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Research Article

Effects of Salinity on Yield, Yield Components and Water Productivity of Black Carrot (*Daucus Carota* L.) Under Water Stress Condition

Mehmet ALTUN*[1], Hakan ARSLAN[2]

[1]Agricultural Structures and Irrigation Department, Faculty of Agriculture, Atatürk University, Erzurum, Turkey
[2]Agricultural Structures and Irrigation Department, Faculty of Agriculture, Ondokuz Mayis University, Samsun, Turkey

[1]https://orcid.org/0000-0001-7807-9810, [2]https://orcid.org/0000-0002-9677-6035

*Corresponding author e-mail: mehmetaltun@atauni.edu.tr

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Irrigation water salinity
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Abstract: Salinity and drought are some of the main problems affecting global crop yields. In this study, interaction effects of irrigation interval and salinity on yield, soil salinity, other parameters of black carrot were evaluated in a covered rain shelter. The treatments consist of three different irrigation intervals (4 days (I_1), 6 days (I_2), and 8 days (I_3) with 6 different irrigation water salinity levels (0.38 (S_1), 1.5 (S_2), 3.0 (S_3), 5.0 (S_4) 7.0 (S_5) and 10.0 (S_6) dS m^{-1}. The results indicated that the effect of interaction between irrigation interval and salinity was significant on yield, evapotranspiration, chlorophyll content, and soluble solid content (SSC). Yield and evapotranspiration decreased significantly with an increase in salinity and irrigation intervals. The highest yield was observed in I_1S_1, and the yield response (Ky) in the black carrot was 1.39. The irrigation water salinity up to 1.5 dS m^{-1} was nonsignificant on yield. However, the increase in soil salinity by 1 dS m^{-1} caused a decrease of 3.83%, 2.93%, and 3.03% in the yields of I_1, I_2, and I_3, respectively. Moreover, increasing the salinity of irrigation water reduced the chlorophyll content and carrot juice pH value. The result of the study indicated that black carrot is sensitive to salt and water deficit, and the maximum irrigation interval using saline water should not be more than 6 days. Therefore, it can be concluded that in regions where salinity is high, more frequent irrigation minimizes losses that may occur in yield.

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Su Stres Koşulları Altında Tuzluluğun Siyah Havuç Bitkisinin (*Daucus Carota* L.) Verim, Verim Bileşenleri ve Bitki Su Tüketimi Üzerine Etkileri

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Öz: Tuzluluk ve kuraklık, küresel anlamda bitkisel üretimi etkileyen en önemli önemli problemlerden bazılarıdır. Bu çalışma, sulama aralığı ve sulama suyu tuzluluğun siyah havucun verim ve büyüme parametreleri ile toprak tuzluluğu üzerine olan etkilerini belirlemek amacıyla yağış örtüsü ile kapalı bir alanda yapılmıştır. Çalışma, 6 farklı sulama suyu tuzluluk seviyesi (0.38 (S_1), 1.5 (S_2), 3.0 (S_3), 5.0 (S_4) 7.0 (S_5) ve 10.0 (S_6) dS/m ve 3 farklı sulama aralığında (4 gün

Anahtar Kelimeler

Sulama tuzluluğu,
Siyah havuç,
Toprak tuzluluğu,
Sulama aralığı,
Kuraklık

(I_1), 6 gün (I_2) ve 8 gün (I_3) yürütülmüştür. Çalışma sonucunda sulama aralığı ve sulama suyu tuzluluğunun interaksiyon etkisinin verim, bitki su tüketimi, klorofil içeriği ve suda çözünebilir katı madde miktarı (SÇKM) üzerine önemli deredece etki ettiği belirlenmiştir. Tuzluluk ve sulama aralıklarının artmasıyla birlikte siyah havucun verimi ve bitki su tükerim değerleri önemli derecede azalış göstermiştir. En yüksek verim I_1 x S_1 konusundan elde edilmiş ve verim tepki faktörü (Ky) 1.39 olarak belirlenmiştir. Sulama suyu tuzluluğunun 1.5 dS/m' ye kadar olması siyah havucun veriminde herhangi bir azalmaya neden olmadığı belirlenmiş bununla birlikte toprak tuzluluğundaki 1 dS/m lik artış, I_1, I_2 ve I_3 sulama aralıklarında sırasıyla % 3.83, % 2.93 ve % 3.03 oranında azalmaya neden olmuştur. Sulama suyu tuzluluğundaki artış klorofil içeriğini ve havuç suyunun pH değerini düşürmüştür. Araştırma sonucunda, siyah havucun tuz ve su kısıtına. Karşı hassas olduğu ve tuzlu su kullanılması durumunda siyah havuç için sulama aralığının en fazla 6 gün olması gerektiği tespit edilmiştir. Sulama suyu tuzluluğunun yüksek olduğu bölgelerde daha sık sulama yapılması ile verimde oluşabilecek kayıpların en aza indirileceği belirlenmiştir.

