Asian Journal of Chemistry Vol. 18, No. 3 (2006), 1871–1878

Effects of Sodium and Chloride Ions on Growth and Mineral Contents of Kiwifruit Plant

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In this study, effects of different Na/Cl ratios applied to soil on shoot growing, membrane permeability, relative leaf water, dry weights and mineral composition (Na, Cl, N, P, K) in shoot, leaf and root of kiwifruit (*A. Deliciosa* var. *Hayward*) plant were investigated. Soils of two years old container plants in plastic plots were treated with 40 mM NaCl, and five Na^+/Cl^- ratio applications (100/0, 75/25, 50/50, 25/75, and 0/100). Shoot height, shoot, leaf, and root dry weights were reduced with Na^+/Cl^- applications. Relative leaf water content of plants was higher for all NaCl treatments compared to the control. Membrane permeability was highest for 100/0 ratio but this was not significantly different from 40 mM NaCl and 75/25 ratio treatments. As expected, Cl^- concentrations in plant organs (shoot, leaf and root) generally increased with increasing Cl^- application. Similar results were obtained for Na^+ concentration in plant organs which were increased with increasing Na^+ application. In general, plant K concentration increased with decreasing Na^+/Cl^- treatment. Even though not statistically different, while total nitrogen content of leaf was higher than other tissues, P concentration of root was higher than leaf and shoot. The P concentration in root was reduced for all treatments compared to the control treatment. Na and P accumulated in the root in accordance with applied Na/Cl. These results clearly show that specific ion ratio (Na/Cl) affects plant growth and mineral contents of kiwifruit plants.

Keywords : Kiwifruit, Nutrient uptake, Sodium chloride, Salinity.

INTRODUCTION

Salinity is considered to be a significant factor affecting crop production and agricultural sustainability in many regions of the world and it reduces productivity of the affected land[1,2]. The chlorides and sulphates of sodium and magnesium are leading causes of salinity and are among the most damaging of salts to plants[3,4]. NaCl is usually the predominant salt in the agricultural soils. NaCl salinity reduces vegetative growth, the rate of plant photosynthesis and nutrient uptake by plants[5,6]. Excessive uptake of mainly Cl^- or Na^+ may lead to ionic disturbance of plants. Despite the essentiality of chloride ion as a micronutrient for all higher plants and of sodium ion as a mineral nutrient for many species, excessive concentrations of both ions lead to toxicity in non-salt tolerant plants[7]. Kiwifruit vines, which grow best in deep, well-drained, alluvial soils, require low-salt water as other fruit crops do[3,4]. Excessive total salts and chloride ions will cause leaf burn and defoliation in

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kiwifruits[3,4]. The reports concerning the benefit and toxicity of chloride ions on kiwifruit plants have been conflicting and need to be studied.

Smith *et al.*[3] reported that salinity problem in kiwifruit field in New Zealand appears to be associated more with excess sodium ions than with excess chloride ions in the cases that have so far been investigated. New Zealand researchers[8-10] claim that particularly unusual feature of kiwifruit nutrition is its abnormally large requirement for chloride, whereas Beutel *et al.*[4] noted that leaf burn caused by excess chloride ions harms vines. For most non-halophytic plants, chloride ions deficiency rarely develops unless the concentrations of chloride ions in their tissues are less than 0.2 g kg^{-1} DW[11,12]. By contrast, kiwifruit requires at least 10 times the concentration of chloride ions (2–6 g kg^{-1} DW) for healthy growth[8], and are only adversely affected when the concentration of chloride ions in the leaves exceeds 25 g kg^{-1} DW[13,14]. However, unlike other plant species, which require large concentrations of chloride ions for growth and can tolerate sodium ions, kiwifruit is extremely sensitive to comparatively low concentrations of sodium ions in their root zone[3]. The accumulation of sodium in the roots is typical for a natrophobic species[15] and may be a mechanism for preventing possible adverse effects of this element on the aerial tissues[16].

