and T 7 = 7.0 dS m^{-1}). Large pots were filled with 20 kg air-dry sandy loam soil (56.8% sand, 32.5% silt, and 10.7% clay), sieved through a 4 mm sieve. Two plants were grown in each pot.

Three salt types ($CaCl_2$, $MgSO_4$, and NaCl) were mixed to achieve the target salinity of the irrigation water. The amount of salt to be used in each mixtures was adjusted to provide a sodium adsorption ratio (SAR) value of 5, a Ca:Mg ratio of 1:1 (mmol $litre^{-1}$), and electrical conductivity (EC) values of 1.5, 2.5, 3.5, 5.0, and 7.0 dS m^{-1}. The EC values of prepared mixtures were checked in the laboratory and corrections were made if needed. Tap water with ECi = 0.75 dS m^{-1} was used as a control treatment. Salt mixtures were stored in 100-litre plastic containers.

Planting and initial water application was implemented on 9 November 2005. At the beginning of experiments, 3.3 g diammonium phosphate (DAP) was applied to each pot. In addition, 2.6 g urea (NH_2CONH_2) was applied, half at the beginning and the rest just after winter (21 February 2006).

The hourly dry bulb temperature, relative humidity and solar radiation values of indoor and outdoor air were measured by an electronic measurement and data logging device (HOBO RH/Temp/SR (attach pyranometer), type HO8-003-02, USA). The device was placed 1.5 meters above the ground in the middle of the greenhouse.

Salinity levels of irrigation water treatments except control treatment were adjusted with NaCl, $CaCl_2$ and $MgSO_4$ salts. Sodium adsorption ratio of these saline water treatments were kept around 5 and the Mg:Ca of saline waters were taken as 1.

Amounts of irrigation water to be applied were determined using equation 1 by weighing method of the pots. A 20% leaching fraction was also added to irrigation water (Ünlükara et al., 2008 a; 2008 b):

$$I = \frac{\dfrac{W_{bi} - W_{fc}}{\rho_w}}{1 - LF} \quad (1),$$

where I is amount of irrigation water applied (litre), W_{bi} is the pot weight just before irrigation (g), W_{fc} is the pot field capacity weight (g), ρ_w is unitvolume weight of water (1000 g $litre^{-1}$) and LF is leaching fraction.

Different salinity levels caused different water consumptions. By weighing pots, we applied only amount of water from which plants consumed with nearly constant leaching fraction. Adverse effects of excess leaching were prevented via application of the above pot weighing method. Amount of drained irrigation water was measured and plant water consumption of lettuce was calculated by water budget method (Ünlükara et al., 2008 a; 2008 b; 2011):

$$ET = (I - D) + \frac{(W_b - W_e)}{\rho_w} \quad (2),$$

where ET is evapotranspiration lettuce (litre), I is amount of irrigation water applied (litre), D is drained water (litre), W_b and W_e are pot weights at the beginning and at the harvest of the experiment (g), ρ_w is unit volume weight of water (1000 g $litre^{-1}$).

Yield, plant height (PH), number of leaves (LN), and amount of dry matter (DM) were determined. Electrical conductivity of soil saturation paste extract (ECe) or soil salinity was determined from saturation extracts of soil samples taken at harvest period. To evaluate the effects of salinity on lettuce, three diomantinal multiple regression analyses were performed. Three diomantional models of lettuce yield and evapotranspiration changes against irrigation and soil salinities, three diomantional models of lettuce yield, plant height, dry matter and number of leaves changes against soil salinities (ECe) and lettuce evapotranspirations (ET) were obtained.

Data for seven out of eight replications from each treatment of experiment were used as materials to develop models and the eighth replication was used for the validation of developed models. F-test was used to evaluate the differences between the observed and estimated values. Means, standard deviations, minimum and maximum values of yield, evapotranspiration, plant height, dry matter, number of leaves, and soil salinity for lettuce grown under different levels of irrigation water salinity were given in Table 1.