1. Introduction

Salinity and drought are two of the most important abiotic stresses, which have affected almost every aspect of plant growth and development, including seed germination, vegetative growth, and reproductive development (Arslan et al., 2018; Sahin et al., 2018; Desire and Arslan, 2021; Ors et al., 2021). Nowadays, the world is experiencing a gradual decrease in freshwater resources (Yerli et al., 2019) as a result of increased salt in irrigation water sources such as rivers, streams, and underground aquifers. Irrigating crops with saline waters causes a reduction in yield and an increase in soil salinity. It is estimated that about 20% of the agricultural land in the world is affected by salt (Munns, 2002). Salt stress prevents the growth of plants by causing osmotic and ionic stress. Salinity becomes a serious concern when soluble salts occur in excessive concentrations in the soil or water. Salinity is a major yield-reducing factor in arid and semi-arid areas (Puvanitha and Mahendran, 2017). With the increase of salt amount in the root rhizosphere, osmotic stress occurs, and this causes a decrease in the amount of usable water.

Azder et al. (2020) examined the effects of different water-deficit treatments on evapotranspiration, yield, and growth parameters of Capia pepper in Tekirdağ, and they stated that the yield values increased as the amount of irrigation water increased. To achieve higher yields from crops, the relationship between the water, salinity, and crop yield should be well known. In several studies, the effects of the water deficit on yield and photosynthetic characteristics of plants have been studied, and variations between plants have been reported (Sahin et al., 2016; Bell et al., 2018; Coban et al., 2018; Ozturk and Korkut, 2018; Ekinci and Basbag, 2019; Cakmakci et al., 2021). The irrigation interval should be a maximum of 14 days for pumpkin (Yavuz et al., 2015) and 7 days for corn (Abd El-Halim and Razek, 2014) to get the highest yield.

Plants have varying tolerance to salinity. Therefore, it is important to know the relationship between salt and yield of plants and salinity threshold values for salinity management. According to Kiremit and Arslan (2016), the percentage of leek yield decrease under increasing soil salinity (ECe) as 0% at 1.1 dS m^{-1}, 11% at 2.84 dS m^{-1}, 19% at 4.65 dS m^{-1}, 25% at 5.6 dS m^{-1}, 38% at 6.41 dS m^{-1} and 43% at 8.27 dS m^{-1}. The salinity threshold values for stevia and carrot are 2.0 dS m^{-1} and 2.5 dS m^{-1}, respectively (Unlukara et al., 2011; Reis et al., 2015). They suggested that these plants should not be irrigated with higher salinity water. Rodrigues et al. (2020) investigated the influence of different electrical conductivities (1.0, 2.0, 3.0, 4.0, and 5.0 dS m^{-1}) of irrigation water salinity on maize crops. They found an increase in salinity reduced unhusked and husked ear weights, cob weight, 1000-grain weight, and yield. However, ear length and diameter were not affected by the increased salinity. Dastranj and Sepaskhah (2019) also showed that water deficit and salinity significantly affected saffron yield and growth parameters.

The combined effects of salinity and water constraint on plant growth and development are more than the effects of each stress separately. There is little literature on the interaction effect of irrigation intervals and irrigation water salinity on yield and yield components. Sepaskhah and Yarami (2009) investigated the effects of 4 different irrigation intervals and 4 different irrigation water salinity on the yield of the saffron crop. They have concluded that saffron is a salt-sensitive plant, and irrigation interval has to be a maximum of 2 days to avoid yield reduction. Abedinpour and Rohami (2017) suggested that soybean plants should be irrigated at 7 days intervals with 1 dS m^{-1} EC of water to get the highest yield. Yuan et al. (2019) examined the interaction effects of irrigation regimes and salinities on corn yield and yield parameters. They suggested that irrigation with 370 mm water with 3 g L^{-1} salinity could be applied to attain maximum yield.

The effects of irrigation and salinity on yield and yield parameters of black carrot have not been studied in the literature. This study was conducted to evaluate the main and interactive effects of irrigation intervals and salinity, as well as the yield and yield parameters, evapotranspiration, and soil salinity of black carrot (*Daucus Carota* L.).

2. Material and Methods

2.1. Study site

This study was conducted between May and August 2017 in a covered rain shelter at Ondokuz Mayıs University Research Field at Samsun, Turkey. The indoor temperature and relative humidity ranged from 12.5 °C to 27.2 °C and 58.8% to 85% throughout the growing period, respectively.

2.2. Experimental design and treatments

The physical properties of the soil were analyzed and classified as a sandy loam (SL). The soil analysis results are shown in (Table 1).

Table 1. The physical and chemical properties of the soil

Parameter	Values
ECe (dS m^{-1})	0.63
pH	7.80
Field capacity (%)	33.24
Wilting point (%)	14.56
Sand (%)	52.3
Silt (%)	38.3
Clay (%)	9.4
Soil texture	Sandy-loam
Organic matter (%)	1.24
P_2O_5 (kg ha^{-1})	40
K_2O (kg ha^{-1})	500

The soil was sieved through 2 mm and after each pot was filled with 17.5 kg air-dried soil. Sand-gravel materials of 2.5 kg were placed at the bottom of each pot to provide drainage. The seeds were placed in Petri dishes and later placed in the incubator for germination before planting. The seeds were germinated at 25°C and 75% humidity in the incubator for 3 days. After germination, five germinated seeds were planted in each pot. The pots were 28 cm in height, 29 cm in diameter, and 18.5 L.