The objective of this study is to determine the effects of Na^+ and Cl^- toxicity by salt treatments on plant parameters and mineral composition in shoot, leaf and root of kiwifruit plant.

EXPERIMENTAL

This study was conducted at the experimental area of Agriculture Faculty of Karadeniz Technical University in Ordu, Turkey during June 4 to August 20, 2004. Two year-old kiwifruit young trees (*Actinidia deliciosa* cv. *Hayward*) and uniform grown plants were planted in plastic plots containing 5 kg air-dried soil.

The experimental soil texture was clay and pH was 5.53. N, P and K contents of soil were 0.104%, 4.1 mg kg^{-1} and 121 mg kg^{-1} respectively. The soil extract electrical conductivity in experimental soil was 0.24 dS/m and organic matter content was 1.60%. There were seven treatments, *i.e.*, control, 40 mM NaCl and five Na^+/Cl^- ratios (100/0, 75/25, 50/50, 25/75 and 0/100). Na^+ and Cl^- ratios were regulated with NaCl, KCl and Na_2SO_4. Prior to planting, the salts were mixed with the soil. Nitrogen and P were applied at the rate of 200 and 100 mg kg^{-1}, respectively to the soil as ammonium nitrate and mono-ammonium phosphate fertilizers prior to planting and mixed into the soil. The plants were irrigated daily with 0.25 L of tap water. At harvest the plants were separated into leaves, stems and roots.

Harvested tissues were dried in forced air oven at 65°C for three days to determine dry weights (DW) and ground to pass 40 mesh for the analysis. Total-N was determined by Kjeldahl digestion method[17]. The dried and finely ground plant tissue was burnt to ash in a muffle furnace at 500°C for 5 h, dissolved in 5 mL of 2 M HNO_3 and finally diluted to 25 mL with reverse osmosis water. Extracts were filtered and stored in plastic vials until analyzed. In the extract solutions, Na and K were determined by flame photometry (Jenway PFP7, ELE

Instrument Co. Ltd), and P by the colorimetric phosphomolybdate method[18] using Shimadzu UV-Vis 1601 spectrophotometer. For the determination of Cl, dried plant samples (100 mg) were suspended in 10 mL reverse osmosis water and incubated at 45°C for 1 h. After mixing, the samples were centrifuged at 5000 × g for 15 min to precipitate tissue residues. Aliquots from decanted supernatants were titrated against 0.05 N $AgNO_3$ using $KCrO_4$ as an indicator[19].

Membrane permeability was measured using an electrical conductivity meter[20]. Two plant leaf samples were taken from the fourth and fifth leaves below the shoot apex that represent developing leaves two days before harvest and weighed into a glass beaker containing reverse osmosis water. The beakers were immersed at 30°C for 3 h and then the conductivity of the solution was measured with a conductivity meter. After boiling the samples for 2 min, their conductivity was measured again when the solution was cooled to room temperature. The percentage of electrolyte leakage was calculated using the formula:

$$\text{Per cent EC} = (C_1/C_2) \times 100,$$

where C_1 and C_2 are the electrolyte conductivities measured before and after boiling, respectively.

Relative leaf water content (RLWC) was calculated as

$$\text{RLWC (\%)} = (\text{FM} - \text{DM}) \times 100/(\text{TM} - \text{DM})[21].$$

For the determination of RLWC, two leaves were collected from the second and third leaf below the shoot apex developing leaves one day before harvest. Individual leaves were first removed from the stem and then weighed to obtain fresh mass (FM). In order to determine the turgid mass (TM), leaves were floated in distilled water inside a closed petri dish. During the imbibition period, leaf samples were weighed periodically, after gently wiping the water from the leaf surface with tissue paper until a steady state was achieved. At the end of the imbibition period, leaf samples were placed in a pre-heated oven at 80°C for 48 h, in order to obtain dry mass (DM). All mass measurements were made using an analytical scale, with a precision of 0.001 g.