Multiple regression analysis was performed with *Microsoft Excel* following the procedure of Gomez and Gomez (1984). Multiple regression analysis of data was performed for each lettuce experiment, separately. For this reason, analysis was conducted with various subsets of the independent variables, namely, irrigation water salinity, soil salinity and evapotranspiration to develop the best model for predicting yield, evapotranspiration, number of leaf, dry matter and plant height of lettuce by using the *Excel 7.0* package program. The unknown fitting parameters in equations were estimated through an optimization procedure by using *MS Excel Solver*. The multiple regression analysis was carried out until the deviation sum of squares was minimized. To validate the equations, Model 1–6 values obtained from each model were plotted against actual some growth, yield and evapotranspiration values of lettuce measured for the eighth replication.

Curve fitting processes were continued until the least sum of squares of residuals was obtained. Fitted planes from multiple regression analysis were shown on 3-D graphs using the *Slide Write* computer package *Version 2.0*.

Table 1. Some statistical values of lettuce from irrigation water salinity experiment*

Water salinity dS m^{-1}	For modeling								
	yield g			evapotranspiration L			plant height cm		
	mean ± SD	min	max	mean ± SD	min	max	mean ± SD	min	max
S0 (0.75)	144.7 ± 20.9	118.1	174.6	11.2 ± 0.57	10.5	11.8	16.4 ± 1.4	14.7	18.3
S1 (1.5)	117.42 ± 28.9	84.2	158.2	10.6 ± 1.42	9.1	13.3	15.7 ± 1.9	13.0	18.0
S2 (2.5)	101.35 ± 32.1	66.3	135.6	11.2 ± 1.02	9.9	12.6	15.1 ± 2.0	13.0	17.5
S3 (3.5)	78.38 ± 24.2	47.4	115.5	9.3 ± 0.86	8.3	10.5	13.9 ± 2.1	11.5	16.7
S4 (5.0)	52.25 ± 8.46	40.2	63.2	9.9 ± 2.13	7.8	13.1	10.7 ± 1.2	9.5	12.5
S5 (7.0)	36.70 ± 17.8	14.9	62.10	8.5 ± 1.04	6.8	9.5	10.4 ± 3.5	6.7	13.8
	Dry matter %			Number of leaves			Soil salinity dS m^{-1}		
	mean ± SD	min	max	mean ± SD	min	max	mean ± SD	min	max
S0 (0.75)	3.6 ± 0.64	2.7	4.5	28.9 ± 3.5	24.5	32.5	1.2 ± 0.07	1.14	1.33
S1 (1.5)	3.5 ± 0.88	2.1	4.3	25.1 ± 4.0	20.5	30.5	3.0 ± 0.47	2.3	3.7
S2 (2.5)	4.4 ± 1.3	2.3	6.0	25.6 ± 3.8	21.5	30.0	4.3 ± 0.86	3.2	5.5
S3 (3.5)	4.6 ± 1.1	3.1	6.2	22.0 ± 1.5	20.0	23.5	5.5 ± 1.01	4.2	6.7
S4 (5.0)	5.3 ± 2.0	2.0	6.9	18.9 ± 1.5	17.0	21.0	7.5 ± 1.23	6.1	9.2
S5 (7.0)	5.9 ± 0.9	4.7	6.7	18.0 ± 0.7	17.5	18.9	11.9 ± 1.40	10.1	13.8

Water salinity dS m^{-1}	For validation					
	yield	evapotranspiration	plant height	dry matter	number of leaves	soil salinity
S0 (0.75)	134.4	10.8	15.2	3.5	29	1.3
S1 (1.5)	124.8	9.7	14.8	3.8	28	2.7
S2 (2.5)	98.6	10.4	14.3	4.6	24	3.9
S3 (3.5)	82.5	8.5	12.8	4.3	23	6.1
S4 (5.0)	48.3	8.2	11.4	4.9	20	7.8
S5 (7.0)	27.8	7.6	9.5	5.4	17	12.3

Notes. * – 8 pots were used for each treatment. Data from 7 pots of each treatment were used to create the models and the data of eighth pot were used for validation of the models. 7 data sets were used in each pot for each treatment; a total of 42 data sets were used to create the models and 7 data sets were used for validation.