The six irrigation water salinity treatments consisted of 0.38 dS m^{-1} (S_1), 1.5 dS m^{-1} (S_2), 3 dS m^{-1}, (S_3), 5 dS m^{-1} (S_4), 7 dS m^{-1} (S_5), 10 dS m^{-1} (S_6) with three intervals: 4 days (I_1), 6 days (I_2) and 8 days (I_3). In the study, 18 treatments were used with combinations of 3 replicates given a total of 54 pots in a randomized complete block design. The irrigation water salinity was prepared for each treatment by mixing $CaCl_2$, $MgSO_4$, and NaCl salts. The fertilizer rates were 90 kg ha^{-1} N and 90 kg ha^{-1} P_2O_5 (Diammonium phosphate), the full dose of P fertilizer and a half dose of N fertilizer were given before planting, and the other half of N fertilizer was given 20 days after salt application (Unlukara et al., 2011).

Before starting the experiment, the pots were saturated with tap water and weighted to determine the field capacity (WFC) of each pot. Irrigation applications were started 15 days after sowing and All pots were irrigated with saline water at intervals of 4, 6, and 8 days. The following equation was used to calculate the amount of irrigation water (IW) applied to the pots in each irrigation.

$$IW = \frac{\frac{W_{FC}-W}{P_W}}{1-LF} \quad \text{(Eq. 1)}$$

Where; W_{FC}, Weight of pots in field capacity (kg), W = weight of the pots before irrigation (kg), Pw = Water density (1 kg l^{-1}) LF =Leacing fraction (leaching fraction was used as 15% (Ayers and Wescot, 1989).

The evapotranspiration was determined the following.

$$ET = IW - D \pm \Delta S \quad \text{(Eq. 2)}$$

Where; ET: Evapotranspiration, IW = Irrigation amount (L), D = Amount of drainage water (L), ΔS = Difference in amount of soil water between irrigation

Water use efficiency (WUE) were determined using Eq. (3) (Howell et al. 1990)

$$WUE = \frac{Y_a}{ET} \quad \text{(Eq. 3)}$$

Where; WUE: Water use efficiency (g pot.mm^{-1}), Y_a= Black carrot fresh weight (g pot-1), ET= Evapotranspiration (mm)

The following equation was used to determine the yield response factor (Ky).

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y \; x \; \left(1 - \frac{ET_a}{ET_m}\right) \quad \text{(Eq. 4)}$$

Where; Y_m and ET_m: maximum yield and maximum evapotranspiration from the control treatment, respectively; Y_a and ET_a, Black carrot fresh weight (g pot^{-1}), and actual evapotranspiration (mm) taken as from each salinity treatment (Doorenbos and Kassam, 1986).

2.3. Plant and soil analysis

The yield, fruit juice EC, and fruit juice pH values were determined in each lysimeter. Chlorophyll content of the youngest and fully expanded leaves was measured with a portable chlorophyll meter (Minolta SPAD-502), and the SSC was measured using a reflectometer (ATC-I, Atago, Japonya).

At the end of the experiment, soil samples were collected from the midpoint of each pot to determine the electrical conductivity and pH values of the soils. Soil salinity and pH values were determined by using Eutech pc510 EC / pH meter at soil saturation paste.

2.4. Statistical analysis

The data were analyzed using analysis of variance (ANOVA) with SPSS 21.0 software to determine the interaction effect between irrigation interval and salinity on the black carrot. The difference between the means was compared with Duncan's multiple comparison test at a level p<0.05. The 3-D graphs were drawn with design expert 11.0 software.

3. Results and Discussion

3.1. Yield and Yield components

The irrigation intervals and irrigation water salinity had significant effects on yield (p < 0.01) while irrigation intervals × irrigation water salinity interactions were statistically significant on yield (p < 0.05) (Table 2).

In all irrigation intervals, increasing salinity significantly decreased the yield of carrots, and the yield was not significantly different between S_1 and S_2. S_3, S_4, S_5, and S_6 decreased in yield by 20%, 25%, 29%, and 41%, respectively, compared to S_1 (Table 3). Salt stress, by affecting cell division and elongation, causes a decrease in the number of cells and cell division rate in the root and stem in plants, which causes a shortening in the height and weight of the plants. Salinity value up to 1.5 dS m^{-1} did not cause a significant reduction in the yield. The black carrot plant was determined to be sensitive to salinity. Kim et al. (2016) reported that the threshold value for the salinity of lettuce and Chinese cabbage is 0.9 dS m^{-1} and 1.5 dS m^{-1}, respectively. Increased salinity caused a significant decrease in tomato and oregano yields (Ahmed et al., 2017; Hancioglu et al., 2019).

The yields of I_2 and I_3 decreased by 3% and 19%, respectively, compared to I_1. However, no statistically significant difference in yield was observed between I_1 and I_2 treatments. Drought negatively affects the yield of the plant as it causes loss of turgor, decrease in energy balance, and decrease in enzymatic activity, cell division, elongation, and differentiation. Ramezanifar et al. (2021) conducted a study on the interactive effects of salinity and water scarcity on spinach. The results of their study indicated that salinity and water scarcity were significant on plant growth and yield. Similarly, Hazrati et al. (2017) and Yurtseven et al. (2012) found that deficit irrigation decreased crop yields.

In each irrigation interval, the highest yields were obtained from treatment irrigated with S1 (Table 3). However, the yield of black carrots under fresh irrigation was preserved by order $I_1 \times S_1 > I_2 \times S_1 > I_3 \times S_1$. In I_1 and I_2, except for $I_1 \times S_1$, there was no statistically significant difference in yields of all the same irrigation water salinity. Irrigation using saline water should be a maximum of 6 days of irrigation interval to avoid decreased yield.

