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Assessment of irrigation water salinity effects on red beet under Mediterranean conditions

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ABSTRACT

Plant tolerance to salinity stress is vital for irrigation scheduling, decision-making, planning and operation, and most critically, water resource management. Although there are numerous scientific data on the response of various plants to salinity stress, there are few studies on red beet in the literature, and specifically under Mediterranean conditions. This study aimed to investigate the effects of water salinity stress on water use, growth, yield parameters, and salinity threshold and slope values of red beet in Mediterranean conditions. In addition to control (0.6 dS m^{-1}), five irrigation water salinity levels including low (1.5 dS m^{-1}), medium-low (3.0 dS m^{-1}), medium (4.5 dS m^{-1}), medium-high (6.0 dS m^{-1}) and high salinity (8.0 dS m^{-1}) stresses were used as treatments. Increased water salinities caused increases in electrical conductivity and pH values of saturated soil paste extracts and drainage waters, while decreases in water use affected plant height storage root yield and water use efficiency. The salinity threshold and slope values of red beet were determined as 3.10 dS m^{-1} and 4.42% per dS m^{-1}.

1. Introduction

Salinity limits plant productivity, particularly in arid and semi-arid climates and is seen to be one of the most significant environmental challenges (Ashraf and Harris 2004). Soil and/or irrigation water salinity is one of the major abiotic stress factors on agriculture worldwide, and the situation has worsened over the last 20 years due to the increase in irrigation requirements in arid and semi-arid regions such as those found in the Mediterranean region (Munns and Gilliham 2015). It is estimated that about 20% of total cultivated and 33% of irrigated agricultural lands are affected by high salinity in the world. Furthermore, the salinized areas are increasing at a rate of 10% annually for various reasons such as low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water, and poor cultural practices (Jamil et al. 2011). Increased salinization of arable land is expected to have devastating global effects, resulting in 30% land loss within the next 25 years, and up to 50% by the year 2050 (Wang et al. 2003; Jamil et al. 2011).

Even though, most of the salinity and all of the sodicity is natural, a significant proportion of recently cultivated land has become saline because of land clearing, shallow saline water tables and saline irrigation water especially coupled with poor irrigation management. Crops grown on saline soils suffer on an account of high osmotic stress (physiological drought), ion toxicities, nutritional disorders (ionic stress), poor soil physical conditions and reduced crop productivity (Shrivastava and Kumar 2015). However, with proper scheduling, saline water available in different regions of the world has been used successfully for irrigation purposes (Rhoades et al. 1992). Theiveyanathan et al. (2004) claimed that accurate scheduling of irrigation, essential for maximizing crop production, requires a good knowledge of water demand and salinity tolerance of the crop in addition to soil water characteristics.

Soil salinity response and tolerance of plants vary widely among crop species and varieties. Although salinity threshold and slope values of more than 130 crop species have been determined under experimental conditions, there is an obvious need for research since little or no useful information exists on crop salt tolerance for a great number of species (Shannon and Grieve 1999). The purpose of this study was to generate realistic data on red beet (*Beta vulgaris* var. *Conditiva* Alef.) under irrigation water salinity levels up to 8.0 dS m^{-1} to fill this gap in the literature.

2. Materials and methods

2.1. Experimental site

The experiment was carried out at the Akdeniz University's Agricultural Research and Implementation Area in Antalya, Turkey, under a polyethene-covered rain-out shelter with uncovered sides. The experimental area is located at 36° 53' 15" north latitude and 30° 38' 53" east longitude, with an average altitude of 54 meters. The Mediterranean climate prevails in this area, with hot, dry summers and mild, wet winters. The long-term annual average temperature is 18.8°C, with the lowest average temperature of 10.0°C and a temperature difference (T_{max}-T_{min}) of 8.9°C in January and the highest average temperature of 28.4°C with a temperature difference of 11.4°C in July. The total annual precipitation is 1059 mm, 538 mm falling between January and April, 61 mm between May and September, and 460 mm between October and December (Anonymous 2021).

