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Assessment of water stress effects on red beet under the Mediterranean conditions

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ABSTRACT

Although there are numerous scientific data on the response of various plants to water stress, there are few studies on red beet in the literature, and non-specifically under the Mediterranean conditions. This study aimed to investigate the effects of water stress (WS) levels (control-WS_0, low-WS_{20}, medium-WS_{40}, high-WS_{60}, and extreme-WS_{80}) on water use, growth, yield parameters, and yield response factor of red beet (*Beta vulgaris*) in Mediterranean conditions. During the growing season, the highest daily evapotranspiration values were 3.7, 2.8, 2.1, 1.4, and 0.7 mm for the control treatment, low, medium, high, and extreme water stresses, respectively. Soil salinity, plant height, fresh leaf yield, and storage-root yield values were decreased as water stress increased. However, there were no significant differences in soil pH, taproot length, and plant water use efficiency between treatments. Significantly important strong- or moderate-positive linear correlations were observed between soil salinity, evapotranspiration, plant height, fresh leaf yield, and storage-root yield values. The yield response factors for red beet storage-root and fresh leaf yields were found to be 0.88 and 0.98, respectively. The results revealed that red beet is slightly tolerant to water stress, with comparatively lower storage-root and fresh leaf yield reductions under the reduced evapotranspiration caused by water stress.

1. Introduction

Abiotic stresses, such as high levels of light, radiation, temperature, water (drought, flooding, and submergence), chemical factors, salinity, essential nutrients, gaseous pollutants, and mechanical factors (Pereira 2016), are the leading causes of crop failure worldwide, limiting average yields by more than 50% (Wang et al. 2003) or as much as 70% (Boyer 1982). Many food crop yields will continue to decline in the future, due to the reduced water supplies and increased global warming trends and climate change in many locations (Lobell et al. 2011). According to Hasanuzzaman et al. (2013), worldwide crop production is expected to decrease around 30% by 2025 compared to current productivity.

Due to their great magnitude of impact and global spread, drought and salinity are two of the most important abiotic stresses (Bartels and Sunkar 2005; Shrivastava and Kumar 2015). More than a quarter of the world's land area is believed to be dry, with roughly a third of the world's cultivable land suffering from water scarcity (Kirigwi et al. 2004). Water extraction by root and water transport within the plant are reduced when soil moisture is consistently low, and a drought-like state prevails. Plants respond to drought stress by improving water extraction efficiency and root water usage efficiency while simultaneously lowering transpiration rates. These two abiotic stresses, in general, cause dehydration or osmotic stress by reducing the availability of water for important cellular activities and turgor pressure maintenance.

Irrigation is critical for food security, employment, and economic development in semi-arid regions of the world, particularly in the Mediterranean region. In such places, it is necessary to irrigate more areas using limited irrigation practices. Because plants' ability to endure water stress varies between species and among populations of the same species, understanding the water-yield function, which is the crop yield response to water stress, is critical in determining and evaluating reduced irrigation management applications (Doorenbos and Kassam 1986; Allen et al. 1998).

Despite extensive research on the response of practically all cultivated plants to water stress, there is little information in the literature about red beet as a vegetable. Therefore, the growth and yield parameters, evapotranspiration, water use efficiency, and water-yield response function of red beet were investigated in this study under various water regimes.

2. Materials and methods

2.1. Experimental site

The experiment was carried out under a polyethylene-covered rain-out shelter with uncovered sides at the Agricultural Research and Implementation Area of Akdeniz University, in Antalya, Turkey. The experimental area with an average altitude of 54 meters is located at 36° 53' 15" north latitude and

30° 38' 53" east longitude. The Mediterranean climate prevails in the 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 millimeters, 538 millimeters falling between January and April, 61 millimeters between May and September, and 460 millimeters between October and December (Anonymous 2021).