Table 2. Analysis of variance of irrigation intervals (I), salinity (S), and their interactions (I*S) on black carrot yield, yield components, and evapotranspiration

Parameter	S	I	I*W
Yield (gr pot^{-1})	56.96**	38.36**	2.46*
Chlorophyll content	104.92**	895.47**	215.99**
SSC	4.29**	9.88**	2.44*
Water Juice EC	20.35**	6.94**	0.83 ns
Water Juice pH	11.19**	8.23***	1.22 ns
ET (mm)	38.34**	182.00**	6.68**
WUE (gr mm^{-1})	8.23**	15.49**	1.33 ns
EC_e	274.26**	5.79**	1.59 ns
pH_e	84.05**	16.97**	0.90 ns

ns = not significant; *p < 0.05; ** p < 0.01.

The black carrot yield had a curvilinear relationship with irrigation water salinity and irrigation interval (Fig. 1). Decreasing irrigation intervals from 8 to 4 days had curvilinearly increased crop yield at the lowest salinity. Under the highest salinity conditions, crop yield was increased slightly with decreasing irrigation intervals from 8 to 4 days. The highest carrot yield was determined with frequent irrigation intervals and low salinity, whereas the lowest yield was recorded in crops irrigated with 10 dS m^{-1} irrigation water and under high irrigation intervals. Sepaskhah and Yarami (2009) recommended that irrigation intervals need to be more frequent when using saline water to avoid water stress for Saffran.

SPAD is proportional to the chlorophyll of the leaf. The main and interaction effects of the irrigation interval and salinity on chlorophyll in black carrots were statistically significant (Table 2). Increased irrigation interval and salinity resulted in a significant decrease in chlorophyll content (Table 3). The highest value was obtained in $I_1 \times S_1$ (40.90), and the lowest value was obtained in $I_3 \times S_6$ (14.67). In salty conditions, the decrease in the amount of chlorophyll in plants can be explained by the increase in the activity of the chlorophyllase enzyme, which breaks down chlorophyll (Rao and Rao, 1981). It has been determined in studies that water constraint and/or salinity stress in a negative way affect the chlorophyll content in plants (Cakmakci et al., 2017; Shah et al., 2017; Guzel et al., 2018; Kiremit and Arslan, 2018; Rostami et al., 2018).

The two-way ANOVA showed that irrigation interval, irrigation water salinity, and interaction of irrigation salinity and irrigation interval had a significant effect on soluble solids content (SSC) (Table 2). SSC varied between 5.64 % and 13.34 % in all treatments and increased in increasing salinity levels but reduced as the irrigation interval increased (Table 3). Similarly to our finding, a high salinity caused an increase in the SSC content of the tomato (Ruiz et al., 2015; El-Mogy et al., 2018)

Table 3. The interaction effect of irrigation interval (I) and salinity (S) on black carrot yield, chlorophyll content (CCI), soluble solid content (SSC), water juice salinity, and water juice pH

