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Araştırma Research

CARROT (*Daucus carota L.*): YIELD AND QUALITY UNDER SALINE CONDITIONS

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ABSTRACT: The effects of 6 irrigation salinity levels on yield and quality, vegetative growth, water consumption and ion accumulation of carrot (D*aucus carota L.*) were studied under greenhouse condition in Tokat/Turkey. The experiment was conducted as a randomized block design with 5 replications using a total of 30 pots. The synthetic saline waters were prepared by adding $CaCl_2$, $MgSO_4$ and NaCl salts to tap water. Tap water (ECi= 0.75 $dS.m^{-1}$) was applied as a control treatment. Irrigation water salinity (T_0= 0.75, T_1= 1.5, T_2= 2.5, T_3= 3.5, T_4= 5.0 and T_5= 7.0 dS m^{-1}) led to increase in soil salinity, carrot flavor, leaf Cl and Na content and decrease in fruit yield, fruit diameter, water use efficiency and leaf K content. Increasing irrigation water salinities did not significantly affect unit weight, color index, height and penetration resistance of fruit, water consumption, leaf Ca and Mg contents but fruit quality such as flavor and dry matter content improved due to salinity, however 50% yield loss occurred even below at 2.5 dS m^{-1} soil salinity level.
Key words: Carrot *(Daucus carota L.),* Water quality, Salinity, Yield, Fruit quality.

TUZLU KOŞULLARDA HAVUÇ (*Daucus carota L.)* VERİM VE KALİTESİ

ÖZET: Bu çalışmada Tokat ilinde, sera koşullarında, 6 farklı tuzluluk düzeyindeki sulama sularının havuçta verim, kalite, vejatatif gelişme, su tüketimi ve mineral madde alımı araştırılmıştır. Çalışma tesadüf bloklarında 5 tekerrürlü olarak toplam 30 saksıda yürütülmüştür. Tuzlu sulama suları $CaCl_2$, $MgSO_4$ ve NaCl tuzlarının şehir şebeke suyuna karıştırılmasıyla elde edilmiştir. Şehir şebeke suyu (ECi= 0.75 $dS.m^{-1}$) aynı zamanda kontrol konusu olarak kullanılmıştır. Sulama sularının tuz içeriğinin artması (T_0= 0.75, T_1= 1.5, T_2= 2.5, T_3= 3.5, T_4= 5.0 ve T_5= 7.0 dS m^{-1}), toprak tuzluluğunun, meyve tadının, yaprakta Cl ve Na miktarının artmasına yol açarken, meyve çapının, su kullanım etkinliğinin ve yaprakta K miktarının azalmasına neden olmuştur. Artan sulama suyu tuzlulukları, meyve birim ağırlığını, rengini, boyunu, sertliğini, bitki su tüketimini, yaprakta Ca ve Mg miktarını istatistiksel olarak etkilememiş ancak meyve tadını, kuru madde miktarını artmış, fakat 2.5 dS m^{-1} toprak tuzluluğu verimde yaklaşık %50 azalmaya neden olmuştur.
Anahtar Sözcükler: Havuç *(Daucus carota L.),* Su kalitesi, Tuzluluk, Verim, Meyve kalitesi.

1. INTRODUCTION

Globally, about 10 Mha of agricultural land is lost annually due to salinization, of which about 1.5 Mha is irrigated areas (Khan et al. 2006). Therefore, for sustaining life on earth, controlling these problems and finding new ways to utilize these extensive sodic and saline soils and water resources, at least for agricultural purposes, are vital and urgent issues. Reclamation, or at least minimizing the effect of salinity and sodicity, is important and necessary. In this respect, proper utilization of water for both plant growth and soil salinity control is probably of the greatest importance (Pessarakli and Szabolcs 1999).