Results and discussion

In general, salinity experiments have been carried out only with NaCl salt. Na and Cl ions have toxic effects to plants and Na anion negatively affects soil physcial conditions. Additionally, excess amount of these ions disturbed plant nutritional uptake. But in the nature, all water sources have different types and concentrations of salts. Therefore three different salts were used in this study to simulate natural water characteristics as close as possible and eliminate adverse effects of saline water on soil physical conditions and prevent nutritional imbalances. So, the plants only experienced effects of different osmotic conditions.

Greenhouse climate conditions. The hourly dry bulb temperature, relative humidity and solar radiation values of greenhouse indoor and outdoor air are given in Table 2. Greenhouse experiments were carried out between November–February. Table 2 indicates that the lowest temperature was observed in December and the highest in November. Outdoor relative humidity values ranged between 36.3–87.3% and indoor values were between 46.8–95.6%. The solar radiation values varied between 4.47–203.3.

The relationships between irrigation water salinity–soil salinity–evapotranspiraton and yield-some growth parameters for lettuce determined by multiple regression analysis are given in Table 3.

Effect of irrigation water salinity and soil salinity on the evapotranspiration (Model 1). The models for lettuce created in this study were based on pot data. Since evapotranspiration monitoring under natural dynamic conditions and especially under saline conditions is a difficult task, the experiment was carried out in pots. The variations of plant water consumptions due to salinity could easily be monitored by weighing the pots regularly.

Linear relationships were found between evapotranspiration, soil salinity and irrigation water salinity. Evapotranspiration increased with decreasing soil salinity at both high and low irrigation water salinity cases. The highest evapotranspiration was obtained in low soil salinity and irrigation water salinity (Fig. 1 a). Ayers and Westcot (1989) stated

1.5 times higher soil salinities than irrigation water salinities for leaching fractions of 15–20%. In our experiments, irrigation applications were carried out by considering a 20% leaching fraction.

There may be various reasons for difference in increase observed in this study and increase specified by Ayers and Westcot (1989). Leaching efficiency and salt deposition in soil can be the most important reasons for this difference. Soil salinity will change with leaching rates; plant growth and water consumption will be affected accordingly. Continuous soil salinity monitoring at a site is a difficult and exhaustive process. However, soil salinity estimation will be easier by using 3-D models constructed among ECe, ECw and ET values as shown in Figure 1. ECw value or irrigation water can easily be measured and plant water consumption can easily be determined by soil moisture monitoring.

Table 2. Monthly average inside and outside temperature, relative humidity and solar radiation

Month	Outside the greenhouse								
	temperature °C			relative humidity %			solar radiation W m^{-2}		
	max	min	mean	max	min	mean	max	min	mean
November	12.16	1.45	5.90	87.3	51.3	69.74	154.65	17.02	90.96
December	5.00	−3.94	0.26	87.3	58.7	69.92	106.70	14.51	74.40
June	8.59	−1.31	3.53	84.3	36.3	61.50	120.14	5.58	86.09
February	8.08	−2.17	2.90	85.3	49.0	64.08	203.30	54.70	119.16
Month	Inside the greenhouse								
	temperature °C			relative humidity %			solar radiation W m^{-2}		
	max	min	mean	max	min	mean	max	min	mean
November	15.40	2.90	7.10	90.4	62.6	76.8	123.72	13.62	72.77
December	7.20	−1.05	2.60	95.6	74.4	80.1	85.36	11.61	59.52
June	11.60	0.85	4.80	90.3	46.8	72.4	96.11	4.47	68.87
February	10.90	1.20	5.40	92.8	52.4	70.5	16.64	43.76	95.33