Irrigation Intervals Effect (I)		**Yield**	**CCI**	**SSC**	**Water Juice EC (dS m-1)**	**Water Juice pH**
I_1 (4 days)		250.7 ± 13a	38.1 ± 0.4a	10.2 ± 0.4a	10.9 ± 0.5a	5.7 ± 0b
I_2 (6 days)		242 ± 13a	34.5 ± 0.9b	8.3 ± 0.6b	9.5 ± 0.7b	5.8 ± 0a
I_3 (8 days)		202.5 ± 8.9b	23.4 ± 0.7c	9.3 ± 0.4ab	9.8 ± 0.5b	5.8 ± 0a
Salinity effect (S)						
S_1 (0.38 dS m^{-1})		289.7 ± 14.3a	37.3 ± 1.3a	7.5 ± 0.7b	7.3 ± 0.4e	5.9 ± 0a
S_2 (1.50 dS m^{-1})		273.7 ± 9.6a	34.4 ± 1.7b	8.6 ± 0.6ab	9 ± 0.4d	5.8 ± 0bc
S_3 (3.0 dS m^{-1})		232.3 ± 11.1b	33 ± 2c	10.1 ± 0.7a	9.7 ± 0.4cd	5.8 ± 0bc
S_4 (5.0 dS m^{-1})		218.2 ± 9.9bc	31 ± 2.6d	10 ± 0.6a	10.2 ± 0.4bc	5.7 ± 0c
S_5 (7.0 dS m^{-1})		206 ± 8.7c	29.4 ± 2.7e	9 ± 0.7ab	11.1 ± 0.5bc	5.7 ± 0c
S_6 (10.0 dS m^{-1})		170.4 ± 5.5d	26.8 ± 3.2f	10.3 ± 0.7a	13.3 ± 0.5a	5.7 ± 0c
Irrigation Intervals x Salinity Interaction						
I_1	S_1	336.3±11.8a	40.9 ± 1a	10.8 ± 0a-d	8.5 ± 0.70	5.8 ± 00
	S_2	295.7 ± 3.9b	38.5 ± 0.2b	11 ± 0.7a-d	9.6 ± 0.70	5.7 ± 00
	S_3	251.2 ± 5.2c	38.2 ± 0.5b-d	11.6 ± 0.4abc	9.9 ± 0.70	5.7 ± 00
	S_4	232.3 ± 2.8cd	37.5 ± 0.1b-e	12.1 ± 1ab	11.1 ± 0.80	5.7 ± 00
	S_5	214.1 ± 6d	36.7 ± 0.1c-e	9.4 ± 2.3bcd	12.5 ± 0.60	5.6 ± 0.10
	S_6	174.5 ± 6fg	36.8 ± 0.1b-e	10.7 ± 2.3a-d	14.1 ± 0.60	5.7 ± 0.10
I_2	S_1	287 ± 11.7b	38.5 ± 0b	6 ± 0.5e	6.6 ± 0.60	6.1 ± 00
	S_2	286.7 ± 2.2b	36.4 ± 0.3d-f	8.7 ± 1cde	8.2 ± 0.20	5.8 ± 00
	S_3	253.3 ± 11.1cd	35.8 ± 0.3ef	10.1 ± 1.4bcd	9.9 ± 0.40	5.8 ± 00
	S_4	232.3 ± 13.5cd	37.5 ± 0.8b-e	11 ± 1.2a-d	11.1 ± 0.60	5.7 ± 00
	S_5	219.3 ± 22.1de	32.5 ± 0.1g	9.8 ± 0.1bcd	9.4 ± 0.50	5.7 ± 0.10
	S_6	174.8 ± 14fg	28.9 ± 0.6h	7.8 ± 1de	13.6 ± 0.50	5.7 ± 00
I_3	S_1	245.9 ± 11.4c	32.5 ± 0.7g	8.2 ± 0.9de	6.9 ± 0.30	6 ± 00
	S_2	238.6 ± 11.6cd	28.3 ± 2.2h	8.5 ± 1.3de	9.1 ± 10	5.9 ± 0.10
	S_3	192.3 ± 12ef	25.1 ± 0.8ı	11 ± 1.8a-d	9.3 ± 1.20	5.8 ± 0.10
	S_4	191.6 ± 21.3ef	20.9 ± 0.5j	9.2 ± 0.6bcd	10.3 ± 0.50	5.8 ± 00
	S_5	184.5 ± 4.8fg	19.1 ± 0.5j	10.1 ± 0.9bcd	11.4 ± 0.40	5.7 ± 00
	S_6	162 ± 10.6g	14.7 ± 0.4k	13.4 ± 0.4a	12.1 ± 0.90	5.7 ± 0.10
$LSD_{0.05}$ I		12.01**	0.75**	1.23**	0.87**	0.057**
$LSD_{0.05}$ S		16.62**	1.04**	1.70**	1.20**	0.079**
$LSD_{0.05}$ I x S		28.80*	1.79**	2.94*	2.08^{ns}	0.14^{ns}

I_1: 4 day irrigation intervals; I_2: 6 day irrigation intervals; I_3: 8 day irrigation intervals; S_1: 0.38 dS m^{-1} ; S_2: 1.50 dS m^{-1} ; S_3: 3.0 dS m^{-1} ; S_4: 5.0 dS m^{-1} ; S_5:7.0 dS m^{-1} ; S_6: 7.0 dS m^{-1} . The values marked with different letters show statistically significant at at $p < 0.05$. ns = not significant; *$p < 0.05$; ** $p < 0.01$.

The electrical conductivity (EC) values of fruit juice varied between 6.56 and 14.09 dS m-1 (Table 3). Irrigation interval and salinity affected a significant effect on juice salinity, but their interaction was not statistically significant. The treatment of $I_1 \times S_6$ acquired the highest value, whereas $I_3 \times S_1$ obtained the lowest value. Kiran et al. (2018) determined that the increase in irrigation water salinity caused an increase in the salinity of the eggplant plant juice. The main effect of irrigation interval and salinity on water juice pH was significant and decreased with increasing salinity. The effects of interaction between irrigation interval and salinity were also insignificant. Furthermore, the differences in water juice pH between I_1 and I_2 were significant, while I_3, I_4, I_5, and I_6 were not significant. Korkmaz et al. (2016) found that the pH value of tomato juice decreased significantly with increasing salinity.

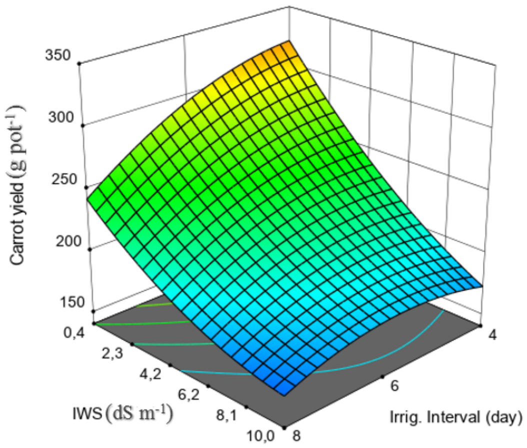

Figure 1. The interactive effects of irrigation interval (I) and salinity (S) and on black carrot yield.
Yield =226.268- [21,5755x (S)]-[56,9777x(I)]+[17.1541x(S)x(I)]-[15.4204x(S)^2]+14.962x(I)^2]
SE = [5.72] [3.38] *** [3.94]*** [4.82]*** [5.71]** [6.70]* $r^2 = 0.84$***
***: $p < 0.001$, **: $p < 0.01$, *: $p<0.05$.

