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Effects of Irrigation with Saline Water on Crop Growth and Yield in Greenhouse Cultivation

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Abstract: Since the salinity of irrigation water is a critical constraint to the production of certain vegetable crops, salinity has been considered as one of the most important factors of irrigation water. The objective of this study was to investigate the response of lettuce and Chinese cabbage to various salinity levels of irrigation water in greenhouse cultivation. A pot experiment was conducted with different salinities under a glasshouse condition in Korea. A completely randomized experimental design was used with three replications. The analysis results of crop growth and yield of lettuce and Chinese cabbage indicated that the factors that were more significantly affected by saline irrigation water were crop yields rather than crop components such as number of leaves, leaf length, and leaf width. In this study, the point of salt concentration during an increase in salinity levels of irrigation water (EC_w) at which yield starts to decline was determined to be 0.9 and 1.5 dS/m for lettuce and Chinese cabbage, respectively. Furthermore, the present study demonstrated that the continuous irrigation of saline water under greenhouse conditions could lead to a significant increase in electric conductivity (EC_e) level and Na^+ concentration in soil, as well as Na^+ concentration in leaves of crops.

Keywords: irrigation water; salinity; lettuce; Chinese cabbage; salt tolerance

1. Introduction

Greenhouse cultivation is a widely used farming system to provide a controlled environment suitable for optimal crop production [1]. For this reason, greenhouse crop production is now a steadily growing agricultural sector throughout the world with an estimated 405,000 ha of greenhouses spread all over the world [2]. In the Republic of Korea, the total area covered under greenhouse cultivation is approximately 93,551 ha, accounting for 82,997 ha for vegetable crops and 2958 ha for flowers [3]. Recently, the Korean government is planning on constructing 5185 ha of new greenhouses for growing horticultural crops including vegetable crops in the reclaimed land. In the reclaimed land, saline water can be used for irrigation due to the absence or limited supply of fresh water. In addition, the groundwater used for irrigating greenhouses near the coastal areas is frequently saline [4].

The use of saline irrigation water has an adverse effect on soil–water–plant relations, occasionally severely restricting the normal physiological activity and productive capacity of the crops [5,6]. Under high salinity level, the crop growth, leaf surface expansion, and primary carbon metabolism of many crops are negatively affected due to osmotic effect, water deficit, nutritional imbalance, and oxidative stress [7]. Several crops are sensitive to salinity and the negative effect on growth leads to the decrease in potential profits. For this reason, salinity has been considered as one of the most important factors of irrigation water [8]. Irrigating saline water can also result in salt accumulation in soil, leading to the decrease in yield and deterioration in soil resource [9,10]. In particular, under greenhouse conditions, the salinity problem is a critical constraint to vegetable production due to rapid accumulation of salts in soil [11,12].

There have been several studies on the effects of saline irrigation water on plant systems in greenhouses [13,14]. In the study by Reina-Sanchez *et al.* [15], effects of salinity on tomato fruit yield have been quantified in experiments under greenhouse and soil-less cultivation with four salinity levels in Malaga, Spain. Lee *et al.* [16] quantified the impact of saline irrigation water on chrysanthemums in a greenhouse in Athens, Georgia. Rameshwaran *et al.* [12] investigated effects of different irrigation regimes with salinity treatments using a drip irrigation system for two pepper varieties in the greenhouse in Antalya, Turkey. Feigin *et al.* [17] tested the response of lettuce and Chinese cabbage to the combination of a wide range of salinity and potassium nitrate levels in the greenhouse using an aero-hydroponic system. Garrido *et al.* [18] evaluated physiological, phytochemical, and structural changes in lettuce by salt stress in a soilless system. In Korea, land constructed by land reclamation projects was mainly used to produce paddy rice. Thus, while many studies have focused on identifying the response of paddy rice under salinity stress [19–21], there still is a lack of information on effects of using saline irrigation water on the growth and yield of crops grown under greenhouse conditions.

