Mitigation of salt stress in strawberry by foliar K, Ca and Mg nutrient supply

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ABSTRACT

Plant root and shoot dry weight, leaf relative water content (LRWC) and chlorophyll content were reduced by 30%, 21%, 15%, 34%, respectively, at 40mM NaCl as compared to non-salt stress conditions. However, membrane permeability (MP) of plant increased (85.0%) with increasing salinity. Foliar nutrient application (FNA) alleviated deleterious effects of salinity stress on growth and this effect was statistically significant. The highest alleviation effect of FNA at 40mM salinity stress was observed in the case of 10mM foliar KNO_3 and $Ca(NO_3)_2$ application, resulting in increase in plant root dry weight (50%), shoot dry weight (50%), LRWC (8.2%) and MP decrease (27.4%) at 40mM NaCl. Phosphorus, Fe and Zn contents in shoots and roots of plants also increased with FNA treatments, but they were still much lower than those of non-salt stress treatment. Sulphur, P, Fe and Zn contents of shoots reached similar values as in non-salt stress treatment when KNO_3 was applied, whereas Fe, Mn, Zn, and Cu contents of roots reached the values of non-salt stress treatment when $Ca(NO_3)_2$ was applied.

Keywords: alleviation; foliar application; NaCl salinity; minerals content

Salinity is a major abiotic stress reducing the yield of wide variety of crops all over the world; high concentrations of salts in soils account for large decreases in crop production. Globally, more than 770.000 km^2 of land is salt-affected by secondary salinization: 20% of irrigated land, and about 2% of dryland agricultural land (FAO 2006).

The relationship between NaCl stress and macronutrient deficiencies is well established. Calcium plays an essential role in processes that preserve the structural and functional integrity of plant membranes, stabilize cell wall structure, regulate ion transport and selectivity, and control ion-exchange behavior as well as enzyme activities (Marschner 1995). Sufficient supply of calcium in saline soil solutions is an important factor in controlling the severity of specific ion toxicities, particularly in crops which are susceptible to sodium and chloride injury (Grattand and Grive 1999). Potassium is another major plant macro-nutrient that plays important roles related to stomatal behavior, osmoregulation, enzyme activity, cell expansion, neutralization of non-diffusible negatively charged ions, and membrane polarization. Metabolic toxicity of Na is largely due to its ability to compete with K for binding site essential for cellular function (Bhandal and Malik 1988). It is evident that salt stress has a significant effect on N nutrition in plants. Salinity reduces the uptake of NO_3^-in many plant species mostly due to high Cl content of saline soil (Grattan and Grieve 1999). Nitrogen application effectiveness was observed on tomato and cucumber under salinity stress conditions (Cerda and Martinez 1998). Magnesium ions are found in the centre of chlorophyll molecules; and as chlorophyll is a key component in the reaction of photosynthesis, which produces energy for growth, Mg ions are therefore essential. Magnesium also plays a substantial part in phosphorus transport in the plant; it assists in phosphate metabolism, plant respiration, protein synthesis, and activation of several enzyme systems (Marschner 1995). It was shown that salt stress reduces the uptake of magnesium by plants (Yildirim et al. 2008).

Strawberry cultivation (with 160 000 t production) (FAO 2006) is of great importance in the

horticulture sector in both domestic and foreign markets in Turkey. Almost all of this production comes from small family farms of 0.05–0.5 ha. Strawberry is considered as NaCl-sensitive species and salinity was shown to reduce leaf number, leaf area, shoot dry weight and number of crowns, leading to low yields (Pirlak and Esitken 2004).

An alternative approach for alleviation of salinity stress could be established with supplementary Mg, Ca, K, and N via leaf spray applications where the growth medium is known to be or may become saline at some time during the growth cycle. An experiment was conducted with strawberry plants grown in pots to assess the effectiveness of foliar application of KNO_3, $Mg(NO_3)_2$, $Ca(NO_3)_2$ for alleviation of salinity stress. The objective of the experiment was to investigate the effects of foliar supplementary Ca, Mg, K and N nutrition on plant growth, chlorophyll concentration, LRWC, MP and plant ion balance of strawberry plants under salt stress and non-stressed conditions.

MATERIAL AND METHODS

Growth conditions and plant materials. The study was conducted under greenhouse conditions at the Atatürk University in Turkey in 2007–2008. Strawberry (*Fragaria* × *ananassa* Duch.) Fern plants were maintained under natural light conditions, approximate day/night temperature of 21/16°C and 75% relative humidity during the experiment.