2.2. Plant material

The plant material used was the red beet cultivar of *Beta vulgaris* var. *Conditiva* Alef.. As a cool climate vegetable, it grows best at 15-18ºC in well-drained loam, sandy or clayey loam soils. The tap root of the plant can reach a depth of 30-40 cm. The plant has the highest water consumption during the period when the storage roots begin to develop. Compared to storage roots, K, Mg, Na, P and vitamin A and C are richer in fresh leaves. Although the fresh beet leaves are used as a filling ingredient of the pasteries, the main part of the plant which is consumed is the storage roots which are pickled or canned (Şalk et al. 2008).

2.3. Experimental design and treatments

The experiment was conducted as a randomized complete block design with four replications per treatment. There were six irrigation water salinity levels (S) with different electrical conductivities including S_0= 0.6 dS m^{-1} (control), S_1= 1.5 dS m^{-1} (low), S_2= 3.0 dS m^{-1} (medium-low stress), S_3= 4.5 dS m^{-1} (medium), S_4= 6.0 dS m^{-1} (medium-high) and S_5= 8.0 dS m^{-1} (high). The experimental soil was sieved with a 4 mm screen to remove large particles and 33 kg of air-dried soil was placed in each lysimeter pot 36 dm^3 in volume. Properties of the soil used in the experiment are presented in Table 1.

Table 1. Some physical and chemical properties of the experimental soil

Physical Properties			
Particle size distribution		Soil water contents	
Sand (%)	57.8	Saturation (%)	31.5
Silt (%)	20.4	Field capacity (%)	17.0
Clay (%)	21.8	Wilting point (%)	9.5
Bulk density (g cm^{-3})	1.4		
Chemical Properties			
Electrical cond. (paste) (dS m^{-1})	0.4		
pHe (paste)	7.7		

Saline waters were prepared by using $CaCl_2$, $MgSO_4$ and NaCl salts. For all salinity treatments, the sodium adsorption ratio (SAR) was kept as close as possible to the SAR value of the tap water source in order to prevent the dominant effect of a particular ion, eliminate the effect of the SAR on the results and therefore only examine the effects of the total salinity. To achieve the desired electrical conductivity values in irrigation waters (EC_i) with a SAR value of less than 5 and a Ca/Mg ratio of 1/1, the required amounts of salts were calculated and EC_i values of the treatments were checked in the laboratory (Duzdemir et al. 2009a, 2009b; Ünlükara et al. 2010; Kurunc et al. 2011; Hancioglu et al. 2019).

All irrigation water salinity treatments were irrigated when 45 to 55% of available water was consumed in the control treatment. To control the soil water status, lysimeters belonging to the control treatment were weighed every other day. The amount of applied irrigation water (AIW) was determined by weighing each lysimeter pots just before irrigation application and calculated by using Equation (1) (Duzdemir et al. 2009a, 2009b; Ünlükara et al. 2010; Kurunc et al. 2011; Hancioglu et al. 2019):

$$AIW = \frac{W_{fc} - W_a}{\rho_w (1 - LF)} \tag{1}$$

Where: W_{fc} and W_a are the weights of the lysimeter at field capacity and just before irrigation practice (kg); ρ_w is bulk density of water (1 kg l^{-1}); and LF is leaching fraction, which was set to a target of 0.15 as suggested by (Ayers and Westcot 1985). A drainage container underneath each lysimeter pot was used to collect drainage water due to the leaching practices. The volume of the drainage water collected in the containers was measured after the drainage ceased in order to control the targeted leaching fraction of 0.15 and adjust field capacity changes of the lysimeters due to plant growth. Also, in situ EC and pH analyses of the leachate water (EC_{dw} and pH_{dw}) were measured with an EC-pH meter after each irrigation (Hancioglu et al. 2019).