Despite the number of studies on the subject, the sensitivity and tolerance of crops to salinity level may vary depending on meteorological and soil conditions in the region, as well as the irrigation method [22,23]. It is also recommended that a seawater or brackish water desalination system be used to solve the salinity problems of irrigation water and soil in greenhouses located in coastal areas [24]. In designing the desalination system, the target salinity level for irrigation water substantially affects the cost of the product water. Thus, it is important to examine the salt tolerance of crops grown in greenhouse conditions and to determine the optimal salinity of irrigation water to minimize the negative impacts on crop production, and at the same time maximize the economic benefits. The objective of this study, therefore, was to investigate the response of vegetable crops to different salinity levels of irrigation water under greenhouse conditions in order to determine the target salinity level for a desalination system and to further our understanding of soil–water–plant relations.

2. Materials and Methods

2.1. Experimetnal Design

In this study, a pot experiment (27.5 cm diameter and 24.8 cm height) was conducted in a glasshouse at the Pyeongchang Campus, Seoul National University, which is located in Gangwon-do, Korea (37°32′51″ N and 128°26′26″ E). The experiment was set up as a completely randomized block design with five treatments and three replications. Pots were filled with a commercial potting soil (Seoul Bio Inc., Chungcheongbuk-do, Korea): The filled soil was loam (49.6% sand, 33.8% silt, and 16.6% clay), and its chemical characteristics were analyzed (see Table 1). The vegetable crops grown were lettuce (*Lactuca sativa* L.) and Chinese cabbage (*Brassica campestris* L. ssp. *pekinensis*), which are the most commonly produced crops grown in greenhouses for sale and home consumption in Korea [3], and considered as moderately sensitive crops [25]. Seeds of vegetables were sown in each pot. The seeding and harvesting times for each vegetable are shown in Table 2. Tap water was used as a control treatment (TR#01). The target salinity levels of irrigation water (EC_w) for other treatments were determined based on the threshold salinity for irrigation water given by Maas and Grattan [25], as shown in Table 3. For example, the EC_w value of irrigation water at the 100% yield potential is 0.9 dS/m for lettuce (TR#03), whereas the EC_w value at the 90% yield potential is 1.4 dS/m (TR#05). The salinity levels of other treatments (TR#02: 0.7 dS/m, TR#04: 1.1 dS/m) were then determined based on those EC_w values. Saline irrigation water with four salinity levels was prepared by adding sodium chloride (NaCl) to tap water used as a control treatment in order to achieve the target salinity level of irrigation water (Table 3). The prepared irrigation water was stored in 20 L plastic containers. All treatments were watered manually, providing the crop growth and soil conditions with the same amount of irrigation water. None of the applied water leaked from the pots. The temperature and relative humidity in the greenhouse were monitored daily during the experimental period. Daily averages of temperature and relative humidity were 31.3 °C and 21.9%, respectively. Fertilizer was not applied to all treatments. The experiments for lettuce and Chinese cabbage were conducted twice. The soils in each pot, however, were not changed after finishing the first experiment. After the removal of crops at the end of the first experiment, the seeds of vegetables were again sown in the same soil to investigate the long-term effects of saline irrigation water and the salinity accumulation in soil and crops.

Table 1. Chemical properties of the initial soil used in the experiment.

PH (1:5)	EC_e (dS/m)	CEC (cmol/kg)	T-N (%)	T-P (mg/kg)	P_2O_5	O.M. (%)	Exchangeable Cation (mg/kg)			
							Ca^{2+}	Mg^{2+}	Na^+	K^+
5.6	8.5	73.2	0.596	1676.0	1521.5	65.5	4534.8	1935.5	1042.1	5478.8

EC_e: electrical conductivity of the saturated-soil extract; CEC: cation exchange capacity; T-N: total nitrogen, T-P: total phosphorus; O.M.: organic matter.

Table 2. Planting and harvesting dates for each vegetable during the experiment period.

Vegetable	Experiment	Seeding Date	Harvesting Date	Total Amount of Irrigation Water
Lettuce	First Second	19.June 2015 7 August 2015	6 August 2015 24 September 2015	5.6 L 5.9 L
Chinese cabbage	First Second	5 June 2015 24 July 2015	10 July 2015 28 August 2015	5.0 L 3.6L

Table 3. Salinity of irrigation water for each treatment and vegetable.