Under saline conditions, irrigation doses should satisfy both the ET and leaching requirements (LR). A small error in the estimate of ET may create a considerable error in the intended extent of leaching because LR constitutes usually a small fraction of the irrigation. The ET for a given crop under given conditions can be adjusted to evaporation demand by using a known pan evaporation factor or calculations based on meteorological data. It is well documented that salinity reduces transpiration. Therefore, the estimation of ET according to these methods should be modified for saline conditions. A second way to estimate ET is to use the soil moisture deficit from field capacity. This method may introduce an error if a constant field capacity is assumed for different irrigation doses (Hoffman, Jobes, 1983). With 3-D models taking plant water consumption into consideration, possible changes in plant water consumption due to salinity can easily be determined without an estimated ET. In this way, required leaching water can be calculated more appropriately. Ferrer-Alegra and Stockle (1999) also tried to modify *CropSyst*, a management-oriented crop growth model, to assess crop response to salinity. They added an osmotic component to the soil water potential of the existing water uptake module and developed a function to account for salinity effects on root permeability. The model simulated well the effect of salinity on water use, biomass and crop yield.

Effect of evapotranspiration and soil salinity on the yield (Model 2). Ferrer-Alegra and Stockle (1999) stated that the effect of salinity on water uptake was the link to simulate crop growth reduction. In considering the effect of evapotranspiration and soil salinity, the yield of lettuce increased with decreasing soil salinity and increasing evapotranspiration. The highest yield was obtained in low soil salinity and high evapotranspiration (Fig. 1 b). While the relationship seems to be curvilinear when only the yield and soil salinity were taken into consideration (Fig. 1 c), it seems to be linear if the yield, plant water consumption and soil salinity were considered (Fig. 1 b).

Although salt tolerance data are available in the literature, their applicability to field conditions may be restricted (Bresler, Hoffman, 1984). Reduction of crop salt tolerance has been reported as the atmosphere is drier and soil water availa-bility decreases (Hoffman et al., 1990; Francois, Maas, 1993). Plant water consumption varies with changing atmospheric conditions. While in some years the weather at a place can get cool, it may get hot in some other years. Plant water consumption is higher during the hot years. Salt response of plants may change with climate. Impacts of climate over salinity can be considered by taking soil salinity and plant water consumption into consideration in 3-D models for evaluation of salinity on plant growth. More reliable universal models may be created with these 3-D models.