Three red beet seeds were directly sown in each lysimeter pot at the end of October. One month after sowing, only one seedling was left in each pot and the saline water application was started. During the experimental period, 5 irrigation practices were realised, except for the life water. Irrigation practices were performed at 11 to 21-day intervals. In order to meet the plant nutrition needs, 3.45 g potassium nitrate and 2.9 g of MKP (mono potassium phosphate) at the beginning of the experiment and 0.7 g of ammonium nitrate at 1.5 months after starting the experiment were applied to each lysimeter (Şalk et al. 2008).

2.4. Data collection and analysis

The volume of crop evapotranspiration (ET_v) between two-sequenced irrigation applications was calculated by using water balance (Equation 2):

$$ET_v = \frac{(W_n - W_{n+1})}{\rho_w} + (AIW - DW) \tag{2}$$

Where: W_n and W_{n+1}, are the weights of the lysimeter before nth and (n+1)th irrigation application (kg), ρ_w is bulk density of water (1 kg l^{-1}) and AIW and DW are amounts of applied and, if any, drainage water (L). The daily ET (ET_d) was calculated from ET_v volume divided by the surface area of soil in the lysimeter and the number of days between the two-sequenced irrigation applications. Then the seasonal ET (ET_s) was calculated from ET_d and the length of the growing season.

Plant heights were measured weekly, in addition certain physical and physiological changes were recorded. At the end of February, the harvested plants were cleaned, leaves and storage roots were weighed and the tap root lengths were measured in the laboratory. Water use efficiency was obtained by using Equation (3):

$$WUE = \frac{Y_{sr}}{ET_s} \tag{3}$$

Where: Y_{sr} is storage root yield (g) and ET_s is seasonal evapotranspiration (mm season^{-1}).

Immediately after the harvest, soil samples were obtained from the lysimeters. These samples were air-dried and sieved with a 2 mm screen. Then electrical conductivities of the saturated extracts (EC_e) and pH values (pH_e) were measured by using an EC and pH meter (Richards 1954; Carter et al. 2007).

The threshold soil salinity and slope values for the storage root yield of red beet were obtained by using the salt tolerance model suggested by Maas and Hoffman (1977) (Equation 4):

$$\frac{Y_a}{Y_m} = 1 - \frac{b}{100} \times \left(EC_e - EC_{e(threshold)} \right) \qquad (4)$$

Where: Y_m and Y_a are the maximum and actual yields (g) from the control (non-saline) and the saline treatments, respectively, b is the slope value (% per dS m^{-1}), $EC_{e\ threshold}$ and EC_e are threshold soil salinity and soil salinity beyond the threshold value (dS m^{-1}).

2.5. Statistical analysis

SPSS statistical analysis software (IBM SPSS Inc. 2012) was used to analyze the obtained data at a significance level of 1%. Where appropriate, mean separations of the data were attained by the Duncan test at a $P<0.05$ level of significance. Correlation coefficient (r) values were used to determine the strength of the linear relationships between the investigated parameters as strong ($r \geq 0.8$ or $r \leq -0.8$), moderate ($0.5<r<0.8$ or $-0.8<r<-0.5$) and weak ($-0.5 \leq r \leq 0.5$) (Peck and Devore 2012).

3. Results

Statistical analysis results for the investigated parameters including electrical conductivity and pH values of the soil and drainage water, evapotranspiration, plant height, tap root length, fresh leaf weight, storage root yield and water use efficiency are given in Table 2. If evaluated in general; tap root length and fresh leaf weight were not affected by irrigation water salinity levels, however, plant height and water usage efficiency at 5% and EC_e, pH_e, EC_{dw}, pH_{dw}, evapotranspiration and storage root yield at 1% probability level showed significant differences among the treatments.