Vegetable	TR#01	TR#02	TR#03	TR#04	TR#05
Lettuce	0.3 dS/m	0.7 dS/m	0.9 dS/m	1.1 dS/m	1.4 dS/m
Chinese cabbage	0.3 dS/m	0.9 dS/m	1.2 dS/m	1.5 dS/m	1.9 dS/m

2.2. *Water Quality, Soil, and Plant Monitoring*

2.2.1. Irrigation Water Quality

Water samples were analyzed according to the standard methods of APHA [26] for conventional parameters including the hydrogen exponent (pH), total nitrogen (T-N), total phosphorus (T-P), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+), chloride (Cl^-), sulfate ($SO_4{}^{2-}$), and nitrate ($NO_3{}^-$).

2.2.2. Soil

Soil samples were taken from depths of 0–20 cm from each pot at the end of the second experiment, and the samples were analyzed for chemical properties with the soil analysis methods of the American Society of Agronomy (ASA) and Soil Science Society of America (SSSA) [27]. The chemical analyses included pH, electrical conductivity of the saturated-soil extract (EC_e), cation exchange capacity (CEC), T-N, T-P, phosphorus pentoxide (P_2O_5), organic matter (OM) as well as exchangeable cations including Ca^{2+}, Mg^{2+}, Na^+, and K^+.

2.2.3. Crop Growth and Yields

For lettuce and Chinese cabbage, numbers of leaves, leaf length, and maximum leaf width were measured on a weekly basis throughout the growing season. At the end of each experiment, fresh crop yield of each treatment was measured.

2.2.4. Sodium Accumulation in Crops

To determine Na^+ accumulation in harvested crops, the crop samples were washed with distilled water in the laboratory to remove soil particles and oven-dried at 60 °C. After grilling, 0.5 g of the crop tissue was digested in 10 mL of HNO_3. The digested solution was filtered into a 25.0-mL volumetric flask through a Whatman No. 40, 125 mm filter paper. In the solution, the Na^+ content was measured by an inductively coupled plasma optical emission spectrometry (ICP-OES; iCAP 7000, Thermo Fisher Scientific Inc., Waltham, MA, USA).

2.3. Statistical Analysis

To compare the effects of the different treatments, data were analyzed using analysis of variance (ANOVA) procedures. Tukey's honestly significant difference (HSD) test was employed as a *post hoc* test to determine significant differences between means at a significance level of $p < 0.05$. All statistical analyses were conducted using SPSS 21.0 (SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. Lettuce

3.1.1. Irrigation Water

The total amount of irrigation water was 5.6 L during the first experiment period and 5.9 L during the second experiment period (Table 2). Table 4 shows the average water quality of irrigation water over the experiment period. The average value of pH was 8.38, ranging from 8.3 to 8.5. The concentration of T-N ranged from 2.00 to 2.75 mg/L, whereas T-P was not detected in all treatments. With increased salinity level of irrigation water, the concentrations of Na^+ and Cl^- increased; the highest concentrations were observed in TR#05 (204.31 mg/L for Na^+ and 291.0 mg/L for Cl^-), while the lowest values were found in TR#01 (8.23 mg/L for Na^+ and 17.0 mg/L for Cl^-). The average concentrations of Ca^{2+}, Mg^{2+}, K^+, $SO_4{}^{2-}$, and $NO_3{}^-$ were 32.27, 5.37, 2.13, 9.8 and 1.8 mg/L, respectively.

Table 4. Average water quality of irrigation water for lettuce over the experiment period.

Treatments	pH (1:5)	T-N (mg/L)	T-P (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Cl^- (mg/L)	$SO_4{}^{2-}$ (mg/L)	$NO_3{}^-$ (mg/L)
TR#01	8.5	2.75	ND	34.08	5.79	8.23	1.84	17.0	10.2	2.3
TR#02	8.3	2.03	ND	32.04	5.35	71.70	2.09	108.9	9.7	1.8
TR#03	8.4	2.21	ND	31.45	5.23	108.13	2.14	161.1	9.8	1.7
TR#04	8.4	2.00	ND	31.95	5.24	144.13	2.21	209.5	9.6	1.6
TR#05	8.3	2.30	ND	31.81	5.23	204.31	2.39	291.0	9.7	1.8

T-N: total nitrogen; T-P: total phosphorus; ND: not detected.