The pot experiment was conducted in a randomized block design with three replicates. Data were analyzed by ANOVA and means were compared by the least significant difference (LSD) with a probability of 0.05.

RESULTS AND DISCUSSION

There were significant differences among treatments for shoot height, shoot, leaf and root dry weight and relative leaf water content at 0.01 probability level (Table-1). The lowest dry weights at tissues and shoot lengths were obtained from 40 mM NaCl treatment. Growth reduction due to 40 mM NaCl treatment is caused either by an excessive uptake and transport of this ion and/or by an inadequate uptake and transport of other essential elements. Excess salinity in the plant root zone has a general deleterious effect on plant growth, which is manifested as a reduction in growth rate, cell enlargement and synthesis of metabolites and structural compounds[22, 23]. Salinity has a strong influence on reducing shoot height, mean shoot fresh weight and mean leaf fresh weight of kiwifruit plants[24].

In a similar research on kiwifruit, salinity led to reduced growth, although foliar symptoms of salt toxicity were absent. Plant dry weight and leaf area were reduced significantly with 10 mM NaCl in nutrient solution. Leaf expansion rate, leaf size and number of leaves per plant were affected by NaCl salinity. In conclusion, the data indicate that kiwifruit is a salt sensitive plant and salinity affects its growth through reduction in leaf area development and decline in photosynthetic capacity[25].

Membrane permeability was highest for the 100/0 treatment but it was not significantly different from 40 mM Na and 75/25 treatments. It was reported that salinity treatment increased the membrane permeability of plants[26].

TABLE-1
EFFECT OF SALINITY TREATMENTS ON CERTAIN GROWTH PARAMETERS OF KIWIFRUIT PLANTS

Treatment	Shoot height (cm)	Dry weights (g plant^{-1})			Membrane permeability (%)	Relative leaf water content (%)
		Shoot	Leaf	Root		
Control	149.70 a	14.70 a	31.10 a	8.0 a	11.3 b	80.4 c
NaCl (40 mM)	32.00 f	2.50 f	5.80 d	2.3 f	13.0 ab	88.2 ab
Na^+/Cl^- (100/0)	95.00 bc	7.80 c	16.80 c	3.6 de	14.6 a	87.5 ab
Na^+/Cl^- (75/25)	114.30 b	10.60 b	22.40 b	6.3 b	12.3 ab	87.2 b
Na^+/Cl^- (50/50)	87.70 cd	6.60 cd	20.10 b	5.5 bc	11.3 b	87.0 b
Na^+/Cl^- (25/75)	53.00 e	4.50 e	14.70 c	4.5 cd	11.5 b	85.0 b
Na^+/Cl^- (0/100)	72.30 de	5.20 de	16.80 c	3.5 e	10.7 b	91.1 a
F-test	†	†	†	†	*	†
LSD (p = 0.05)	20.77	1.879	3.228	0.965	2.343	3.825

* and † significant at $P < 0.05$ and $P < 0.01$ F level, respectively.
Means followed by the same letter are not significantly different (LSD test, $P < 0.05$).

Relative leaf water content (RLWC) was lowest in control plants, compared to other treatments (Table-1). In plants supplied with Na the relative leaf water content is maintained at a higher level even at low substrate water availability in saline soils[7]. It was determined that NaCl applications increased water content of leaf tissue in tamarind trees[27].

Nutrient Concentrations

Chloride and sodium concentrations in plant tissue were affected by the treatments ($p < 0.01$) and increased with increasing rates of these ions (Table-2). These results are in agreement with other reports for kiwifruit[8], olive[24], strawberry[28] and lettuce[29]. It is widely accepted[30] that the accumulation of chloride ions by plants contributes greatly to an increase in cell hydration and turgor pressure which are essential for cell elongation[8].