Agricultural drainage waters often contain high concentration of salt ions (Ayers et al., 1993; Skarie et al., 1986). Land disposal of saline drainage water can lead to serious environmental consequences since dissolved ion species such as sodium, calcium and chloride may accumulate to extremely high levels, becoming toxic to plant growth (Grieve and Suarez1997; Rhoades et. al., 1988). To maintain soil and crop productivity, a critical question for saline drainage water reuse is to determine the fate of major and toxic salts ions, which is related to the potential effect of these salts on soil salinization, plant growth, crop quality and yield (Wang et. al., 2002). Most of the salinity studies in the literature were carried out only in the presence of NaCl salt. Munns and Passioura (1984) and Berstain and Ayers (1953) studied the salinity tolerance of carrot in the presence of NaCl and reported that the plant was salt sensitive. However, later studies have reported large differences in salinity tolerance for carrot (Maas and Hoffman, 1977; Matsubara and Tasaka 1988; Mangal et. al. 1989; Gibbererd at al. 2002). Many other studies have shown that salt stress can also be alleviated by an increased supply of calcium to the growth medium (Rausch *et al*., 1996). Depending on the concentration ratio, sodium and calcium can replace each other from the plasma membrane, and calcium might reduce salt toxicity (Rausch *et al*., 1996). If none of these mechanisms are available to the plant, then eventually the leaf death rate will overcome the leaf growth rate, and plant death will occur. The differences found in salt tolerant plant species are related to the time it takes salt to reach its maximum accumulation and causes plant death. By studying plants with varying tolerance, eventually scientists will discover the differences in the plant genome that are causing sensitivity or resistance. A new strategy to study salt sensitive plants involves selecting root mutants with high sensitivity (Maggio *et al*., 2001).

The aim of the study is to determine the effects of salinity on carrot plant in terms of yield and quality such as color, size and penetration rate, and water consumption, water use efficiency, ion uptake and soil salinity and pH, in the presence of $CaCl_2$, $MgSO_4$ and NaCl with increasing concentration levels.

2. MATERIAL AND METHODS

The experiment was conducted under greenhouse conditions in Tokat/Turkey. In the experiment, carrot plants (*Daucus carota L.*) were exposed to six different salinity levels. Electrical conductivity of the irrigation waters were T_0= 0.75, T_1= 1.5, T_2= 2.5, T_3= 3.5, T_4= 5.0 ve T_5= 7.0 dS m^{-1}. The experiment was conducted as a randomized block design with 5 replications, with a total of 30 pots. Tap water (EC_i= 0.75 dS.m^{-1}) was applied as control treatment. Compositions of irrigation water were shown in Table 1. Fertilization needs were met by applying 90 kg.ha^{-1} of N as urea and 90 kg.ha^{-1} of P diammonium phosphates (DAP) (Doorenbos and Kassam 1986). At the beginning of the experiment, the entire P requirement and half of the total N requirement were supplied. The rest of N was applied 20 days after the first application.

The synthetic saline waters were prepared by adding $CaCl_2$, $MgSO_4$ and NaCl salts to tap water. In order to eliminate the adverse effect of sodium adsorption ratio (SAR), irrigation water SAR values were maintained around 5.0. The Ca requirement of the plants is generally low and depends on the presence of the other cations. The Ca requirement may be related to ion competition and, thus, better expressed in terms of ion ratios. High Mg/Ca ratios in solution may result in Ca deficiencies in plant, despite of high absolute Ca concentration (Pratt and Suarez, 1990). In other word, to eliminate Ca deficiency, we chose the ratio of Ca/Mg of 1/1 in $meqL^{-1}$. Thus, the irrigation water composition should not cause any specific major ion imbalance on the plant. Irrigation waters were stored in 100 liter pots and before each irrigation event, waters were measured for EC.

The experimental soil was sieved through a 4 mm screen to remove large particles and break up dry soil aggregates. Twenty kg of air-dried soil was placed in each pot. The experimental soil's texture was sandy loam with 18.2% clay, 25% silt and 56.8% sand. Pots' height, upper diameter and bottom diameter were 28, 29 and 25 cm, respectively. Thus total volume and surface area of each pots were 16 liters and 660 cm^2, respectively. To determine the field capacity of each pot, they were saturated with tap water and then the top of the pots were covered in order to prevent evaporation. The water contents of the pots after the drainage stopped were assumed as field capacity (W_{FC}), so that we determined each pot separately. Soil water content was monitored by weighing the pots as weighing lysimeter method, thus each pot was weighed before each irrigation practices (W).