3.1.2. Soil

The EC_e values ranged from 6.77 (TR#01) to 18.21 (TR#04) dS/m. As the salinity of irrigation water (EC_w) increased, EC_e tended to increase except for the case of TR#05 (Table 5). Compared to the initial soil before irrigation (Table 1), the concentration of Na^+ in soil increased in all treatments (Table 5). A notable change in Na^+ was observed in TR#05, where water of a high salinity level was irrigated. These results indicated that the use of saline irrigation water results in an increase in soil salinity.

3.1.3. Crop Growth and Yield

The increased salinity level of irrigation water did not significantly affect the number, length, or width of leaves among the treatments ($p > 0.05$) of both experiments (Table 6). In the first experiment, the highest leaf number was observed in TR#04, followed by TR#03 and TR#05, TR#02, and TR#01, whereas the highest leaf number of the second experiment was found in TR#03, followed by TR#01 and TR#02, TR#04, and TR#05. Andriolo *et al.* [13] reported that the number of lettuce leaves was not affected by salinity treatments. While in the first experiment, the highest values for leaf length and width were observed in TR#01, in the second experiment, they were found in TR#03.

Table 5. Chemical properties of the sampled soils at the end of the second lettuce experiment.

Treatment	pH (1:5)	EC_e (dS/m)	CEC (cmol/kg)	T-N (%)	T-P (mg/kg)	P_2O_5 (mg/kg)	O.M. (%)	Exchangeable Cation (mg/kg)			
								Ca^{2+}	Mg^{2+}	Na^+	K^+
L_TR#01	6.1	6.77	72.95	0.627	905.87	434.78	59.71	7154.25	2074.11	1414.89	1963.74
L_TR#02	6.3	8.01	73.34	0.663	748.93	344.56	45.57	7570.83	1990.77	1836.78	2118.81
L_TR#03	6.1	17.72	76.83	0.693	659.17	284.79	67.74	7688.73	2085.51	2544.09	2336.58
L_TR#04	6.1	18.21	78.84	0.629	867.40	435.60	61.56	7093.77	1956.78	3031.32	2253.69
L_TR#05	6.4	19.64	79.88	0.592	767.10	303.74	65.39	7647.57	1949.40	3775.17	2274.39

Table 6. ANOVA and *post-hoc* test of growth components, yield, and Na^+ concentration in lettuce.

Treatments	Leaf Number (ea)	Leaf Length (cm)	Leaf Width (cm)	Fresh Weight (g)		Na^+ (mg/kg)
				Total	Shoot	
First experiment						
L-TR#01	22.0 ± 1.0a	18.2 ± 2.1a	18.5 ± 0.5a	133.3 ± 6.4a	120.3 ± 3.2a	7398.7 ± 2467.8a
L-TR#02	22.3 ± 0.6a	17.3 ± 0.3a	17.6 ± 1.4a	137.7 ± 9.1a	124.7 ± 9.6a	8508.9 ± 3391.8a
L-TR#03	22.7 ± 1.5a	17.7 ± 0.8a	17.6 ± 1.3a	141.7 ± 7.6a	128.7 ± 10.0a	8928.0 ± 343.0a
L-TR#04	23.3 ± 1.5a	16.6 ± 0.7a	17.7 ± 2.0a	136.0 ± 8.2a	123.7 ± 13.6a	9476.2 ± 3075.2a
L-TR#05	22.7 ± 0.6a	17.9 ± 1.8a	18.1 ± 0.6a	138.0 ± 5.3a	128.3 ± 4.7a	9646.1 ± 1147.7a
F	0.579	0.590	0.281	0.502	0.441	0.301
p	0.685	0.677	0.884	0.735	0.777	0.871
Second experiment						
L-TR#01	19.0 ± 2.5a	17.7 ± 1.1a	20.8 ± 0.4a	144.5 ± 7.8abc	130.0 ± 5.7ab	7457.1 ± 157.5a
L-TR#02	19.0 ± 0.0a	17.6 ± 0.8a	20.2 ± 1.5a	146.7 ± 2.5bc	127.0±3.6ab	10,679.2±1242.4b
L-TR#03	20.5 ± 0.7a	18.3 ± 0.1a	21.1 ± 0.7a	152.0 ± 4.2c	134.0 ± 2.8b	12,848.0 ± 748.6bc
L-TR#04	18.3 ± 1.2a	17.8 ± 0.5a	19.3 ± 1.0a	133.7 ± 3.8ab	116.3 ± 6.8a	13,513.9 ± 589.1bc
L-TR#05	18.0 ± 0.0a	17.0 ± 0.6a	20.2 ± 1.1a	131.7 ± 5.5a	117.7 ± 6.1ab	13,689.1 ± 1090.5c
F	1.860	1.805	0.975	0.690	5.105	19.855
p	0.221	0.221	0.472	0.005	0.024	0.000