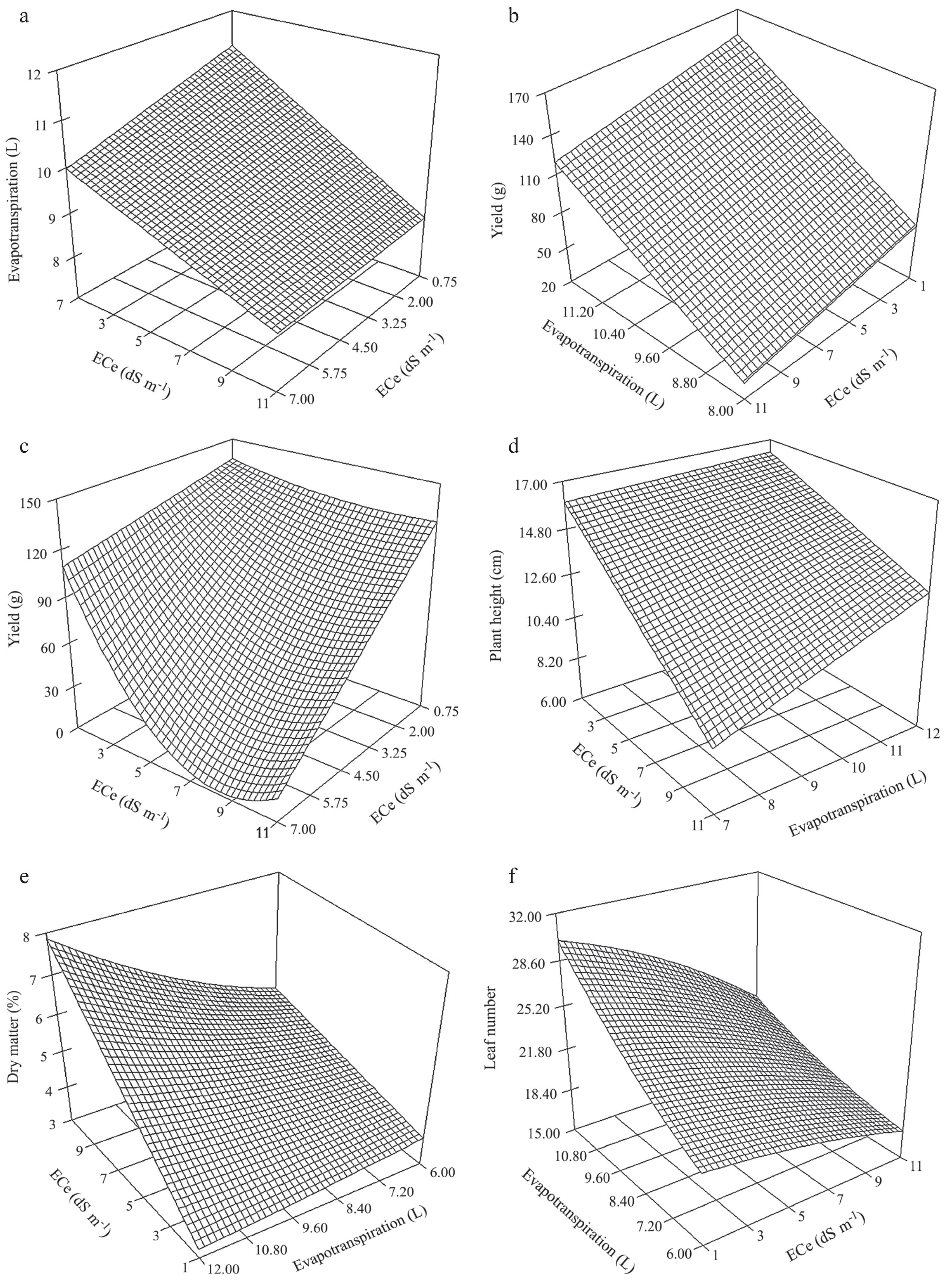

Figure 1. The relationships between: evapotranspiration and irrigation water salinity–soil salinity (a), yield and evapotranspiration–soil salinity (b), yield and irrigation water salinity–soil salinity (c), plant height and evapotranspiration–soil salinity (d), dry matter content and evapotranspiration–soil salinity (e), number of leaves and evapotranspiration–soil salinity (f)