2.2. Plant material

The cultivar *Beta vulgaris* var. *Conditiva* Alef. was used as a red beet plant material in the experiment. The plants' taproot can grow to a depth of 30-40 cm. It grows best in well-drained loam, sandy, or clayey loam soils at 15-18^{o}C as a cool climate vegetable. This plant consumed the most water during the period that storage-root began to develop. Fresh leaves have higher levels of K, Mg, Na, P, and vitamin A and C than storage roots. Although fresh beet leaves are used as a filling ingredient of pastry, the storage roots are the most commonly consumed part of the plant, whether as a canned or pickled (Şalk et al. 2008).

2.3. Experimental design and treatments

The experimental design was a randomized complete block with four replications per treatment. There were four water stress (WS) levels including WS_{20} (low stress) WS_{40} (medium stress), WS_{60} (high stress), and WS_{80} (extreme stress), in addition to the control treatment (WS_0). To remove large particles, the soil used in the experiment was sieved with a 4 mm screen. A 33 kg air-dried soil was placed in lysimeter pots with a capacity of 36 dm^3. Table 1 shows the properties of the experimental soil used in the experiment.

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

Physical Properties			
Particle size distribution		Soil water contents (dry weight basis)	
Sand (%)	58.7	Saturation (%)	31.9
Silt (%)	20.7	Field capacity (%)	16.0
Clay (%)	20.6	Wilting point (%)	9.0
Bulk density (g cm^{-3})	1.4		
Chemical Properties			
Electrical cond. (paste) (dS m^{-1})	0.4		
pHe (paste)	7.7		

Before the experiment began, the soil in each lysimeter was saturated with tap water and then covered to prevent evaporation. After the lysimeters' drainage stopped, the weights were assumed to be field capacity. Similarly, weight of the lysimeters at wilting point were calculated by using the wilting point of the experimental soil given in Table 1. Throughout the experiment, all treatments were irrigated when 45 to 55% of available water in the control treatment was utilized. To keep track of the soil water status, replications of the control treatment were weighed every other day. The amount of applied irrigation water (AIW) was calculated by using the equation (1) (Duzdemir et al. 2009a, 2009b; Cemek et al. 2011; Kurunc et al. 2011; Ünlükara et al. 2015; Hancioglu et al. 2020):

$$AIW = \frac{W_{fc} - W_a}{\rho_w} x P_I \qquad (1)$$

where: W_{fc} and W_a are the weights of lysimeter at field capacity and right before irrigation (kg), ρ_w is bulk density of water (1 kg L^{-1}) and P_I is the water application rate, which is 1.0, 0.8, 0.6, 04, and 0.2 for WS_0, WS_{20}, WS_{40}, WS_{60}, and WS_{80} treatments, respectively. To capture possible drainage water, a drainage container was placed under each lysimeter pot. After each irrigation practice, the amount of drainage water volume, (if any) was measured as leachate and considered in the calculation of crop evapotranspiration.

At the end of October, three red beet seeds were sown directly into each lysimeter pot and 1.5 L of water was applied. One month after sowing, two seedlings were removed and only one seedling remained in each pot, then the experiment was initiated by saturating all treatments. After the experiment was initiated, 5 irrigation practices were realized during the experimental period. Irrigation practices were performed in intervals between 11- to 21-days. To meet the plant nutrition needs, 3.45 g of potassium nitrate and 2.9 g of MKP (mono-potassium phosphate) were applied to each lysimeter at the beginning of the experiment and 0.7 g of ammonium nitrate 1.5 months later (Şalk et al. 2008).

2.4. Analyses and measurements

The amount of crop evapotranspiration (ET_v) between two-sequenced irrigation applications was calculated by using the following water balance equation (2):

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

where: W_n and W_{n+1}, are the weights of lysimeter before n^{th} 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_d (mm day^{-1}) was calculated by ET_v divided to the surface area of soil in the lysimeter and the number of days between the two-sequenced irrigation applications.

Plant heights were measured on a weekly basis. At the end of February, the harvested plants were cleaned, leaves and storage roots were weighed and the taproot lengths were measured in the laboratory. Soil samples were taken from the lysimeters immediately after the harvest. These samples were air-dried and sieved. Saturation extracts were obtained from saturated soil pastes, then electrical conductivities of the extracts (EC_e) and pH values (pH_e) were measured by using an EC and pH meter (Richards 1954; Carter et al. 2007).