Cold-stored bare-rooted strawberry plants with one well-developed crown of 8–10 mm in diameter were planted in celled-trays containing peat (pH 5.5, EC 250 mmhos/cm, N 300 mg/l, P_2O_5 132 mg, K_2O 332 mg, organic matter 2%). Plants were transferred to free draining pots (20 and 17 cm in top and bottom diameter, respectively, and 20 cm in height, with holes in the bottom) filled with a mixture (1/1 v/v) of soil and sand (pH 7.36, EC 1.12 dS/cm, N 12.9 mg/kg, P 14.55 mg/kg, exchangeable K 1.55 meq/100 g soil, organic matter 4.5%) 20 days after planting (DAP). All pots were randomized on the benches in the greenhouse. There were 2 stress conditions (0 and 40mM NaCl), 2 foliar application salt doses (0, 10mM), 3 foliar fertilizer types [KNO_3, $Ca(NO_3)_2$ and $Mg(NO_3)_2$], with 4 replicates per treatment and 10 plants per replicates.

Spray treatments. KNO_3, $Ca(NO_3)_2$ and $Mg(NO_3)_2$, were obtained from the Sigma Chemical Co. UK, concentrations of 10mM were made up with distilled water containing 0.02% Tween 20 (Polyoxyethylene sorbitan monolaurate, Sigma Chemicals, UK). The initial foliar treatments were applied three days before the seedlings were transferred to the pots. Both lower and upper leaf surface was sprayed until wetted. Three subsequent applications were done at 7-day intervals. Plants were sprayed with the solutions until dripping, with a held atomizer. Plants sprayed with 0.02% Tween 20 served as the control.

Salt treatments. Salinity treatments were established by adding 0 and 40mM of NaCl to a base complete nutrient solution (SoFertig) when the plants were transplanted. The composition of the SoFertig (Elfatochem Co., Paris, France) was (%): N 17, P_2O_5 9, K_2O 31, Mg 2, SO_4 4, Na 0.001, Fe 0.02, Zn 0.002, Cu 0.002, B 0.01, Mn 0.01, Mo 0.001. The dilute solution (1/10) was prepared by adding SoFertig to the distilled water. The soil was maintained at 70% field capacity by watering the soil every 6–7 day with dilute solution. The electrical conductivities of these solutions after adding 0 and 40mM of NaCl were determined with a conductivity meter, Model 470 (Jenway Limited). Electrical conductivities (EC) of the solutions were 1.71 dS/m for 0mM NaCl and 4.86 dS/m for 40mM NaCl. All pots were irrigated to 70% field capacity with 0 or 40mM saline solutions to maintain the level of salinity after transplanting.

Chlorophyll measurements. A portable chlorophyll meter (SPAD-502, Konica Minolta Sensing, Inc., Japan) was used to measure leaf greenness of the plants. SPAD-502 chlorophyll meter can estimate total chlorophyll amounts in leaves of a variety of species with a high degree of accuracy, with a non-destructive method (Neufeld et al. 2006). For each plant, measurements were taken at four locations on each leaf; two on each side of the midrib on all fully expanded leaves, and then averaged.

Measurements of electrolyte leakage (membrane permeability). For measurements of electrolyte leakage, 10 leaf discs (10 mm in diameter) from the young fully expanded leaves from two plants per replicate were placed in 50 ml glass vials, rinsed with distilled water to remove electrolytes released during leaf disc excision. Vials were then filled with 30 ml of distilled water and allowed to stand in the dark for 24 h at room temperature. Electrical conductivity (EC1) of the bathing solution was determined at the end of incubation period. Vials were heated in a temperature-controlled water bath at 95°C for 20 min, and then cooled to room temperature and the electrical

conductivity (EC2) was measured. Electrolyte leakage was calculated as percentage of EC1/EC2 (Shi et al. 2006).

Leaf relative water content (LRWC). LRWC is a useful measure of the physiological water status of plants. Two leaves were collected from the young fully expanded leaves of two plants per replicate. Individual leaves were first detached from the stem and then weighed to determine fresh weight (FW). In order to determine turgid weight (TW), leaves were floated in distilled water inside a closed Petri dish. Leaf samples were weighed periodically, after gently wiping the water from the leaf surface with the tissue paper until a steady state achieved. At the end of imbibition period, leaf samples were placed in a pre-heated oven at 80°C for 48 h, in order to determine dry weight (DW). Values of FW, TW, and DW were used to calculate LRWC using the equation below (Kaya et al. 2003):

$$LRWC\ (\%) = [(FW - DW)/(TW - DW)] \times 100$$

Growth parameters. Forty days after planting, eight plants from each replicate were harvested, and data on plant growth variables such as shoot fresh weight, root fresh weight, shoot dry weight and root dry weight per plant were determined. The plant material for dry weight was dried at 70°C for 48 hours.