The Na contents in root tissue increased linearly with increasing Na^+ ratios in the treatments. The highest concentrations of Na^+ accumulated in roots for 100/0 treatment. On the other hand, Cl^- concentration at all tissues increased with

increasing Cl^- ratios in treatments. A research on growth, ion content and photosynthetic performance of salt-stressed kiwifruit, sodium accumulated mainly in roots while chloride content in leaves and roots increased significantly above 10 mM NaCl[25].

TABLE-2
CHLORIDE AND SODIUM IONS CONCENTRATION (mmol kg^{-1}) OF SHOOTS, LEAVES AND ROOTS OF KIWIFRUIT PLANT IN RELATION TO DIFFERENT TREATMENTS

	Cl^-			Na^+		
	Shoot	Leaf	Root	Shoot	Leaf	Root
Control	122.1 f	192.5 d	305.1 e	12.03 cd	20.17 c	48.4 ef
NaCl (40 mM)	333.3 cd	495.8 c	546.5 d	78.40 a	31.43 a	197.3 c
Na^+/Cl^- (100/0)	192.5 e	220.7 d	230.0 e	10.00 d	23.00 bc	584.3 a
Na^+/Cl^- (75/25)	286.4 d	469.5 c	615.0 cd	10.30 cd	24.93 b	283.7 b
Na^+/Cl^- (50/50)	356.8 bc	690.1 b	683.6 bc	18.87 b	24.80 bc	152.3 d
Na^+/Cl^- (25/75)	391.5 ab	887.3 a	752.1 ab	19.13 b	23.07 bc	86.1 e
Na^+/Cl^- (0/100)	422.5 a	967.2 a	859.2 a	15.20 bc	24.90 b	23.5 f
F-test	†	†	†	†	†	†
LSD (p = 0.05)	56.82	101.0	120.2	4.940	4.699	38.09

† Significant at $p < 0.01$ F level.
Means followed by the same letter are not significantly different (LSD test, $P < 0.05$)

Accumulated Cl^- in root tissue disrupts membrane uptake mechanisms, causing or permitting increased entry and translocation of Cl to the shoot tissue[31]. The decrease in leaf Na content may partially be explained by "dilution effect", that is, increase in dry matter accumulation. It has been declared that NaCl applications increase Na^+ and Cl^- accumulation and toxic effects related to the accumulation of these ions causes necrosis and molding in leaves[31]. Generally, root concentration of Na was higher than the leaf concentration of Na[3, 27] and these results are closely in agreement with the findings obtained by others, for example, kiwifruit[33] and in lettuce[34].

In general, there was an increase in K content of the plant tissue with decreasing Na^+/Cl^- ratio applied to the soils (Table-3). The increment in K uptake by Na is a well-known competitive process[35, 36]. While Na content of root was higher than Na content of shoot and leaf, K content of root was less than K content of leaf except for the 25/75 and 0/100 Na/Cl treatment. Potassium is an essential cation for plants and is required for the regulation of ion transport and osmotic regulation[37]. Similar results were also obtained in strawberry[28], lettuce[29] and wheat[38].

Decreasing Na^+/Cl^- ratio increased K^+/Na^+ ratio in the leaf and root of the plants (Table-3). The decreased ratio of K/Na is due to the higher concentrations of Na in the root. These results are similar with the ones in lettuce[29], black sapota[39], melon[40], suaeda salsa[41].

TABLE-3
POTASSIUM CONCENTRATION (mmol kg^{-1} DW) AND K/Na RATIO OF SHOOTS, LEAVES, AND ROOTS OF KIWIFRUIT PLANT IN RELATION TO DIFFERENT TREATMENTS.