2.5. Water use efficiency and yield response factor

The water use efficiency, or the amount of consumed water to produce one-unit storage-root yield, was calculated by using the equation (3):

$$WUE = \frac{Y}{ET_s} \qquad (3)$$

where: Y is the fresh leaf yield or storage-root yield (g) and ET_s is seasonal evapotranspiration (mm $season^{-1}$).

The response of yield to the water supply was quantified through the yield response factor (k_y) by using the following water production function equation (4) (Stewart and Hagan 1973);

$$k_y = \left(1-\frac{Y_a}{Y_m}\right) \Big/ \left(1-\frac{ET_a}{ET_m}\right) \tag{4}$$

where: Y_m and Y_a are the maximum and actual storage-root yields (g), ET_m and ET_a are the maximum and actual seasonal evapotranspiration (mm season^{-1}) from the control (non-stress) and water stress treatments, respectively (Doorenbos and Kassam 1986).

2.6. Statistical analysis

SPSS statistical analysis software (IBM SPSS Inc. 2012) was used to analyze the obtained data at $P<0.01$ significance level. Where appropriate, mean separations of the data were realized by the Duncan test at a $P<0.05$ level of significance. Considering correlation coefficient (r) values, the strengths of the linear relationships between investigated parameters were evaluated as strong ($r \geq 0.8$), moderate ($0.5 < r < 0.8$), and weak ($r \leq 0.5$) (Peck and Devore 2012).

3. Results

Table 2 shows the statistical analysis results for the studied parameters including evapotranspiration; electrical conductivity and pH of saturated paste extract plant height; taproot length, fresh leaf weight, storage-root yield, and irrigation water use efficiency. In general, soil pH_e, taproot length, and water use efficiency values were not affected by the water stress treatments. However, soil EC_e ($P<0.05$) and evapotranspiration, plant height, fresh leaf yield, and storage-root yield values ($P<0.01$) showed significant differences between treatments.

3.1. Soil salinity and pH

The highest EC_e value was determined for the control (0.63 dS m^{-1}), low stress (0.61 dS m^{-1}), and medium stress (0.54 dS m^{-1}) treatments, whereas the lowest value was observed for extreme stress treatment (0.47 dS m^{-1}), which did not differ statistically from the high and medium stress treatments (Table 2). Compared to the extreme water stress treatments, the increases in EC_e values for low stress and control treatment were calculated to be 30 and 34%, respectively. Despite the fact that pH_e levels ranged from 8.00 to 8.13, there was no significant difference observed between treatments (Table 2).

3.2. Crop evapotranspiration

Throughout the experiment, changes in daily ET values (mm day^{-1}) of the treatments were calculated and are presented in Figure 1. In general, daily ET values for all treatments showed increased in the middle of the growing season around the third irrigation application and then decreased. As expected, the daily water consumption values for the control treatment were the highest during the whole growing season, but the lowest for the extreme water stress treatment. The highest daily ET values obtained in the middle of the growing season were 3.7, 2.8, 2.1, 1.4, and 0.7 mm for the control treatment, low, moderate, and extreme water stresses, respectively. The greatest variation in daily plant water consumption was again observed for the control while the smallest change occurred under extreme water stress (Figure 1).

According to the statistical analysis results, the seasonal ET values of red beet were strongly affected by water stress levels at the 0.01 probability level. Seasonal ET values were calculated as 241 (WS_0), 187 (WS_{20}), 140 (WS_{40}), 93 (WS_{60}), and 47 (WS_{80}) mm and they were significantly different from each other (Table 2). Compared to the control treatment, seasonal ET values for the low, medium, high, and extreme water stress treatments were reduced by 22, 42, 61, and 81%, respectively.