Mineral analysis. Shoot and root samples were washed carefully to remove soil using deionised water. In order to determine the mineral contents of shoot and root, plant samples were oven-dried at 70°C for 48 h and ground to pass 1 mm sieve. The Kjeldahl method and a Vapodest 10 Rapid Kjeldahl Distillation Unit (Gerhardt, Konigswinter, Germany) were used to determine total N. Phosphorus and S contents were determined after wet digestion using a HNO_3-$HClO_4$ acid mixture (4:1 v/v) (AOAC922.02 2005); P and S in the extraction solution were measured spectrophotometrically using the indophenol-blue and ascorbic acid method (AOAC931.01 2005) and a UV/VIS Aqumat Spectrophotometer at 660 nm and at 440 nm, respectively (Thermo Electron Spectroscopy LTD, Cambridge, UK). Potassium, Na, Ca, and Mg, Fe, Mn, Zn, and Cu were determined after wet digestion using a HNO_3-$HClO_4$ acid mixture (4:1 v/v). In the diluted digests, K, Na, Ca, Mg, Fe, Mn, Zn, and Cu analysis were determined by atomic absorption spectrometry (Perkin Elmer 3690) (AOAC975.03 2005).

Statistical analysis. The statistical analysis was conducted using the GLM procedure of SPSS. The experimental design was hierarchical with respect to two factors arranged in a completely randomized design with four replications. Data were subjected to analysis of variance (ANOVA) to compare the effects of salt stress treatments and foliar treatments. The differences between the means were compared using the least significant difference test (LSD, $P < 0.05$).

RESULTS AND DISCUSSION

The results obtained from this experiment showed that salinity stress reduced plant shoot and root fresh weight, shoot and root dry weight and chlorophyll content. Plant root and shoot dry weight and chlorophyll content were reduced in average by 30%, 21%, 34% at 40mM NaCl, respectively, as compared to non-salt stress condition. However, supplementary foliar nutrient application increased all the above mentioned parameters compared to FNA-untreated plants (Figures 1 and 2). Foliar nutrient application alleviated deleterious effects of salinity stress on growth and growth

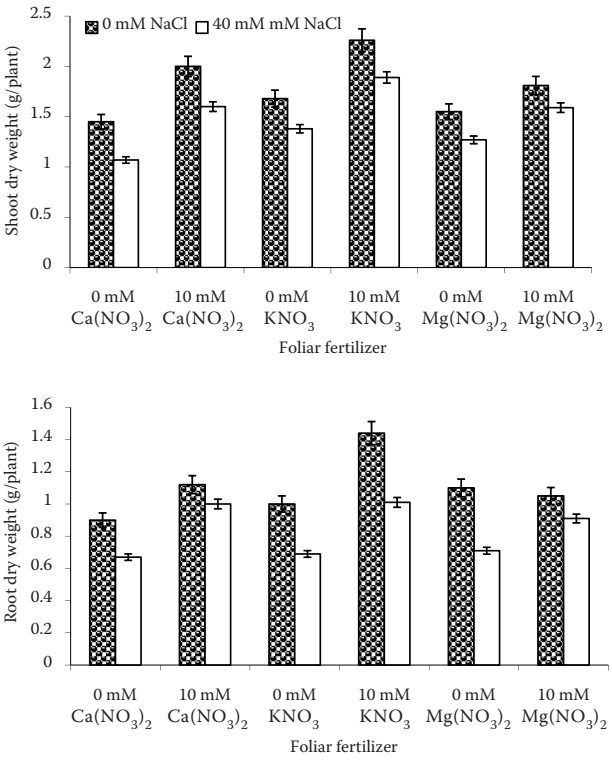

Figure 1. Effects of foliar nutrient application (10mM) on shoot and root dry weight of strawberry plant grown under with (40mM NaCl) and without salinity stress