3.1. Effect on soil and drainage water

In the experiment, attained leaching fractions ranged from 15% (for S_0, S_3 and S_4) to 16% (for S_1, S_2 and S_5) with no significant difference among treatments, indicating that a constant leaching fraction was maintained as aimed for. Since the same leaching fraction with different salt concentrations were applied to the plants during the growing period, significant differences among treatments were observed for EC_e, pH_e, EC_{dw} and pH_{dw} values ($P<0.01$). In general, increasing salinities caused increases in both soil and drainage water EC but decreases in pH values (Table 2).

The changes in average EC_{dw} values throughout the growing season are presented in Figure 1. Differences in average EC_{dw} values among the treatments started to form at the beginning of the experiment. In general, EC_{dw} values throughout the growing season presented relatively stable trends for control and low salinity treatments, while it shows a moderate increase for medium-low salinity and high increased trends for medium, medium-high and high salinity treatments (Figure 1).

The Duncan's test results showed that the lowest soil and drainage water EC value was determined for the control treatment (0.76 and 0.87 dS m^{-1}, respectively), whereas the highest value was observed for high salinity treatment (11.13 and 12.28 dS m^{-1}, respectively) (Table 2). Unlike EC_e and EC_{dw} values, the highest pH_e value was observed for the control (7.75), low (7.75) and medium-low (7.59) salinity treatments whereas the highest pH_{dw} value for the control treatment (8.04). The lowest both pH_e and pH_{dw} value were obtained for the high salinity treatment but they were not significantly different from those of medium and medium-high treatments (Table 2).

3.2. Effect on crop evapotranspiration

Throughout the experiment, changes in daily ET values (mm day^{-1}) of each treatment were recorded and are presented in Figure 1. Differences in daily water consumption among treatments began to assume a pattern at the beginning of the experiment. The highest daily ET value in all treatments, except medium-high and high water salinity, occurred during the third irrigation period. However, seasonal ET (175-261 mm) and daily ET (2.3-3.4 mm) showed statistically significant but relatively low change among treatments. The biggest variation in daily plant water consumption was observed for control, low and medium-low salinities while the lowest change occurred under high water salinity treatment (Figure 2).

The highest ET value was determined as 261 mm for control but this value did not differ statistically from those of low and medium-low salinity treatments. As expected, the lowest water consumption was measured for medium-high (189 mm) and high salinity treatments (Table 2). Compared to the control, decreases in water consumption ranged from 16% (medium salinity) to 33% (high salinity).

3.3. Effects on growth and yield parameters

Throughout the growing season, changes in plant heights under different irrigation water salinity levels were recorded and are presented in Figure 3. In general, it is seen that plant heights increased rapidly at the beginning of the experiment, and then slowed down during the 4-5 weeks before harvest. By the end of the growing period, the average plant lengths ranged from 42.3 cm for low and medium-low salinities, which were not significantly different from those of control, medium and medium-high salinities, to 34.8 cm for high water salinity, which was statistically different from all other treatments (Table 2).

Even though tap root lengths and fresh leaf yields of red beet plants ranged from 15.8 to 18.5 cm and from 142 to 153 g $plant^{-1}$, respectively, statistical analyses showed that these parameters were not affected by increasing irrigation water salinities. On the other hand, average storage root yields of red beet plant showed statistically significant changes due to increasing irrigation water and hence soil salinity levels ($P<0.01$). The highest storage root yield was observed for control (244 g $plant^{-1}$) but it was not significantly different from that of low salinity treatment (237 g $plant^{-1}$) whereas the lowest storage root yield (140 g $plant^{-1}$) was recorded for high salinity treatment (Table 2). Compared to control, calculated decreases in storage root yields were 6, 10, 24 and 42% for medium-low, medium, medium-high and high water salinity treatments, respectively.

3.4. Effect on plant water use efficiency

Statistical analysis results show that the WUE values of red beet plant were significantly affected by the irrigation water salinity levels ($P<0.05$). According to the results, while the highest water use efficiency was obtained from medium salinity with 1.01 g mm^{-1}, this value was found to be significantly different from high water salinity treatment (0.80 g mm^{-1}) which has the lowest water use efficiency (Table 2).