	K^+ content			K^+/Na^+		
	Shoot	Leaf	Root	Shoot	Leaf	Root
Control	355.6 d	515.4 c	367.5 cd	29.64 cd	25.57 bc	7.62 bc
NaCl (40 mM)	388.9 cd	478.6 c	338.4 d	4.96 e	15.71 e	1.76 d
Na^+/Cl^- (100/0)	374.4 d	481.2 c	457.3 bc	37.47 ab	20.88 d	0.79 d
Na^+/Cl^- (75/25)	406.0 bcd	590.6 b	418.0 bcd	40.93 a	23.73 cd	1.48 d
Na^+/Cl^- (50/50)	440.2 bc	598.3 b	510.2 b	23.37 d	24.32 cd	3.35 cd
Na^+/Cl^- (25/75)	464.1 ab	676.1 a	714.5 a	24.21 d	29.29 ab	8.29 b
Na^+/Cl^- (0/100)	522.2 a	743.6 a	759.8 a	34.35 bc	29.94 a	33.0 a
F-test	†	†	†	†	†	†
LSD (p = 0.05)	63.87	69.24	103.8	6.554	4.209	4.629

† Significant at P < F level.
Means followed by the same letter are not significantly different (LSD test, P < 0.05).

No significant difference was observed for leaf N and P contents; however, there were significant differences among treatments for the concentration of N and P in root and shoot (Table-4). With kiwifruit, however, an analysis of the cation-anion balance of the leaves showed that increasing the concentration of the chloride merely resulted in an equivalent decrease in the concentration of nitrate-nitrogen[10]. Similar results were obtained in lettuce[42] and tomato[43]. It was also reported that osmotic stress caused decreasing N concentration of citrus seedlings[36].

TABLE 4
NITROGEN AND P CONCENTRATION (mmol kg^{-1} DW) OF SHOOTS, LEAVES AND ROOTS OF KIWIFRUIT PLANTS IN RELATION TO DIFFERENT TREATMENTS

	Nitrogen content (%)			Phosphorus content (%)		
	Shoot	Leaf	Root	Shoot	Leaf	Root
Control	533 d	1588	1169 de	54.9 bc	53.8	91.8 a
NaCl (40 mM)	740 ab	1676	1036 e	78.3 a	72.5	58.9 d
Na^+/Cl^-(100/0)	669 bc	1812	1471 ab	49.7 c	58.7	69.0 cd
Na^+/Cl^- (75/25)	617 cd	1593	1295 cd	55.1 bc	57.6	77.1 bc
Na^+/Cl^- (50/50)	795 a	1700	1543 a	67.7 ab	61.6	79.8 b
Na^+/Cl^- (25/75)	745 ab	1619	1252 cd	71.1 a	66.3	74.0 bc
Na^+/Cl^- (0/100)	788 a	1595	1376 bc	67.5 ab	62.1	75.8 bc
F-test	†	†	†	†	Ns	†
LSD (p = 0.05)	117.1		161.2	13.43		10.32

† Significant at p < 0.01 F level; ns: not significant.
Means followed by the same letter are not significantly different (LSD Test, p < 0.05).

Salinity treatments affected P content of shoot and root. Different researchers reported contradictory results concerning differences of plant content in salt stress conditions. It was suggested that the P uptake is markedly increased and may result in P toxicity when high salinity is accompanied by enhanced P supply[44-46]. Salinity decreases the content of P in plant tissue, for example, in tomato[43], cucumber[47] and eggplant[48].

Conclusions

From the results of this experiment, it can be concluded that 40 mM NaCl treatment can affect shoot height, shoot, leaf and root dry weights. Membrane permeability was highest at 100/0, 40 mM NaCl and 75/25 treatments. Relative leaf water content increased by applying salt treatments. Chloride and Na content of plant tissues increased with increasing these ion rates, especially in root. The leaf K concentration was higher than those of roots and shoots and the K content of plant tissues increased by increasing Cl treatment. The ratio of K/Na was generally found high in the treatments in which Na was not included. Salinity treatments affected P content of shoot and root. Phosphorus content of the root was slightly higher than phosphorus contents of leaf and shoot. In addition to these, it was also apparent that different rates of Na/Cl can be affected not only by osmotic stress but also by ionic stress.

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(*Received*: 23 June 2005; *Accepted*: 1 March 2006) AJC-4663