Table 1. Compositions of irrigation water

Konu	EC (dSm^{-1})	Na (me/L)	K (me/L)	Ca (me/L)	Mg (me/L)	Cl (me/L)	SO_4 (me/L)	HCO_3 (me/L)	pH	SAR
T_0	0.75	1.15	0.077	4.27	2.98	0.80	6.01	0.84	6.69	0.60
T_1	1.5	6.61	0.077	6.12	4.98	8.12	8.01	0.84	6.68	2.81
T_2	2.5	11.13	0.077	9.00	8.15	15.51	11.18	0.84	6.67	3.80
T_3	3.5	15.69	0.077	12.80	12.40	23.88	15.43	0.84	6.68	4.42
T_4	5.0	21.62	0.077	19.38	19.65	36.40	22.68	0.84	6.65	4.89
T_5	7.0	28.82	0.077	29.38	30.65	53.60	33.69	0.84	6.64	5.26

Amount of irrigation water to be applied (I) was calculated by equation (1):

$$I = \frac{\dfrac{W_{FC} - W}{\rho_w}}{1 - LF} \qquad (1)$$

where, I is amount of irrigation water (Liter), LF is leaching fraction, W is the pot weight just before irrigation starts and ρ_w is density for water (1.0 kg/liter). The pot surface area is 0.066 m^2, so the depth of irrigation amount can be calculated by dividing 'I' to pot surface area. We selected LF= 0.30. Amount of drainage water was measured after irrigation. A drain pan was placed underneath each pot to collect leachate. Collected drainage water volume was measured after irrigation. Seasonal evapotranspration was determined by means of modified equation of Jensen et al. (1989);

$$ET = d_b + d - d_d - d_s \qquad (2)$$

Where, ET is seasonal evapotranspration (L), d_b is soil moisture at the beginning of the experiment (L), d is total irrigation water (L), d_s is soil moisture at the end of the experiment (L), d_d is drainage volume (L).

At the end of the experiment, to determine dry weight ratio, the harvested fruits and leaves were weighed as fresh and oven-dried at 70°C to a constant dry weight. Penetration resistance of carrot was determined by penetrating a pin of 1.8 mm in diameter at three points in the carrot. Penetration speed was 60 mm/min and penetration depth was 30 mm. Color index was calculated as follows (Garcia-Sanchez et al. 2003):

$$CI=1000\times a / (L\times b) \quad (3)$$

Where L indicates lightness, a and b are the chromaticity co-ordinates.

Effect of salinity on carrot taste was also investigated. Fifteen individuals tasted carrot fruits and gave the taste scores from 1 to 5. The higher the score is the higher the flavor quality. Immediately after the plants were removed, soil samples were taken from the entire depth of root zone of each pot. Soil samples were crushed to pass through a 2-mm screen. Handbook 60 procedures were followed to measure EC of saturated soil paste (ECe). To determine mineral matter accumulations in leaves, samples were collected at harvest. These samples were washed with tap water and then distilled water in turn, then dried in an oven and grounded. For the measurements of mineral nutrients, plant samples were ashed in a muffle furnace at 500 °C for 6 h, dissolved in 5 mL of 2 M HNO_3, and finally diluted to 25 mL with distilled water. Extracts were filtered and stored in plastic vials until analyzed. Sodium and K were measured by flame photometer and water extractable Cl was determined by potentiometer titration with $AgNO_3$ as described by Lambert and DuBois (1971). Calcium and Mg were determined by EDTA titration method described by Richards (1969).

The experimental data were analyzed by SPSS statistical analysis software (SPSS, 2002). The General Linear Model procedure was used to perform analysis of variance. Unless otherwise noted, all statistical tests were performed at 0.01 level of significance. Duncan's multiple range tests were used to separate means of the data at 0.05 level of significance.

3.RESULTS AND DISCUSSION

3.1.Soil Salinity

At the end of the experiment, treated experimental soils did not reach the irrigation water salinity levels, because the initial soil was not saline and evapotranspiration rate was low in the period studied. On the other hand, the effect of irrigation water quality on soil salinity (ECe) were statistically significant, $p<0.05$ (Table 2 and Figure 1). Soil salinity increased with increasing water salinity. Our soil salinity data showed similarity to Kadayıfçı et al. (2004) which reported that increasing salinity of irrigation water led to increase in soil salinity. Authors also reported that the salinity of the experimental soils at the harvest was still below the irrigation water salinity level.

The differences in pH were found to be statistically significant, $p<0.05$ (Table 2). Pratt and Suarez (1990) reported that high pH values, i.e., pH> 8.5 indicate waters with an excess of alkalinity over Ca, which usually pose a sodicity hazard. Our results suggested that there was no excessive alkalinity hazard during the experiment. The presence of salt will lower soil pH reading compared to the absence of salts; the lower pH is often referred to as salt depression of pH. Salts may depress pH slightly (0.1 pH units) or by as much as 1.0 pH units (Hardly, 2008).