Table 2. Effect of irrigation water salinity on soil, drainage water and water use, growth, and yield parameters of red beet

Analysis	Irrigation water salinity (dS m^{-1}) treatments						P>F
	S_0 (0.6)	S_1 (1.5)	S_2 (3.0)	S_3 (4.5)	S_4 (6.0)	S_5 (8.0)	
Leaching fraction	0.15#	0.16	0.16	0.15	0.15	0.16	ns
Saturated paste extract EC_e (dS m^{-1})	0.76f †	2.31e	5.14d	7.50c	8.62b	11.13a	**
Saturated paste extract pH_e	7.75a	7.75a	7.59a	7.49b	7.52b	7.38b	**
Drainage water EC_{dw} (dS m^{-1})	0.87f	1.97e	5.16d	7.87c	9.83b	12.28a	**
Drainage water pH_{dw}	8.04a	7.94b	7.71c	7.64cd	7.63d	7.62d	**
ET (mm season^{-1})	261a	253a	235ab	220b	189c	175c	**
Plant height (cm)	41.8a	42.3a	42.3a	39.3ab	38.0ab	34.8b	*
Tap root length (cm)	15.8	16.0	17.5	18.3	18.5	18.5	ns
Fresh leaf yield (g plant^{-1})	153	156	144	143	142	143	ns
Storage root yield ((g plant^{-1})	244a	237ab	229bc	220c	185d	140e	**
Water use efficiency (g mm^{-1})	0.94a	0.95a	0.98a	1.01a	0.99a	0.80b	*

#: each value is the mean of four replications, †: 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 probability level, *: significant at the 0.05 probability level, ns: non-significant.

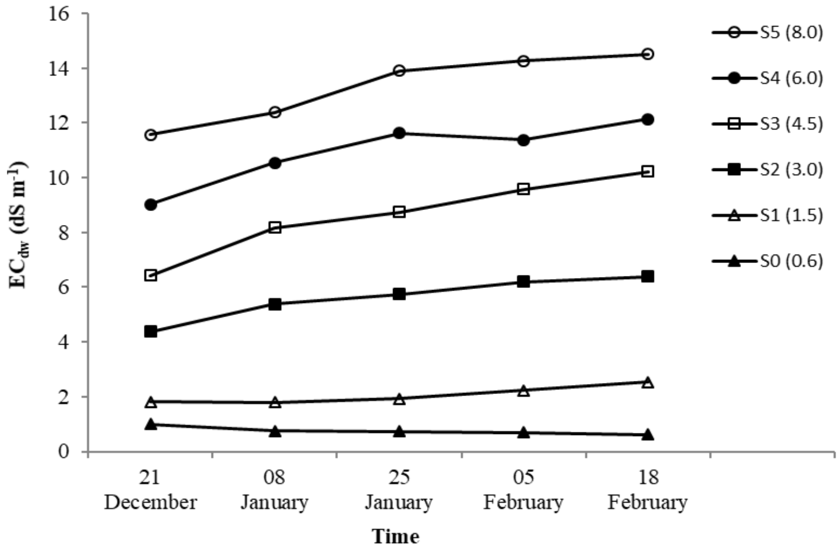

Figure 1. Changes on drainage water throughout the growing season.