3.3. Growth and yield parameters

Throughout the growing season, changes in red beet plant heights under varied water stress levels were presented in Figure 2. During the first two weeks of the experiment, there was no significant difference in plant heights between treatments. Following this, differences in plant heights began, particularly for the high and extreme water stress treatments and the plants in these treatments remained stunted. At the end of the experiment, the control treatment had the highest average plant height (41.3 cm), but it was not substantially different from the low (38.0 cm) and medium stress (36.8 cm) treatments. On the other hand, it can be said that high and extreme water shortages in irrigation levels caused significant decreases in plant height (Table 2 and Figure 2). Compared to the control treatment, decreases in plant heights for WS_{60} and WS_{80} treatments were calculated as 35% and 45%, respectively.

Table 2. Effect of water stress on water use, growth, yield parameters of red beet

Analysis	Water stress levels					P>F
	WS_0	WS_{20}	WS_{40}	WS_{60}	WS_{80}	
Sat. paste extract EC_e (dS m^{-1})	0.63# a£	0.61 a	0.54 ab	0.50 b	0.47 b	*
Sat. paste extract pH_e	8.02	8.10	8.13	8.02	8.00	ns
ET (mm season^{-1})	241 a	187 b	140 c	93 d	47 e	**
Plant height (cm)	41.3 a	38.0 a	36.8 a	27.0 b	22.8 b	**
Tap root length (cm)	16.0	15.3	15.0	13.0	11.3	ns
Fresh leaf yield (g plant^{-1})	134.7 a	116.5 a	79.3 b	49.0 bc	29.0 c	**
Storage-root yield (g plant^{-1})	169.0 a	157.0 ab	116.8 bc	82.5 c	34.8 d	**
Water use efficiency (g mm^{-1})	0.70	0.84	0.83	0.89	0.74	ns

#: 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.

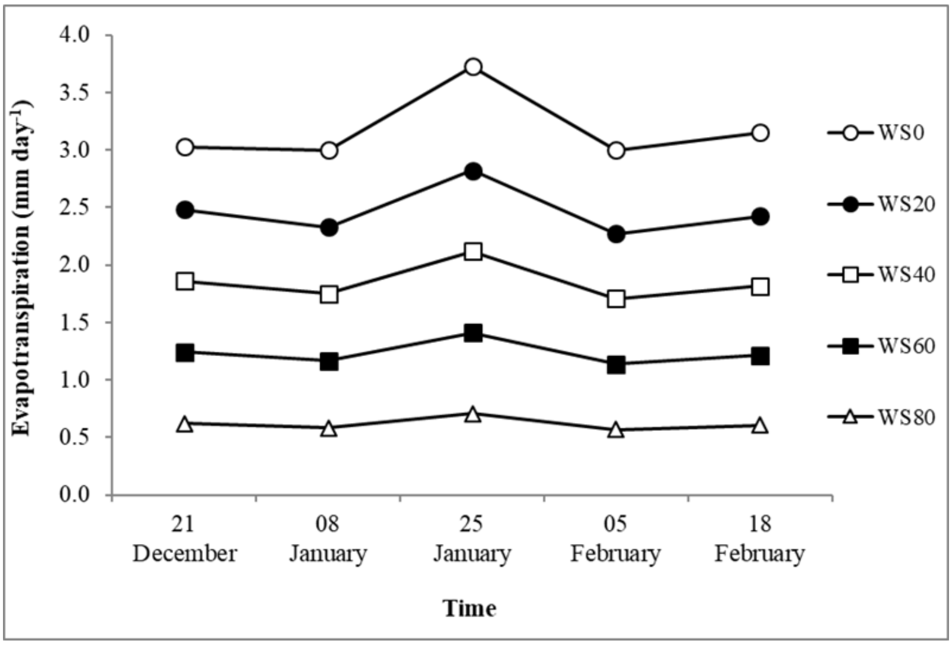

Figure 1. Changes on daily ET of red beet throughout the growing season.