Different letters indicate significant differences by Turkey's honestly significant difference test at $p < 0.05$

Up to an irrigation salinity of 0.9 dS/m (TR#03), both total and shoot fresh weight yields gradually increased along with the escalation of salinity level, while salinity levels above 0.9 dS/m reduced total and shoot fresh weight yields (Table 6). The highest shoot and total fresh weight yields in both experiments were all observed in TR#03. Significant differences ($p < 0.05$) among the treatments were found in total and shoot fresh weight yields of the second experiment, whereas significant differences were not observed in the first experiment. This result demonstrated that the yield of lettuce was affected by the salinity of irrigation water, and the negative effect of EC_W level was found at salinity levels above 0.9 dS/m. Previous studies [13,14] described that the decrease in crop yields with the increase in the salinity of irrigation water was caused by disturbances in physiological and biochemical activities under saline conditions. In this study, a similar trend was observed in the second experiment. Based on statistical results, the point of salt concentration during an increase in salinity levels of irrigation water (EC_W) at which yield starts to decline was determined to be 0.9 dS/m. This value agreed with the value reported by Maas and Grattan [25], but was lower than the values of 2.0 and 1.1 dS/m reported by Andriolo *et al.* [13] and Ünlükara *et al.* [14], respectively.

3.1.4. Sodium Accumulation in Crops

With an increased salinity level of irrigation water, Na^+ concentration in the leaves increased (Table 6). There were no significant differences ($p > 0.05$) between treatments in the first experiment, while highly significant differences were observed in the second experiment ($p < 0.01$). Compared to results from the first experiment, the concentration of Na^+ increased in all treatments of the second experiment. The greatest difference between the first and second experiments was found in TR#05 (4043.0 mg/kg), followed by TR#04 (4037.7 mg/kg), TR#03 (3920.0 mg/kg), TR#02 (2170.3 mg/kg), and TR#01 (58.4 mg/kg). These results indicated that the saline irrigation water led to the increase in Na^+ concentration in the leaves and that the continuous use of saline irrigation water caused Na^+ accumulation in leaves of lettuce.

3.2. Chinese Cabbage

3.2.1. Irrigation Water

The total amount of irrigation water during the first and second experiment periods was 5.0 L and 3.6 L, respectively (Table 2). As shown in Table 7, the pH was maintained between 8.4 and 8.7. The average concentration of T-N was 2.28 mg/L, ranging from 2.15 to 2.48 mg/L. T-P was not detected in all treatments. As salinity level of irrigation water increased, the concentrations of Na^+ and Cl^- increased as well; the highest concentrations were observed in TR#05 (264.08 mg/L for Na^+ and 387.8 mg/L for Cl^-), while the lowest values were found in TR#01 (8.16 mg/L for Na^+ and 17.1 mg/L for Cl^-). The average concentrations of Ca^{2+}, Mg^{2+}, K^+, $SO_4{}^{2-}$, and $NO_3{}^-$ were 32.26, 5.38, 2.27, 9.8 and 1.9 mg/L, respectively. With the exception of Na^+ and Cl^- concentrations, average water quality parameters of irrigation water for Chinese cabbage were close to those of irrigation water for lettuce (Tables 4 and 7).