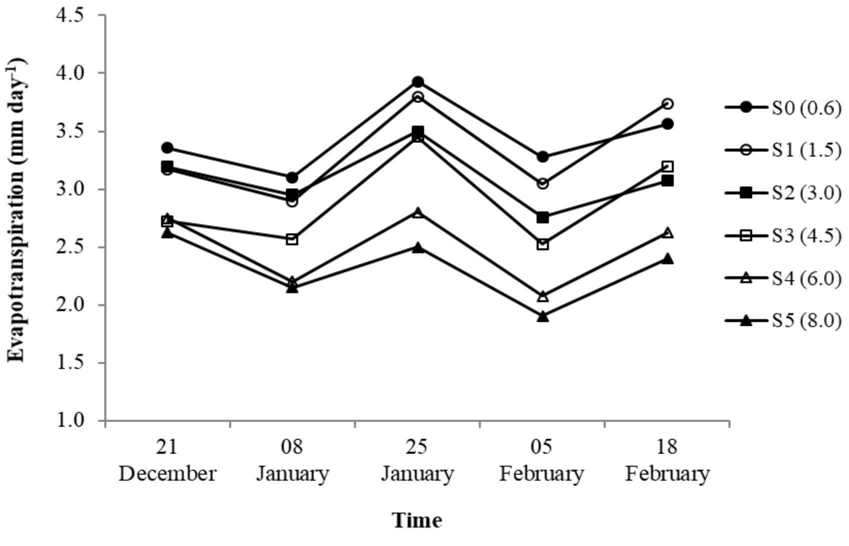

Figure 2. Changes on daily ET of red beet throughout the growing season.

The salinity-response model was created and threshold salinity and slope values were determined for red beet storage root yield. The salt tolerance model for red beet plant is presented in Figure 4. As shown, threshold salinity and slope values of red beet plant were determined as 3.10 dS m^{-1} and 4.42%, respectively.

3.5. Relationship between parameters

The correlation coefficients (r) and significance levels of the relationships between all the parameters obtained from the experiment are given in Table 3. There were significantly important (P<0.01) strong-positive linear correlations between EC_e vs EC_{dw}; ET vs storage root yield, whereas strong-negative linear correlations between EC_e vs pH_{dw}, ET and storage root yield; EC_{dw} vs pH_{dw}, ET and storage root yield. Similarly, significantly important (P<0.01) moderate-positive linear correlations between pH_e vs pH_{dw}, ET and storage root yield; pH_{dw} vs ET, plant height and storage root yield; tap root length vs fresh leaf yield; storage root yield vs plant height and water use efficiency whereas moderate-negative linear correlations between EC_e vs pH_e and plant height; EC_{dw} vs pH_e and plant height were observed. There were also significantly important (P<0.05) weak-positive linear correlations between plant height vs ET and water use efficiency (Table 3).

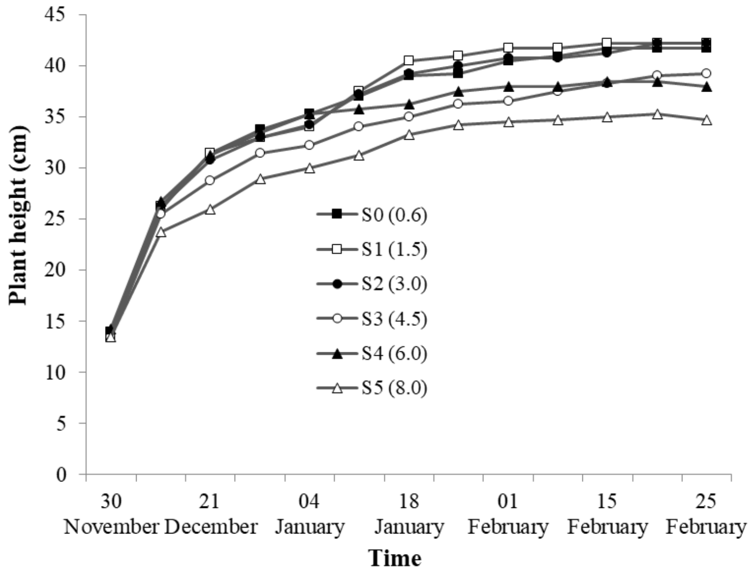

Figure 3. Changes on red beet plant heights throughout the growing season.