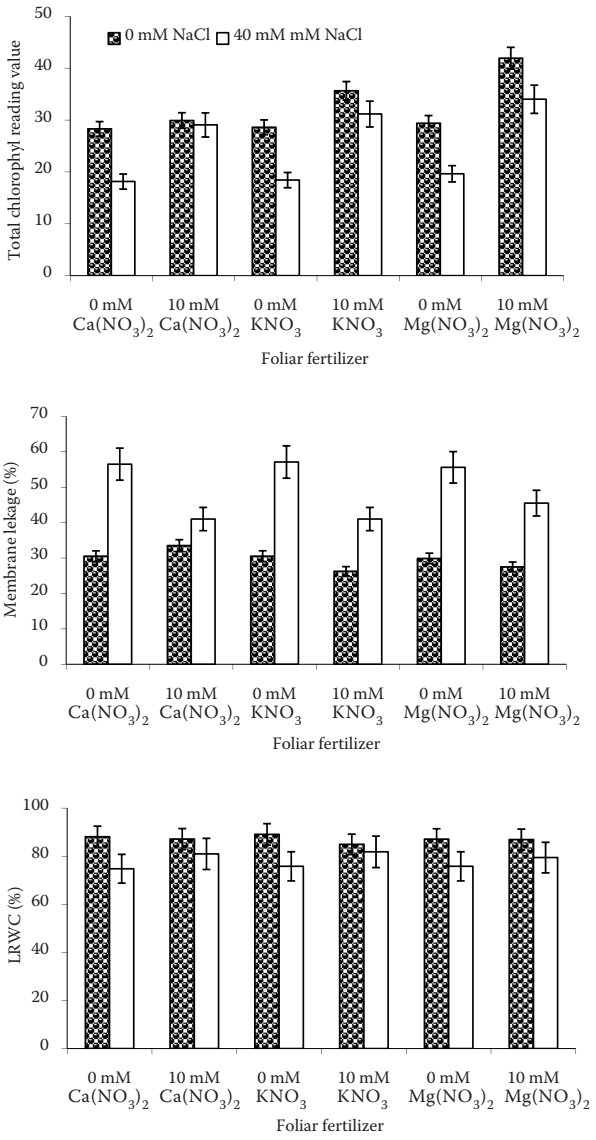

Figure 2. Effects of foliar nutrient application(10mM) on total chlorophyll reading value, MP and LRWC of strawberry plant grown under with (40mM NaCl) and without salinity stress

parameters of strawberry, depending on nutrient types. The highest alleviation effect of FNA under salt stress was observed in 10mM foliar $Mg(NO_3)_2$ application, when chlorophyll at the ratio 73,2% is taken into consideration; however, 10mM foliar $Ca(NO_3)_2$ application was the most effective for plant root dry weight (50%), and shoot dry weight (50%) (Figure 1). Furthermore, the parameters of salt-stressed plants receiving supplementary FNA were still lower than the values of non-salt stress treatment. The results presented here are in partial agreement with Martinez and Cerda (1999) who applied supplementary N alone in salt-stressed cucumber. It is also in accordance with previous findings of Kaya et al. (2002) for strawberry.

The adverse effect of high NaCl on chlorophyll concentration was previously shown (Yildirim et al. 2008). The application of KNO_3, $Mg(NO_3)_2$ and $Ca(NO_3)_2$ significantly improved chlorophyll content. Magnesium ions are found in the centre of chlorophyll molecules. Calcium plays an essential role in processes that preserve the structural and functional integrity of plant membranes (Marschner 1995). Foliar applications of these elements could thus increase the chlorophyll content in plants under salt stress.

Salt stress reduced leaf relative water content (LRWC) of plants compared with the non-salt stress treatment; plant LRWC was reduced by 15% at 40mM NaCl (Figure 2). Higher alleviation effect was observed in the case of 10mM foliar KNO_3 and $Ca(NO_3)_2$ application at 8.0–8.2% at 40mM NaCl salinity stress, as compared to $Mg(NO_3)_2$ – 4.8%. A decrease in LRWC under salinity stress was reported (Yildirim et al. 2008); it indicates a loss of turgor resulting in limited water availability for the cell-extension process. The application of KNO_3, $Mg(NO_3)_2$ and $Ca(NO_3)_2$ significantly improved this parameter.

Electrolyte leakage was measured to determine membrane permeability. Membrane permeability (MP) of plant increased (85%) with addition of 40mM NaCl. However, supplied FNA decreased MP of plant compared to untreated plants. The application of KNO_3, $Mg(NO_3)_2$ and $Ca(NO_3)_2$ significantly improved MP; higher alleviation effect was observed in the case of 10mM foliar $K(NO_3)_2$ and $Ca(NO_3)_2$ application at 27.4–28% at 40mM NaCl salinity stress. Although FNA led to a partial decrease in the leakage, the value was still higher compared to the non-stressed (0mM NaCl) treatment; the exact structural and functional modification caused by stress was not determined. The cellular membrane dysfunction caused by salt stress is well expressed in its increased permeability for ions and electrolytes, which can be readily measured by the efflux and electrolytes (Lutts et al. 1996).