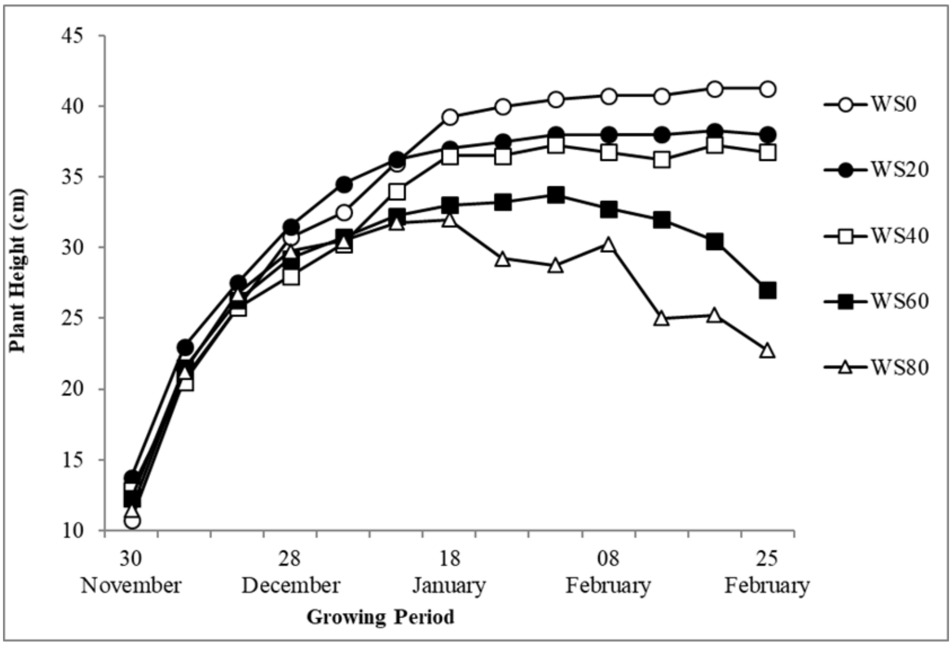

Figure 2. Changes on red beet plant heights throughout the growing season.

The statistical analyses revealed that increasing or decreasing water stresses did not cause a significant difference in red beet taproot lengths. On the other hand, fresh leaf and storage-root yields were significantly influenced by water stress levels ($P<0.01$). In general, increased water stresses resulted in considerable reductions in fresh leaf and storage-root yields. For these two yield parameters, the highest value was obtained from the control (134.7 and 169.0 g plant^{-1}, respectively) and low stress (116.5 and 157.0 g plant^{-1}, respectively) whereas the lowest value was observed from the extreme stress (29.0 and 34.8 g plant^{-1}, respectively) treatment, but the fresh leaf yield value was not significantly different from that of the high water stress treatment (49.0 g plant^{-1}) (Table 2). Considering the control treatments, calculated decreases were 41, 64, and 88% in fresh leaf yields and 31, 51, and 79% in storage-root yields for the medium, high, and extreme water stresses, respectively.

3.4. Plant water use efficiency and yield response factor

The statistical analysis showed that water stress levels had no effect on red beet WUE, despite the fact that they ranged from 0.70 to 0.89 g mm^{-1}. The relative evapotranspiration deficit (1–ETa/ETm) corresponding to the relative yield decrease (1–Ya/Ym) for each replication of the experiment was plotted to determine k_y values for fresh leaf and storage-root yield parameters. As shown in Figure 3, there are strong correlations between relative evapotranspiration deficit versus relative fresh leaf yield (R^2= 0.98) and storage-root yield (R^2= 0.94). The calculated k_y coefficients were 0.98 and 0.88 for fresh leaf and storage-root yields, respectively.