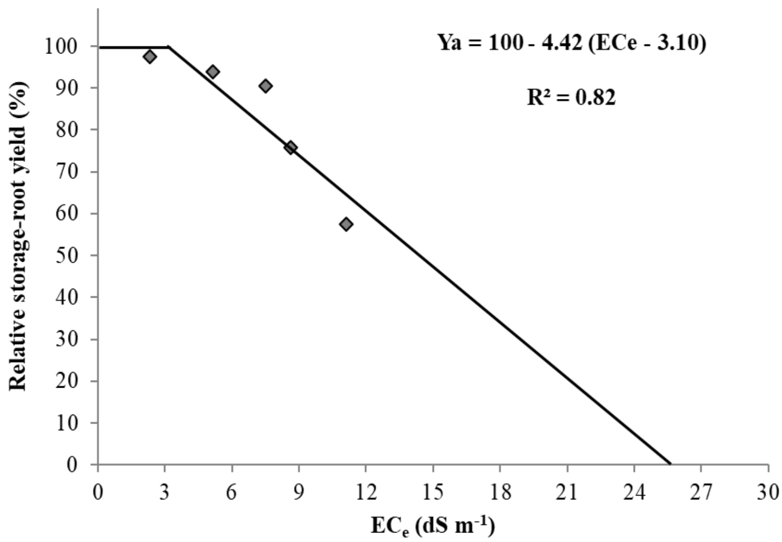

Figure 4. Yield response factors for storage root and fresh leaf yields of red beet.

Table 3. Relationship between investigated parameters

	EC_e	pH_e	EC_{dw}	pH_{dw}	ET	PH	TRL	FLY	SRY
pH_e	-0.73 **								
EC_{dw}	0.99 **	-0.74 **							
pH_{dw}	-0.89 **	0.65 **	-0.89 **						
ET	-0.86 **	0.67 **	-0.89 **	0.72 **					
PH	-0.61 **	0.37 ns	-0.60 **	0.52 **	0.42 *				
TRL	0.29 ns	-0.26 ns	0.31 ns	-0.35 ns	-0.40 ns	-0.28 ns			
FLY	-0.23 ns	0.14 ns	-0.24 ns	0.23 ns	0.17 ns	-0.08 ns	0.63 **		
SRY	-0.87 **	0.60 **	-0.90 **	0.68 **	0.83 **	0.66 **	-0.29 ns	0.12 ns	
WUE	-0.24 ns	0.06 ns	-0.24 ns	0.08 ns	-0. 04 ns	0. 50 *	0.08 ns	-0.06 ns	0.53 **

EC_e: Electrical conductivity of soil saturated paste extract, pH_e: pH of soil saturated paste extract, EC_{dw}: Electrical conductivity of drainage water, pH_{dw}: pH of drainage water, ET: evapotranspiration, PH: plant height, TRL: tap root length, FLY: fresh leaf yield, SRY: storage root yield, WUE: water use efficiency, **: significant at $P<0.01$, *: significant at $P<0.05$, ns: non-significant.

4. Discussion

Ayers and Westcot (1985) declared that assuming ECe= 0.5×ECsw, (EC of soil water), the expected EC_e/EC_w ratio is 1.6 under a leaching fraction of 0.15 i.e. the ECe value will be about 1.6 times of the EC_w. The EC_e/EC_w ratios were calculated as 1.26, 1.54, 1.71, 1.67, 1.44, and 1.39 for the control, low, medium-low, medium, medium-high, and high water salinity levels, respectively. In general, EC_e/EC_w ratios of all treatments were close to the specified value except for the control treatment which had a relatively lower ratio. Similarly, EC_w and EC_e values under low, medium-low, medium, medium-high and high water salinity levels were 2.5, 5.0, 7.5, 10.0, and 13.3 times and 3.0, 6.8, 9.9, 11.4, and 14.7 times, respectively, higher than that of the control treatment. According to these results, compared to the control, the EC_w ratios of all treatments were less than the EC_e ratios of the same treatments.