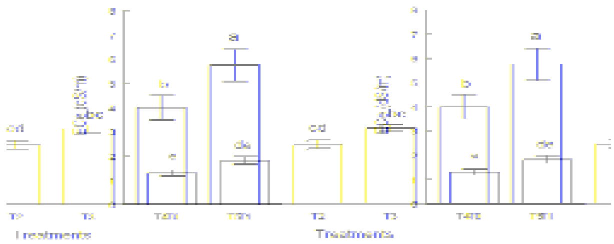

Figure 1. Effects of water salinity (EC_w) on soil salinity at the harvest (EC_e).

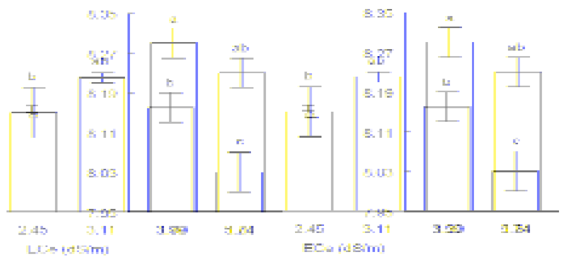

Figure 2. Effects of soil salinity (EC_e) on pH of the experimental soils at the harvest (pH_e).

3.2. Carrot Yield and Quality

Increasing water salinity led to significantly reduced carrot yield, (Table 2). The highest yield was obtained from the control treatment, 103.6 g/pot. Comparing to control treatment, the yield reductions were, 35, 50, 39, 61.5 and 50.8% for 1.5, 2.5, 3.5, 5.0 and 7.0 dS m^{-1} irrigation water, respectively (Figure 3). A sudden yield decrease was observed at the first saline treatment, the salinity level of which was slightly higher than control treatment. Yield differences among the treatments except control were not significant statically. The similar results for vegetative yield were found and shown in Figure 4. Maas (1986) reported that root yield declines %14 for every unit increase in salinity beyond the threshold of 1.0 dS/m.

Table 2. Effects of irrigation water salinity (EC_w) on experimental data observed.

Analysis	Treatments (dS/m)													
	T_0(0.75)		T_1(1.5)		T_2(2.5)		T_3(3.5)		T_4(5.0)		T_5(7.0)		Mean	P>F
ECe (dS/m)	1.30[#]	e[t]	1.81	de	2.45	cd	3.11	bc	3.99	b	5.74	a	3.06	*
pH	8.29	a	8.23	ab	8.15	b	8.22	ab	8.16	b	8.03	c	8.17	*
I, applied irrigation water, (lt)	13.2		13.9		13.7		13.8		13.1		12.7		13.4	NS
Drainage water, (lt)	4.5		4.6		4.5		4.6		4.6		4.2		4.5	NS
LF	0.34		0.33		0.33		0.33		0.35		0.33		0.33	NS
ET (lt)	7.3		7.9		7.8		7.7		7.00		6.9		7.44	NS
WUE (g/lt)	14.3	a	8.5	b	6.6	b	8.3	b	6.0	b	7.4	b	8.5	*
Yield (g/pot)	103.6	a	66.8	b	51.5	b	63.4	b	42.1	b	50.9	b	61.5	**
Veg. Yield (g/pot)	21.9	a	9.20	b	8.47	b	8.09	b	5.97	b	10.24	b	10.16	*
Fruit Dry Matter (%)	12.4		12.5		11.9		12.0		12.2		11.7		12.1	NS
Fruit unit weight (g/cm^3)	1.00		1.01		0.99		1.02		1.04		1.07		1.02	NS
Fruit dia.(mm)	29.3	a	22.1	b	20.9	b	22.0	b	19.0	b	19.8	b	21.9	*
Fruit height (cm)	20.1		21.1		20.3		21.7		18.9		18.9		20.2	NS
Color index	7.35		7.40		6.48		7.22		7.66		7.38		7.24	NS
Penetration resistance	19.85		16.78		15.98		18.00		16.65		15.48		17.03	NS
Taste score	2		2.5		2.3		3.1		3.3		3.7		2.82	-
Cl %	-	-	3.05	c	4.07	bc	5.18	ab	5.65	b	7.60	a	4.99	*
Ca %	2.43		2.87		2.90		2.94		3.10		2.94		2.88	NS
Mg %	0.80		0.86		0.91		1.13		0.89		1.30		0.98	NS
K %	1.43	a	1.40	a	1.15	ab	0.83	bc	0.75	c	0.69	c	1.04	*
Na %	0.44	b	0.56	ab	0.54	ab	0.66	a	0.71	a	0.60	ab	0.59	**

#	: each value is the mean of five replications,
t	: within rows, means followed by the same letter are not significantly different according to Duncan's multiple range test at 0.05 significance level,
*, **	: significant at the 0.01 and 0.05 probability levels, respectively,
NS	: non-significant,
LF	: Leaching fraction,
ET	: Evapotranspiration,
WUE	: Water use efficiency (fresh fruit yield (g)/water consumption (lt).