3.5. Relationship between parameters

Table 3 shows the statistical evaluation (r and P values) of the linear relationships between parameters. There were significantly important ($P<0.01$) strong-positive linear correlations between ET values versus plant height, fresh leaf yield, and storage-root yield values; plant height values versus fresh leaf and storage-root yield values; fresh leaf yield values versus storage-root yield values. Similarly, there were moderate-positive linear correlations between soil EC_e values versus ET, plant height, fresh leaf yield ($P<0.05$) and storage-root yield values; ET values versus taproot length values ($P<0.05$); taproot length values versus fresh leaf yield values ($P<0.05$) were observed. However, neither the soil pH_e nor the WUE values showed a strong or moderate linear relationship with any of the other parameters (Table 3).

4. Discussion

In this study, the effects of water stress on growth (plant height and taproot length), yield parameters (fresh leaf and storage-root yields), water consumption, and water use efficiency, of red beet were investigated. Although the salinity of the irrigation water used in all treatments was the same, the soil salinity values showed statistically significant differences between them. This is because the salinity in the crop root zone may have increased due to an evapo-concentration process driven by ET under non-leaching conditions in the soil because pure water is evaporated from the wet soil surfaces and is transpired from crop leaves and the amount of salt taken up by the plants is negligible in comparison to the amount of salt in the soil and that added by irrigation water (Hanson et al. 2006). Duzdemir et al. (2009a, 2009b), Kurunc et al. (2011) and Ünlükara et al. (2015) claimed that if salts are not leached out of the crop root zone, the amount of salt delivered to the soil increases as the amount of applied water increases depending on the salt concentration of irrigation water. They also reported that EC_e values were higher in control treatments with more water was delivered to the soil than in limited water treatments, as expected.

Initial, crop development, mid-season, and late-season are the four key stages of a typical K_c curve. The K_c coefficient increases with increasing plant growth during the crop development period then becomes stationary in the mid-period and subsequently drops till the harvest (Allen et al. 1998). However, in this experiment, the K_c curve did not have a stable pattern in the mid-season, because the number of irrigation

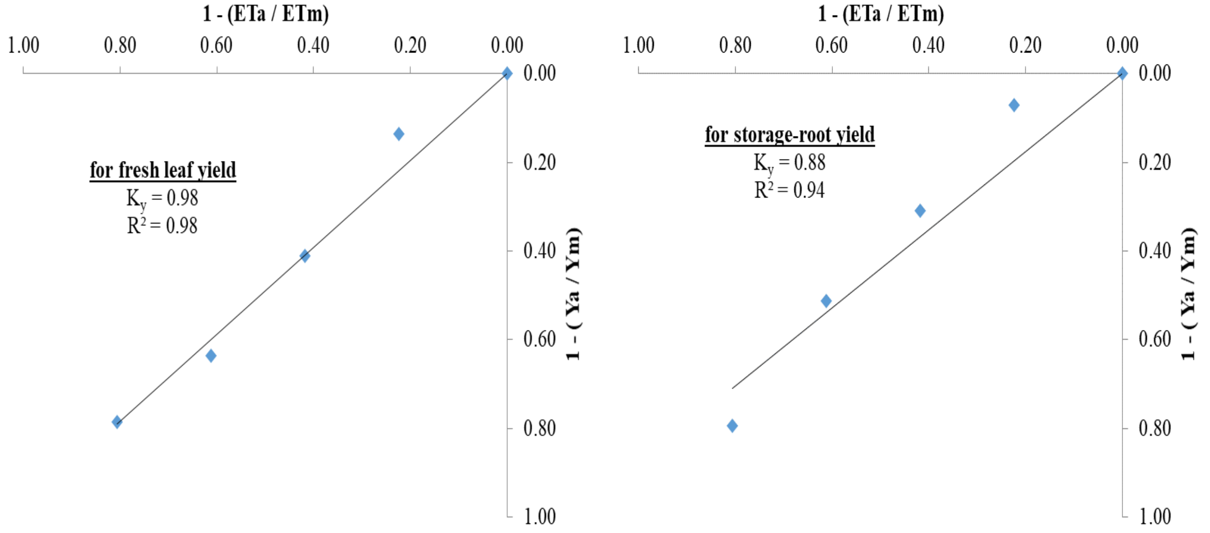

Figure 3. Yield response factors for storage-root and fresh leaf yields of red beet.