EC_{dw} values can also be calculated from the EC_w/LF relationship (Ayers and Westcot 1985). Using the actual LF values given in Table 2, EC_{dw} values were calculated as 3.90, 9.23, 19.27, 31.01, 40.05, and 51.31 dS m^{-1} for the control, low, medium-low, medium, medium-high, and high water salinity levels, respectively. However, the actual EC_{dw} values were 4.50, 4.70, 3.73, 3.94, 4.08, and 4.18 times, respectively, which was less than those of the calculated EC_{dw}'s. All these results may indicate that the plant removes some salt from the soil and/or the number of irrigations applied during the growing period was not sufficient to stabilize soil and thus drainage salinity. The ongoing increases in the EC_{dw} values shown in Figure 1, especially for medium, medium-high, and high salinity levels, indicate that the equilibrium conditions in terms of salinity had not occurred in the soil and drainage water. As a general approach, soil and drainage salinities might become stable, by at least 4-6 irrigation applications and in some cases after a few growing periods depending on management practices, climate and soil characteristics, and the irrigation water salinity level (Ayers and Westcot 1985).

Daily mean ET values were calculated as 3.4, 3.3, 3.1, 2.9, 2.5, and 2.3 mm under the control, low, medium-low, medium, medium-high, and high water salinity levels, respectively. Similarly, many researchers reported decreased water consumption under salinity conditions for plants i.e. pepper (Ünlükara et al. 2015), oregano (Hancioglu et al. 2019), bell pepper (Kurunc et al. 2011), pea (Duzdemir et al. 2009a), cowpea (Duzdemir et al. 2009b), and eggplant (Ünlükara et al. 2010).

Storage root yields declined significantly, especially with an irrigation water salinity lever higher than 3.0 dS m^{-1}. Rhoades et al. (1992) concluded that yield is reduced due to excessive salinity, because plants divert their energy to making the biochemical adjustments necessary to survive under stress conditions, instead of plant growth and yield. Pessarakli (1991) reported that the use of nutrients taken by the plant under the salinity stress was greatly reduced and thus the growth and yield decreased significantly.

In Maas and Hoffman (1977), a threshold salinity of 4.0 dS m^{-1} and a slope value of 9.0% for red beet plant was reported. When compared, the threshold salinity and slope values determined in our study were found to be lower than those reported in Maas and Hoffman (1977). The disparities in these values are thought to be caused by the variety of plant used in the experiments and the differences in the environmental conditions in which the investigations were conducted.

5. Conclusions

In this study, the effects of irrigation water salinity on growth (plant height and tap root length), yield parameters (fresh leaf and storage root yields), evapotranspiration and water use efficiency of red beet were investigated. Under the same leaching fraction, different salt concentrations were applied to the plants throughout the growing season. In general, increasing irrigation water salinities caused increases in both soil and drainage water EC as expected but also decreases in pH values. Although the differences in EC_{dw} values among the treatments started to form at the beginning of the experiment, the ongoing increases in the EC_{dw} values under the application of saline irrigation water with greater than 3 dS m^{-1} indicate that the equilibrium conditions did not occur in soil and drainage water. Daily water consumption among treatments began to differentiate at the beginning of the experiment. Throughout the growing season, the smallest variation in daily plant water consumption was observed for irrigation waters having greater than 3.0 dS m^{-1} salinities. Even though tap root length and fresh leaf weight were not affected by irrigation water salinity levels, plant height and storage root yield have significantly declined especially with irrigation water salinity greater than 3.0 dS m^{-1}. Red beet plant water use efficiencies showed an increasing pattern with increased irrigation water salinity up to 6.0 dS m^{-1} and then decreased. In general, significantly important positive or negative linear correlations were observed among EC_e, pH_e, EC_{dw}, pH_{dw}, ET, plant height and storage root yield values. The salinity threshold and slope value of red beet were determined as 3.10 dS m^{-1} and 4.42% per dS m^{-1} for red beet plant under Mediterranean climate conditions.

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