Unit weight and the height of carrot plant were not statistically affected by salinity, (Table 2). The diameter of the fruit, which is another quality parameter of the carrot, decreased with increasing salinity level. In other words, fruit height and fruit unit weight were not affected by salinity but the diameter of the fruit decreased with increasing the salinity. Our results agreed with Öztürk (1997) who reported that salinity affected fruit diameter negatively but had no effect on fruit height. The yield decreases were well correlated with the decrease of the diameter which means that the yield decreases of carrot were the result of decreasing diameter (Figure 5).

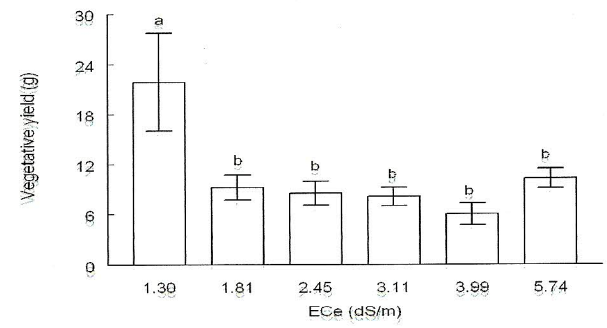

Figure 4. Effects of soil salinity (EC_e) on vegetative yield

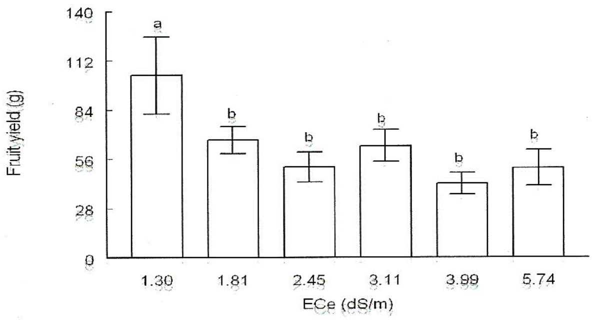

Figure 3. Effects of soil salinity (EC_e) on fruit yield

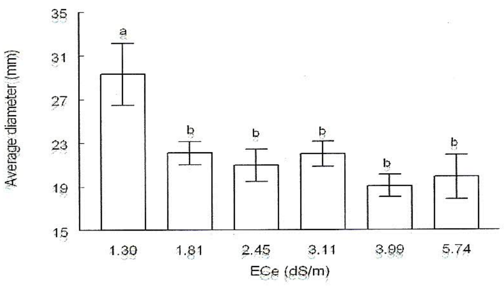

Figure 5. Effects of soil salinity (EC_e) on fruit diameter.

The effects of salinity on carrot color and carrot firmness were not found statistically significant (Table 2). Carrot color index and penetration resistance did not statistically change. Changes in carrot taste because of salinity were also investigated. Fifteen individuals tasted carrot fruits and gave the taste score 1 to 5. The higher score was given to the more flavor the average taste scores were 2, 2.5, 2.3, 3.1, 3.3 and 3.7 for T_0, T_1, T_2, T_3, T_4 and T_5 treatments, respectively. According to these results, salinity improved carrot flavor.

3.3. Effect of Salinity on Evapotranspration and Water Use Efficiency

The experiment was conducted in cool season in a greenhouse without heating. Because of the low temperature, low solar radiation and high relative humidity, evaporative demand of atmosphere and plant water needs were also low. Although the differences in evapotranspration/water consumption were not significant, yield decreases occurred (Table 2). The effects of salinity, soil aeration and nutrient level on the transpiration coefficient of carrot were evaluated under non-limited water supply condition (Schmidhalter and Oertli 1991). The authors observed no change in the transpiration coefficient at salt concentration up to 16 dS/m in the soil solution and suggested that in the absence of toxic ion effects and nutrient imbalances, salinity had little effect on the transpiration coefficient (Shannon and Grieve, 1999). Salinity impaired plant growth even in the cool season without causing a decrease in water consumption. Water use efficiency (WUE) decreased with increasing salinity level (Table 2). The highest WUE was obtained in the control treatments, 14.3 g lt^{-1} and the rest of the treatments caused to decrease in WUE.