Table 7. Average water quality of irrigation water for Chinese cabbage over the experiment period.

Treatments	Ph (1:5)	T-N (mg/L)	T-P (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Cl^- (mg/L)	$SO_4{}^{2-}$ (mg/L)	$NO_3{}^-$ (mg/L)
TR#01	8.4	2.23	ND	32.95	5.57	8.16	1.76	17.1	9.8	1.9
TR#02	8.6	2.18	ND	31.94	5.33	105.65	2.17	155.9	9.8	1.8
TR#03	8.4	2.48	ND	31.97	5.30	168.50	2.35	243.0	9.8	2.0
TR#04	8.7	2.15	ND	33.48	5.60	194.74	2.55	319.1	9.8	1.8
TR#05	8.5	2.36	ND	30.94	5.08	264.08	2.50	387.8	9.7	1.9

T-N: total nitrogen; T-P: total phosphorus; ND: not detected.

3.2.2. Soil

The results for soil analysis showed that the increase in salinity level of irrigation water (EC_w) led to an increase in EC_e (Table 8). The concentration of Na^+ in soil also increased compared to the initial condition of soil before irrigation (Tables 1 and 8). A remarkable difference in Na^+ concentration was found in TR#05 where water with a high salinity level was irrigated. Like the lettuce experiment, these results demonstrated that the use of saline irrigation water caused an increase in salinity level (EC_e) and Na^+ concentrations in soil.

Table 8. Chemical properties of the sampled soils at the end of the second Chinese cabbage experiment.

Treatment	Ph (1:5)	EC_e (dS/m)	CEC (cmol/kg)	T-N (%)	T-P (mg/kg)	P_2O_5 (mg/kg)	O.M. (%)	Exchangeable Cation (mg/kg)			
								Ca^{2+}	Mg^{2+}	Na^+	K^+
C_TR#01	6.1	6.20	74.08	0.612	880.00	339.47	66.43	6681.51	1668.51	907.44	2031.90
C_TR#02	6.2	9.33	76.04	0.606	708.90	213.15	60.35	6521.01	1589.76	2136.27	1604.37
C_TR#03	6.0	15.69	75.85	0.629	788.55	251.06	67.94	5851.71	1385.25	3012.78	2446.56
C_TR#04	5.9	16.83	73.69	0.437	839.3	217.68	61.56	5004.60	1184.49	3116.13	1784.73
C_TR#05	6.0	18.69	67.25	0.460	722.5	165.90	60.55	5077.89	1149.63	3782.40	1780.29

3.2.3. Crop Growth and Yield

In the first experiment, the leaf number and length significantly increased ($p < 0.05$) with the increase in salinity level compared to the control treatment with tap water (TR#01), while, for leaf width, no significant differences were found among the treatments (Table 7). However, in the second experiment, there were no significant differences in leaf number, length, or width among the treatments. In the first experiment, both shoot and total fresh weight yields tended to gradually increase up to an irrigation salinity of 1.5 dS/m (TR#04), and decreased after that point (Table 9). There were significant differences ($p < 0.05$) in shoot fresh weight among the treatments in both experiments where, in the second experiment, a decrease in shoot and total fresh weight yields was observed at salinity levels above 0.3 dS/m (TR#01). Based on statistical analysis, the salinity of irrigation water at which yield reduces for Chinese cabbage was determined to be 1.5 dS/m in this study because a significant decrease in shoot fresh weight yield was found between TR#4 (1.5 dS/m) and TR#5 (1.9 dS/m) in the first experiment. This value was higher than the value (1.2 dS/m) reported by Maas and Grattan [25]. Furthermore, the present study showed that the salinity of irrigation water at which yield reduces can vary depending on the duration of saline irrigation water supply. The results from the second experiment demonstrated that the reduction in Chinese cabbage yield was found at a low salt conservation (0.3 dS/m) due to continual supplement of saline irrigation water, although not at a statistically significant level.