Table 3. Relationship between investigated parameters

	EC_e	PH_e	ET	PH	TRL	FLY	SRY
pH_e	0.29^{ns}						
ET	0.67^{**}	0.19^{ns}					
PH	0.61^{**}	0.36^{ns}	0.88^{**}				
TRL	0.34^{ns}	-0.01^{ns}	0.54^{*}	0.34^{ns}			
FLY	0.55^{*}	0.16^{ns}	0.94^{**}	0.88^{**}	0.53^{*}		
SRY	0.64^{**}	0.26^{ns}	0.90^{**}	0.81^{**}	0.44^{ns}	0.81^{**}	
WUE	-0.13^{ns}	0.07^{ns}	-0.12^{ns}	-0.09^{ns}	-0.23^{ns}	-0.22^{ns}	0.28^{ns}

EC_e: Electrical cond. of soil saturated paste extract; pH_e: pH of soil saturated paste extract; ET: evapotranspiration; PH: plant height; TRL: tap root length; FLY: fresh leaf yield; SRY: storage-root yield; WUE: water use efficiency; **: significant at the 0.01 probability level; *: significant at the 0.05 probability level; ns: non-significant.

practices throughout the season was limited to 5. The changes in daily evapotranspiration and K_c curves of the water regime treatments can be seen in Figure 1. As a result, it can be claimed that red beet, as a late autumn plant, exhibits a partially conventional K_c use curve.

In a study, investigating the effects of three different water application levels (100%, 50%, and 30%) on red beet, Stagnari et al. (2014) found that storage-root and dry leaf yields decreased with increasing water stress. They calculated that, compared to the control, the reductions in dry storage-root yield were 62 and 75%, whereas in leaf dry yields 45 and 69% for 50 and 30% stress treatments respectively. Our findings (respectively 31, 51, and 79% decreases in storage-root and similarly 41, 64, and 88% reductions in fresh leaf yields for 60, 40, and 20% water applications) are consistent with Stagnari et al. (2014). These findings reveal that a significant reduction in irrigation water has a negative impact on the red beet plant's growth and yield parameters. It was shown that increased water stress adversely affected the growth and yield parameters of different plants such as cowpea (Duzdemir et al. 2009b), bell pepper (Kurunc et al. 2011), and long pepper (Ünlükara et al. 2015). The decrease in growth and yield parameters could be attributed to biomass production primarily taking place in the roots under water stress conditions (Albouchi et al. 2003) or a decrease in chlorophyll content and hence photosynthetic activity (Viera et al. 1989).

The yield response factor is used to assess a plant's water stress tolerance (Doorenbos and Kassam 1986). If $k_y \leq 1$, the plant is tolerant to water stress; otherwise it is sensitive. In this study, the yield response factors for storage-root and fresh leaf yields were determined to be 0.88 and 0.98, respectively. It may be inferred that red beet is slightly tolerant to water stress, with comparatively lower yield reductions when water consumption is reduced due to stress. Stagnari et al. (2014) stated that red beet plants can show high adaptation to water stress based on changes in growth and physiological characteristics that modify the yield and quality.

5. Conclusions

In this study, the effects of irrigation water regime on growth (plant height and taproot length), yield parameters (fresh leaf and storage-root yields), and irrigation water use efficiency of red beet plant were investigated. In general, increasing water stress significantly decreased soil salinity, plant height, fresh leaf yield, and storage-root yield, but had no influence on soil pH, taproot length, and plant water use efficiency. Under high water stress, the smallest variation in daily plant water consumption was recorded, whereas the largest change occurred under the control treatment. Significantly important strong- or moderate-positive linear correlations were found between soil salinity, evapotranspiration, plant height, fresh leaf yield, and storage-root yield values; however, soil pH_e and WUE values showed no strong or moderate linear relationship with any of the other investigated parameters. The yield response factors for fresh leaf and storage-root yields were found to be 0.98 and 0.88, respectively, indicating that the red beet plant is slightly tolerant to water stress.

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