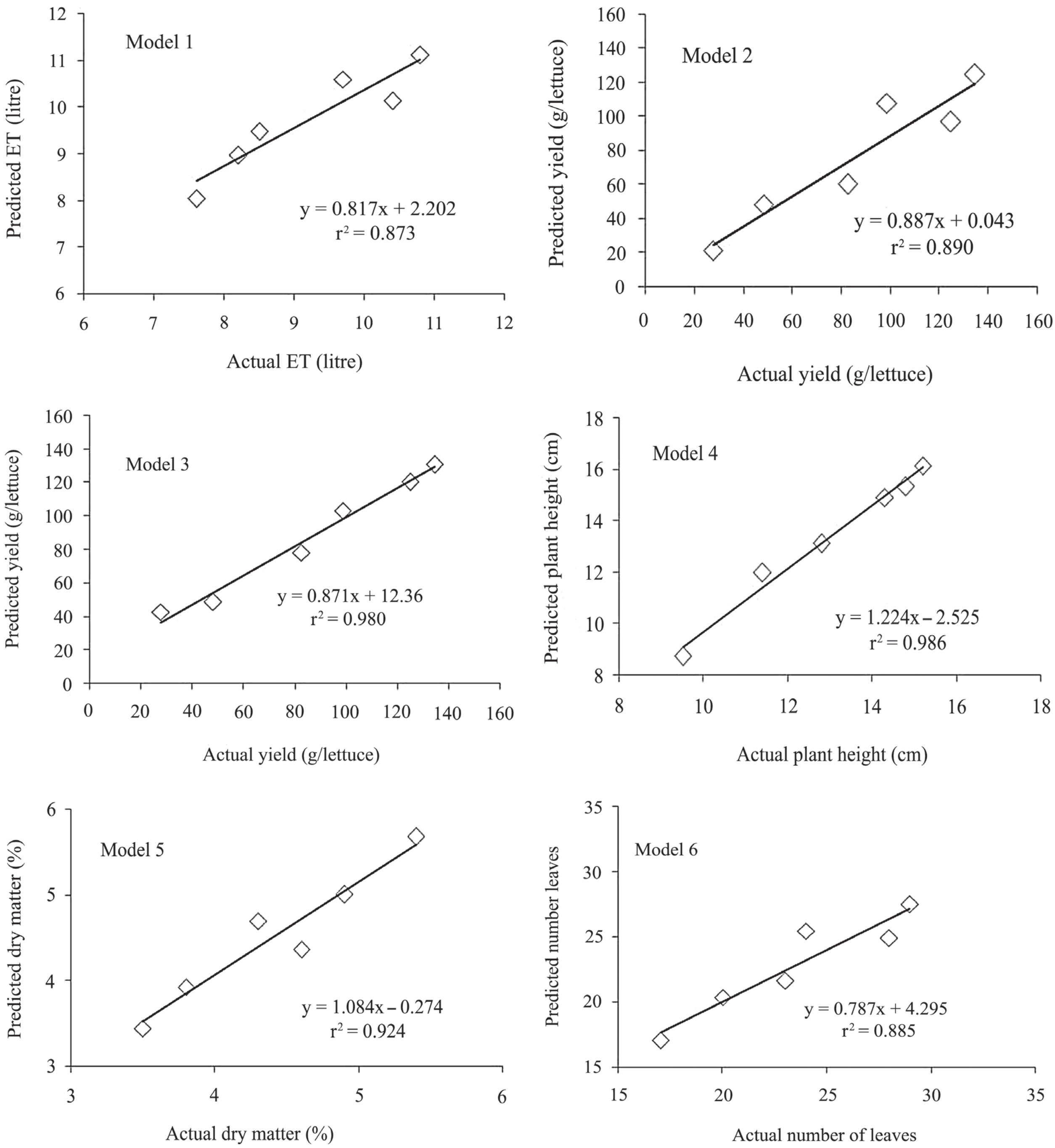

Figure 2. Comparison of growth, yield and evapotranspiration characteristics of lettuce grown under different irrigation water salinity with predicted values from multiple regression analysis

Effect of irrigation water salinity and soil salinity on the yield (Model 3). In this study, plant water consumption under varying climate and soil salinity conditions was used together with salinity of soil saturated extract to determine salt response of plants. In this way, impacts of variable climate conditions were tried to be reflected in plant salt tolerance model.

The effects of soil salinity and irrigation water salinity on the yield of lettuce were examined. The yield of lettuce in both high irrigation water salinity and low irrigation water salinity cases increased with decreasing soil salinity. A curvilinear relationship was observed between soil salinity and yield. In low irrigation water salinity cases, the yield of lettuce increased with decreasing soil salinity. The highest yield was determined in low irrigation water salinity and soil salinity, whereas the lowest yield was obtained in high irrigation water salinity and soil salinity (Fig. 1 c).

The model developed by Maas and Hoffman (1977) is commonly used to model the salt tolerances of plants. In this model, yield loss is not observed until a threshold salinity value, and then yield exhibits a linear decrease with per unit increase in salinity after this threshold value. In this model, there is also a salinity value with zero-yield and plant death. Ünlükara et al. (2008 b) determined the threshold value of 1.1 dS m^{-1} for lettuce and a yield decrease of 9.3% after this threshold value. Based on these values, lettuce was exposed to 45.6% yield loss at 6 dS m^{-1} level.