3.2. Evapotranspiration and water use efficiency

The main and interactive effects of irrigation intervals and salinity on evapotranspiration were statistically significant (Table 2). Evapotranspiration followed the order $I_1 > I_2 > I_3$, and for I_2 and I_3, it decreased by 19.2 % and 28.60 %, respectively, compared to I_1 (Table 4). By increasing the irrigation water salinity, evapotranspiration decreased statistically significantly, and no statistical difference was determined between S_1 and S_2 treatments. Evapotranspiration in S_3, S_4, S_5, and S_6 decreased by 5%, 14%, 16%, and 28%, respectively, compared to S_1.

It is thought that the increase in soil salinity was effective on the decrease in plant water consumption since the water and nutrient intake of plants decreased due to the effect of osmotic conditions due to high salinity. Similar to our results, Unlukara et al. (2008) and Jiang et al. 2012 determined that increased irrigation water salinity decreased evapotranspiration on lettuce and wheat. The highest evapotranspiration value was obtained at $I_1 \times S_1$ with the lowest irrigation water salinity (0.38 dS m^{-1}) and lowest irrigation interval (4 days), while the lowest evapotranspiration value was obtained under the conditions with the highest irrigation water salinity and irrigation interval ($I_3 \times S_6$). The evapotranspiration in $I_2 \times S_2$ and $I_3 \times S_2$ treatments decreased by 14% and 33%, respectively, when compared to the $I_1 \times S_2$ treatment. There was no statistically significant difference in evapotranspiration for all salinity treatments of I_3 except S_6. Turhan and Kuşcu (2019) examined the effect of different water salinity levels on salt tolerance, evapotranspiration, plant height, leaf area of eggplant in the greenhouse. The results indicated that the evapotranspiration of eggplant was significantly affected by increasing salinity levels.

The irrigation water salinity and irrigation intervals had linear and curvilinear effects on evapotranspiration (Fig 2). Evapotranspiration decreased sharply with irrigation intervals up to 6 days and decreased linearly after that at all irrigation water conditions. Furthermore, evapotranspiration declined increasingly at all irrigation water saline conditions.

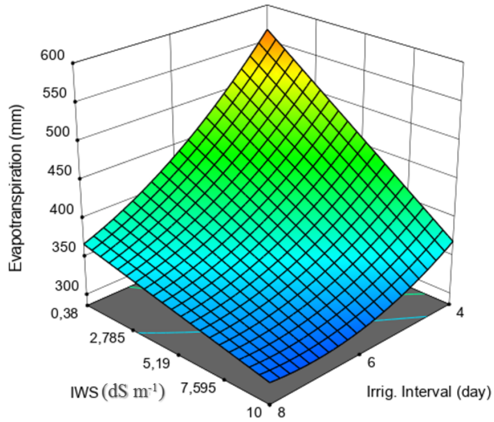

Figure 2. The interactive effects of irrigation interval (I) and salinity (S) and on evapotranspiration (ET).

ET = 380.658 –[64.19x(I)]-[63.07x(S]+[34.98x(IxS)]+[24.24x(I)^2]
SE = [6.30] [4.52]***[5.27]***[6.46]***[7.659]** $r^2 = 0.889$***
***: $p < 0.001$, **: $p < 0.01$.

Table 4. The interaction effect of irrigation interval (I) and salinity (S) on black carrot evapotranspiration, water use efficiency, soil salinity, and soil pH