Table 9. ANOVA and *post-hoc* test of growth components, yield, and Na^+ concentration in Chinese cabbage.

Treatments	Leaf Number (ea)	Leaf Length (cm)	Leaf Width (cm)	Fresh Weight (g)		Na^+ (mg/kg)
				Total	Shoot	
First experiment						
C-TR#01	23.3 ± 0.6a	25.9 ± 0.8a	18.4 ± 0.6a	189.3 ± 12.1a	172.3 ± 0.6ab	10,279.0 ± 1095.1a
C-TR#02	25.0 ± 1.0ab	27.0 ± 0.0ab	18.8 ± 1.5a	183.7 ± 1.5a	175.3 ± 1.5ab	14,444.7 ± 1815.2b
C-TR#03	26.0 ± 1.0b	28.0 ± 0.9b	20.2 ± 1.6a	184.0 ± 7.5a	176.0 ± 5.0ab	15,511.3 ± 893.6b
C-TR#04	26.3 ± 0.6b	27.5 ± 0.7ab	19.5 ± 0.8a	187.0 ± 6.1a	178.7 ± 3.1b	14,921.0 ± 829.5b
C-TR#05	24.7 ± 1.2ab	28.8 ± 0.3b	19.7 ± 0.3a	168.3 ± 7.6a	163.7 ± 9.9a	19,241.0 ± 1324.8c
F	5.292	4.535	1.314	3.402	3.738	19.767
p	0.015	0.024	0.330	0.053	0.041	0.000
Second experiment						
C-TR#01	19.3 ± 0.0a	26.4 ± 0.8a	15.9 ± 0.8a	102.0 ± 11.5b	96.7 ± 8.6b	9,867.6 ± 774.9a
C-TR#02	20.0 ± 1.7a	26.2 ± 1.1a	15.5 ± 0.1a	94.0 ± 2.6ab	86.7 ± 5.5ab	11,558.6 ± 1932.7ab
C-TR#03	20.7 ± 1.2a	26.6 ± 2.2a	16.3 ± 1.8a	92.7 ± 8.6ab	86.0 ± 7.0ab	12,901.9 ± 1956.9ab
C-TR#04	19.7 ± 1.5a	25.5 ± 0.9a	15.3 ± 0.8a	81.3 ± 5.0a	75.7 ± 3.8a	13,529.1 ± 850.7ab
C-TR#05	20.3 ± 1.2a	25.9 ± 0.7a	15.1 ± 1.2a	76.0 ± 3.5a	72.7 ± 4.0a	16,392.3 ± 3227.2b
F	0.368	0.342	0.764	6.482	7.494	4.580
p	0.826	0.884	0.572	0.008	0.005	0.023

Different letters indicate significant differences by Turkey's honestly significant difference test at $p < 0.05$.

3.2.4. Sodium Accumulation in Crops

Like the lettuce experiment, Na^+ concentration in the leaves increased along with the increased salinity level of irrigation water (Table 9). Significant differences ($p < 0.05$) were observed among the treatments in both experiments. In contrast with the lettuce experiment, the concentration of Na^+ decreased in all treatments in the second experiment. This decrease in Na^+ concentration in the leaves was probably attributed to the combined effects of the decreased shoot fresh weight and crop growth reduction.

4. Conclusions

In this study, the responses of vegetables irrigated with water of different salinity levels were investigated under greenhouse conditions. The analysis results of crop growth components and yields of lettuce and Chinese cabbage demonstrated that the factors that were more significantly affected by saline irrigation water were crop yields rather than crop components such as number of leaves, leaf length, and leaf width. In particular, compared to the first experiment, there were more significant differences in yields of lettuce and Chinese cabbage among treatments in the second experiment where saline irrigation water was continually supplied without the change of soil after the first experiment. This result led to the conclusion that the continuous application of saline irrigation water resulted in noticeable changes in crop yields in relation to the negative effect of saline irrigation water. Furthermore, it was found that the use of saline irrigation water under greenhouse conditions stimulated Na^+ accumulation in both soil and crops.

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