While the yield decrease with soil salinity was linear until 6 dS m^{-1} level, lower decreases were observed after 6 dS m^{-1}. Maas and Hoffman (1977) stated in their model that relationship between soil salinity and yield was linear until 50% yield loss and this linearity was lost at excessive salinity levels.

The relationship between irrigation water salinity and yield seems to be more linear. However, the obtained relationships between irrigation water and yield may direct the researchers toward erroneous conclusions because soil salinity and yield may significantly be affected by leaching fractions in irrigation applications. In this study, leaching fraction was taken as LF = 0.20 and results were obtained for these conditions.

Effect of evapotranspiration and soil salinity on plant height (Model 4). The plant height of lettuce was not affected by decreasing and increasing evapotranspiration and low soil salinity. Changes in plant height were observed with increasing soil salinity. The plant height increased with decreasing soil salinity in all cases of evapotranspiration. The lowest plant height was determined in low evapotranspiration and high soil salinity, whereas the highest plant height was obtained in high evapotranspiration and low soil salinity (Fig. 1 d).

Effect of evapotranspiration and soil salinity on dry matter content (Model 5). Significant interactive relationships were determined as seen in Figure 1 e. The dry matter content in all cases of evapotranspiration increased with increasing soil salinity. The dry matter content in low soil salinity cases increased with decreasing evapotranspiration, whereas in high soil salinity cases increased with increasing evapotranspiration. The highest dry matter content was obtained in high evapotranspiration and soil salinity. The lowest dry matter content was obtained in high evapotranspiration and low soil salinity.

Effect of evapotranspiration and soil salinity on number of leaves (Model 6). Significant relationships were observed between number of leaves and evapotranspiration and soil salinity (Fig. 1 f). Number of leaves increased with decreasing soil salinity in all cases of evapotranspiration. The highest number of leaves was obtained in the low soil salinity and high evapotranspiration.

Andriolo et al. (2005) found that dry mass of leaves increased by 24.4% with an increase in salinity from 0.80 dS m^{-1} to 2.81 dS m^{-1}. They grew lettuce under five salinity levels (0.80, 1.93, 2.81, 3.73 and 4.72 dS m^{-1}) in a hydroponical experimental bed and reported that number of leaves was 18 per plant and was not affected by treatments.

The data given in Table 1 for validation were used to test the validity of the models given in Table 3. Precision analyses of models given in Table 3 are presented in Figure 2. The coefficient of determination values (r^2) for Model 1–6 were 0.873, 0.890, 0.980, 0.986, 0.924, 0.885, respectively.

Table 3. The relationships between irrigation water salinity–soil salinity–evapotranspiraton and yield–some growth parameters for lettuce determined by multiple regression analysis

Model 1	The relationships between evapotranspiration and irrigation water salinity–soil salinity	ET = 11.64 − 0.214 × EC − 0.29 × ECe + 0.017 × EC × ECe SE = (0.178) (0.087) (0.0703) (0.008) r^2 = 0.89
Model 2	The relationships between yield and evapotranspiration–soil salinity	Yield = −102.48 − 3.165 × ECe + 21.4 × ET SE = (10.886) (0.305) (0.963) r^2 = 0.97
Model 3	The relationships between yield and irrigation water salinity–soil salinity	Yield = 134.56 − 4.18 × EC × ECe + 0.253 EC × ECe^2 SE = (3.873) (0.412) (0.034) r^2 = 0.91
Model 4	The relationships between plant height and evapotranspiration–soil salinity	PH = 16.74 − 1.15 × ECe + 0.066 × ECe × ET SE = (0.264) (0.151) (0.019) r^2 = 0.88
Model 5	The relationships between dry matter content and evapotranspiration–soil salinity	DM = 4.47 − 0.14 × ET + 0.0032 ECe × ET^2 SE = (0.135) (0.013) (7.5×10^{-5}) r^2 = 0.98
Model 6	The relationships between number of leaves and evapotranspiration–soil salinity	LN = 17.13 − 0.0029 × ECe^2 × ET + 0.093 × ET^2 − 0.003 × ET^2 × ECe SE = (0.368) (0.0005) (0.004) (0.0007) r^2 = 0.98

Note. All r^2 (coefficient of determination) and coefficients were significant at $p < 0.001$.