Irrigation Intervals Effect (I)		**ET (mm)**	**WUE**	**Soil EC (dS m^{-1})**	**Soil pH**
I_1 (4 days)		483.6 ± 18.6a	0.52 ± 0.01a	6.96 ± 1.03a	7.32 ± 0.07a
I_2 (6 days)		390 ± 13.4b	0.62 ± 0.03a	7.03 ± 1.44a	7.35 ± 0.07a
I_3 (8 days)		344.9 ± 9c	0.59 ± 0.02b	6.14 ± 0.86b	7.19 ± 0.03b
Salinity Effect (S)					
S_1 (0.38 dS m^{-1})		457.1 ± 34.1a	0.64 ± 0.02a	0.68 ± 0.05f	7.72 ± 0.04a
S_2 (1.50 dS m^{-1})		440.3 ± 22.8ab	0.63 ± 0.02a	2.82 ± 0.32e	7.48 ± 0.02b
S_3 (3.0 dS m^{-1})		435.1 ± 25.3b	0.54 ± 0.02b	5.13 ± 0.28d	7.3 ± 0.04c
S_4 (5.0 dS m^{-1})		393.7 ± 20.8c	0.56 ± 0.04b	8.63 ± 0.38c	7.18 ± 0.03d
S_5 (7.0 dS m^{-1})		382.8 ± 18.9c	0.55 ± 0.03b	9.92 ± 0.27b	7.08 ± 0.05e
S_6 (10.0 dS m^{-1})		327.7 ± 10.7d	0.52 ± 0.02b	13.07 ± 0.49a	6.96 ± 0.04f
Irrigation Intervals x Salinity Interaction					
I_1	S_1	587.5 ± 14.3a	0.57 ± 0.03	0.66 ± 0.03	7.79 ± 0.06
	S_2	513.5 ± 7.9b	0.58 ± 0.01	3.28 ± 0.33	7.53 ± 0.06
	S_3	525.9 ± 15.6b	0.48 ± 0.02	6.11 ± 0.11	7.3 ± 0.1
	S_4	473.4 ± 6.3c	0.49 ± 0	8.42 ± 0.83	7.23 ± 0.04
	S_5	448.7 ± 25.2cd	0.48 ± 0.03	10.04 ± 0.59	7.14 ± 0.08
	S_6	352.4 ± 25.2e	0.5 ± 0.03	13.23 ± 0.59	6.95 ± 0.08
I_2	S_1	416.5 ± 18.5d	0.69 ± 0.04	0.71 ± 0.06	7.74 ± 0.05
	S_2	448.7 ± 7.3cd	0.64 ± 0.01	2.49 ± 0.97	7.47 ± 0.01
	S_3	421.5 ± 16.1d	0.6 ± 0.01	4.66 ± 0.43	7.4 ± 0.04
	S_4	473.4 ± 17.1e	0.49 ± 0.07	8.42 ± 0.14	7.23 ± 0.04
	S_5	360.6 ± 11.6e	0.61 ± 0.08	10.53 ± 0.24	7.16 ± 0.02
	S_6	337.9 ± 1.6e	0.52 ± 0.04	14.07 ± 1.19	7.06 ± 0.02
I_3	S_1	367.4 ± 10.1e	0.67 ± 0.03	0.67 ± 0.16	7.64 ± 0.08
	S_2	358.8 ± 8.8e	0.67 ± 0.03	2.7 ± 0.14	7.44 ± 0.02
	S_3	357.9 ± 2.3e	0.54 ± 0.03	4.62 ± 0.17	7.19 ± 0.01
	S_4	353 ± 9.2e	0.54 ± 0.06	7.76 ± 0.21	7.07 ± 0.02
	S_5	339.2 ± 12.3e	0.55 ± 0.02	9.2 ± 0.18	6.93 ± 0.03
	S_6	292.9 ± 5.7f	0.55 ± 0.03	11.92 ± 0.39	6.87 ± 0.03
$LSD_{0.05}$ I		15.40**	0.037**	0.56**	0.06**
$LSD_{0.05}$ S		21.31**	0.052**	0.78**	0.085**
$LSD_{0.05}$ I x S		36.92**	0.089^{ns}	1.35^{ns}	0.15^{ns}

The values marked with different letters show statistically significance at $p < 0.05$; ns = not significant; *$p < 0.05$; ** $p < 0.01$.

Water use efficiency (WUE) was significantly affected by irrigation interval and irrigation water salinity, while their interaction was not statistically significant (Table 2). The WUE of I_1, I_2, I_3 were 0.52, 0.62, and 0.59 g mm^{-1} at the same salinity level, respectively, and there was no statistical difference between I_2 and I_3 (Table 4). The WUE value decreased as irrigation salinity increased, and the difference in WUE was insignificant between S_1 and S_2. Irrigation salinity up to 1.5 dS m^{-1} has no negative effect on water use efficiency. Ors and Suarez (2016) stated that salinity had a negative effect on WUE.

3.3. Soil salinity and soil pH

Soil salinity showed significant differences with irrigation interval and salinity; however, interactions of the effect of the treatment were not significant (Table 2). There was no statistical difference between I_1 and I_2 in terms of soil salinity. The average soil salinity in I_3 was 11.6 % less than in I_1. Evapotranspiration of I_3 was the lowest, so the soil salinity was lower than other irrigation intervals (Table 4).

The highest salinity in the soil was in the I_6 treatments in all irrigation intervals, while the lowest was in the S_1 treatments. There was no increase in salinity values of S_1 soils from the beginning of the experiment for all irrigation intervals. Similar to our results, the increase in irrigation water salinity caused an increase in soil salinity, and the decrease in irrigation water amount for the same salinity level decreased the soil salinity (Chen et al., 2017; Mosaffa and Sepashah, 2019).

The relationship between mean values of soil salinity and other parameters (yield, evapotranspiration, chlorophyll content, and fruit juice salinity) obtained from the three irrigation intervals is shown in (Fig. 3). The yield decreased linearly with the increase in soil salinity at all irrigation intervals, and the growth reduction per unit increase in soil salinity for yield at I_1, I_2, and I_3 was 3.83%, 2.93%, and 3.03% per dS m^{-1}, respectively. Evapotranspiration significantly decreased with increased soil salinity for all irrigation intervals and decreased by 18.71 mm, 5.85 mm, and 6.63 mm for I_1, I_2, and I_3, respectively, with the increase in soil salinity by 1 dS m^{-1}. The reduction in chlorophyll content of I_1 and I_2 similarly occurred with the increase in soil salinity, whereas the chlorophyll content of I_3 decreased sharply compared to I_1 and I_2. This may be due to excessive water stress on I_3 and, thus, decreased soil water availability for crops. The fruit juice salinity increased linearly with increasing soil salinity. The effect of soil salinity on fruit juice salinity was found to be higher than the irrigation interval.

The main effect of irrigation level and irrigation water salinity on soil pH was significant. I_1 and I_2 treatments were significantly higher than I_3 treatments. The value of soil pH was reduced significantly as the irrigation water salinity increased, and the highest mean pH value was 7.72 for S_1 (Table 4).