3.4. Ion Uptake

Increasing salinity led to increase in Cl and Na and decrease in K accumulation in leaves. Ca and Mg contents in leaves also increased slightly but this increase was not found to be statistically significant (Table 2). The highest Cl content in leaves occurred at the highest salinity treatment. Increasing salinity levels led to increase in Cl content in leaves for each treatment (Figure 6). Preparing the synthetic saline water, chloride salts such as $CaCl_2$ and NaCl were utilized, thus Cl became the major anion in the irrigation water.

Potassium content of carrot leaves were reduced significantly by the effect of salinity (Figure 7). The competition between Na and K, increasing quantity of Na in the soil media caused to decrease in K accumulation and led to increase in Na accumulation in leaves. The differences in Na content of carrots were found to be significant and Na content increased as soil salinity increased (Figure 8). Na content ratios in T_1, T_2, T_3, T_4 and T_5 treatments were 1.3, 1.2, 1.5, 1.6 and 1.4 times higher than the control treatment.

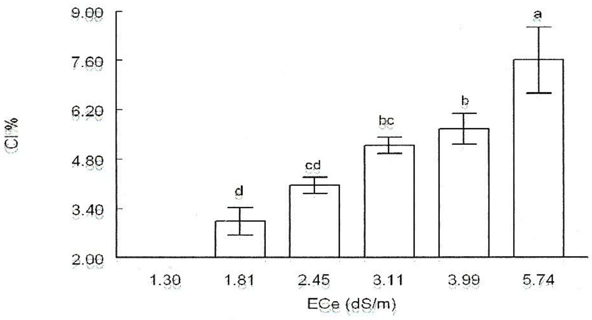

Figure 6. Effects of soil salinity (EC_e) on chloride accumulation in leaves.

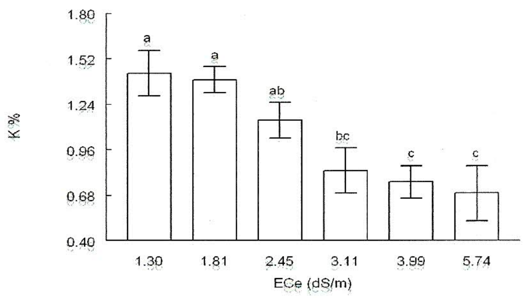

Figure 7. Effects of soil salinity (EC_e) on potassium accumulation in leaves.

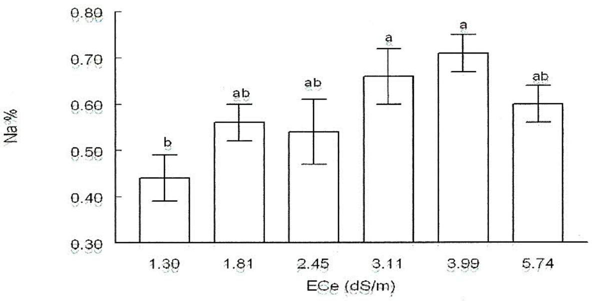

Figure 8. Effects of soil salinity (EC_e) on sodium accumulation in leaves.

In terms of ion uptake, our results were similar to those reported by De Pascale and Barbieri (2000). The authors reported that Cl and Na contents increased, but K content decreased in carrot leaves with increasing salinity. They also reported the antagonistic effect of Na to K.

4. CONCLUSION

Experimental results on carrot fruit (root) and leaves revealed that irrigation water salinity induced an increase in carrot flavor, leaf Cl and Na content and soil salinity, and a decrease in fruit yield, fruit diameter, water use efficiency and leaf K content. Some characteristics like unit weight, color index, height and penetration resistance of fruit, water consumption, leaf Ca and Mg contents, were not affected due to irrigation water salinity. Fruit quality such as flavor content improved due to salinity but 50% yield loss occurred even before 2.5 dS m^{-1} soil salinity. Yield losses were nearly constant against increases in soil salinity, at the levels of higher than 2.5 dS m^{-1}. We concluded that carrot plant is very sensitive to soil and water salinity.

5. ACKNOWLEGMENT

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