Conclusions

In this study, salt tolerances of plants were evaluated by taking plant yield, plant height, and amount of dry matter, number of leaves, soil salinity and plant water consumption into consideration with 3-D models. Following conclusions can be drawn from this study carried out to determine the impacts of evapotranspiration and soil salinity over some growth parameters and yield of lettuce (*Lactuca sativa* var. *crispa*):

1. Evapotranspiration increased with decreasing soil salinity at different irrigation water salinity levels. Therefore, irrigation doses should meet both evapotranspiration lettuce (ET) and leaching requirements (LR) under saline conditions.

2. The yield of lettuce increased with decreasing soil salinity and increasing evapotranspiration. The decrease in yield with soil salinity was linear until 6 dS m^{-1} and the decrease with irrigation water salinity were found to be more linear.

3. The plant height of lettuce was not affected by decreasing and increasing evapotranspiration and low soil salinity. Changes in plant height were observed only increasing soil salinity.

4. The dry matter content of lettuce leaves in all cases of evapotranspiration increased with increasing soil salinity.

5. Number of leaves increased with decreasing soil salinity in all cases of evapotranspiration.

6. The models 2, 5 and 6 representing respectively the relationships between yield and evapotranspiration–soil salinity, between dry matter content and evapotranspiration–soil salinity, between number of leaves and evapotranspiration–soil salinity were found highly stronger (r^2 = 0.97, 0.98, 0.98, respectively). These models can be used to estimate yield, dry matter and number of leaves of lettuce by using the parameters of evapotranspiration and soil salinity.

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Evapotranspiracijos ir dirvožemio druskingumo įtaka salotų augimo rodikliams bei derliui

B. Cemek[1], A. Ünlükara[2], S. Karaman[3], Z. Gökalp[2]

[1]Turkijos Ondokuz Mayis universitetas
[2]Turkijos Erciyes universitetas
[3]Turkijos Gaziosmanpaşa universitetas

Santrauka

Augalų tolerancija druskingumui gali būti vertinama taikant keletą modelių, ir dauguma jų ribojančiu veiksniu laiko tik dirvožemio druskingumą. Tyrimų metu buvo atsižvelgta į klimato įtaką augalų druskingumo tolerancijai ir taikant 3-D modelius vertinta augalų derlius, aukštis, lapų skaičius, sausųjų medžiagų kiekis, dirvos druskingumas bei augalų drėgmės panaudojimas. Nustatyti ryšiai, siekiant išreikšti dirvožemio druskingumo bei evotranspiracijos kompleksinį poveikį salotų derliui ir augimo rodikliams: augalų aukščiui, lapų skaičiui, sausųjų medžiagų kiekiui. Didžiausias derlius gautas mažo druskingumo dirvožemyje ir esant intensyviai evapotranspiracijai, mažiausias – didelio druskingumo dirvožemje ir esant ekstensyviai evapotranspiracijai. Evapotranspiracijos bei dirvožemio druskingumo ir derliaus bei tirtų augimo rodiklių ryšiai dažniausiai buvo linijiniai. Evapotranspiracijos bei dirvožemio druskingumo įtakos platus diapazonas salotų derliui ir kai kuriems augimo rodikliams gali būti naudingas kontroliuojant druskingumą. Be to, druskingumo poveikis salotų augimui, vystymuisi ir derliui gali būti panaudojamas išvedant ryšius tarp evapotranspiracijos bei dirvožemio druskingumo.

Reikšminiai žodžiai: *Lactuca sativa* var. *crispa*, dirvožemio druskingumas, evapotranspiracija.