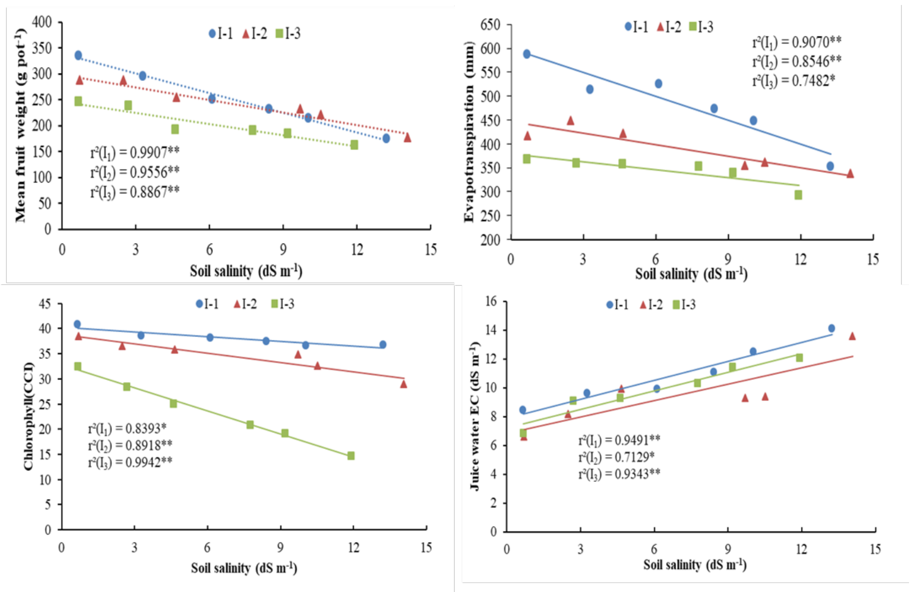

Figure 3. Relationships between mean fruit weight, evapotranspiration, chlorophyll juice water EC with soil salinity.
(** $p < 0.01$, *: $p<0.05$).

3.4. Yield response factor

The relative yield reduction (Ky) value was calculated by using fruit weights obtained from the I_1 treatment with the highest yield, and the Ky value was determined to be 1.39 (Fig. 4). When Ky ≤ 1 is higher, the plant is tolerant of salinity-related drought (Katerji et al., 1998). In literature, there is no report about the black carrot, but Carvalho et al. (2016) reported that the Ky value of carrot was 0.82 under different irrigation regimes. The black carrot was found to be sensitive to water stress caused by salt stress. Moreover, when saline water was applied for black carrot irrigation, the yield was significantly affected by saline water.

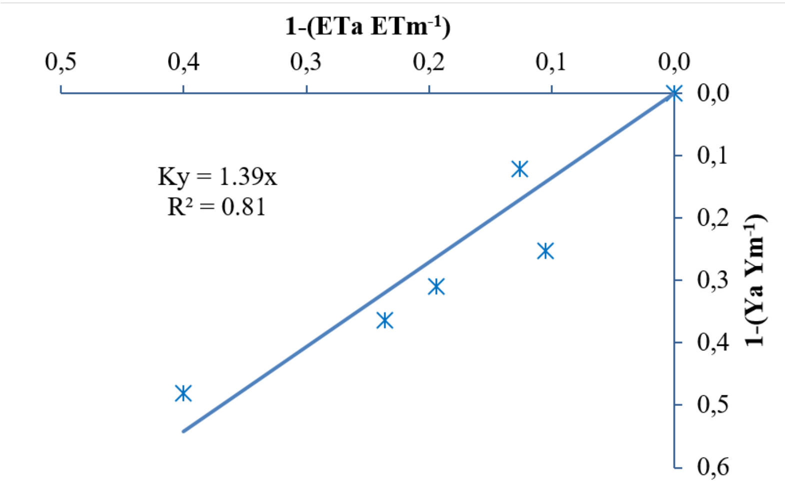

Figure 4. Relationship between relative evapotranspiration and yield of the black carrot plant.

Conclusion

This study investigated the interaction effects of irrigation interval salinity on the yield, yield parameters, evapotranspiration, and water use efficiency of black carrots. As the irrigation water salinity increased, soil salinity and SSC values increased, but yield, evaporation, chlorophyll, and soil pH values decreased. There was no statistically significant difference between the yields of I_1 and I_2, irrigated with water having the same salinity except for I_1S_1. It can be concluded that the 4 and 6 days irrigation intervals will provide the same yield under the same water salinity treatment. The highest yield was obtained from I_1S_1 and the lowest yield from I_3S_6, and the difference was a 42.20 % decrease in yield. A linear relationship between soil salinity, yield, and evapotranspiration was observed, and a unit increase in soil salinity caused a decrease in plant yield of 2.93 % to 3.83 %, depending on the irrigation interval. Irrigation water salinity up to 1.5 dS m^{-1} was determined not to cause a significant reduction in yield, and the Ky value of black carrot was calculated as 1.39. The carrot plant was found to be sensitive to salinity and water stress. The irrigation interval should be a maximum of 6 days to avoid a decrease in the yield of black carrot, and more frequent irrigation should be done in case of using high saltwater. Water deficit under saline conditions may cause more yield reduction in plants. It is definitely recommended to carry out additional studies to investigate the combined effects of salinity and drought stress on plants.

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