Salinity reduced plant macro and micro nutrient contents except for Na and Cl content of plant shoots and roots. The foliar application of KNO_3, $Mg(NO_3)_2$, $Ca(NO_3)_2$ increased the concentration of N, K, Mg, Ca, S and P content under salinity stress. It is not surprising that supplementary KNO_3, $Mg(NO_3)_2$, $Ca(NO_3)_2$ enhanced concentrations of N, K, Ca, and Mg; however, contents of these elements in plants receiving supplementary KNO_3, $Mg(NO_3)_2$, $Ca(NO_3)_2$ were still much lower than those of non-salt stress treatment (Tables 1 and 2). Similarly, P, Fe and Zn contents of plants

Table 1. Effects on foliar nutrient application on shoot macro element concentration of strawberry plant grown under with and without salinity stress

Salinity doses (mM NaCl)	Foliar nutrient (mM)	Doses	N	P	K	Ca	Mg	S
			(% DW)					
0	KNO_3	0	3.27 ± 0.022^b	0.36 ± 0.011^b	3.57 ± 0.015^b	0.31 ± 0.020^b	0.17 ± 0.008^b	0.27 ± 0.016^a
		10	3.75 ± 0.023^a	0.47 ± 0.011^a	4.42 ± 0.049^a	0.37 ± 0.024^a	0.21 ± 0.009^a	0.28 ± 0.017^a
40	KNO_3	0	1.74 ± 0.017^d	0.20 ± 0.034^c	0.92 ± 0.023^d	0.18 ± 0.010^d	0.06 ± 0.005^d	0.14 ± 0.010^c
		10	2.93 ± 0.020^c	0.33 ± 0.010^b	3.00 ± 0.013^c	0.25 ± 0.014^c	0.08 ± 0.007^c	0.23 ± 0.014^b
LSD			0.017	0.016	0.024	0.015	0.006	0.012
0	$Ca(NO_3)_2$	0	2.80 ± 0.020^b	0.27 ± 0.009^b	1.38 ± 0.045^{ab}	0.87 ± 0.043^b	0.12 ± 0.008^a	0.16 ± 0.006^c
		10	3.93 ± 0.042^a	0.50 ± 0.023^a	1.43 ± 0.047^a	1.64 ± 0.065^a	0.11 ± 0.007^a	0.29 ± 0.007^a
	$Ca(NO_3)_2$	0	1.89 ± 0.012^d	0.20 ± 0.011^d	0.98 ± 0.026^c	0.20 ± 0.017^d	0.08 ± 0.005^b	0.12 ± 0.000^d
		10	2.35 ± 0.017^c	0.23 ± 0.008^c	1.34 ± 0.035^b	0.63 ± 0.031^c	0.12 ± 0.007^a	0.19 ± 0.007^b
LSD			0.023	0.011	0.032	0.035	0.005	0.005
0	$Mg(NO_3)_2$	0	3.39 ± 0.024^b	0.42 ± 0.021^b	1.63 ± 0.000^b	0.37 ± 0.015^b	0.57 ± 0.024^b	0.23 ± 0.026^a
		10	3.57 ± 0.016^a	0.47 ± 0.016^a	2.02 ± 0.000^a	0.45 ± 0.018^a	0.71 ± 0.029^a	0.23 ± 0.016^a
40	$Mg(NO_3)_2$	0	1.87 ± 0.007^d	0.18 ± 0.011^c	1.01 ± 0.017^d	0.18 ± 0.005^d	0.08 ± 0.005^d	0.13 ± 0.007^b
		10	3.07 ± 0.021^c	0.41 ± 0.020^b	1.39 ± 0.024^c	0.24 ± 0.007^c	0.46 ± 0.020^c	0.22 ± 0.024^a
LSD			0.015	0.014	0.012	0.010	0.017	0.016

Table 2. Effects on foliar nutrient application on shoot micro element concentration of strawberry plant grown under with and without salinity stress

Salinity doses (mM NaCl)	Foliar nutrient (mM)	Doses	Fe	Mn	Zn	Cu	Cl	Na
			(mg/kg DW)					
0	KNO_3	0	97.35 ± 1.708^a	44.40 ± 1.708^a	81.98 ± 3.416^a	17.08 ± 1.708^b	518.19 ± 7.003^c	165.43 ± 3.873^c
		10	98.16 ± 2.319^a	41.49 ± 0.876^a	78.43 ± 2.319^b	22.26 ± 1.753^a	341.45 ± 3.727^d	106.30 ± 1.697^d
40	KNO_3	0	51.71 ± 2.749^c	24.03 ± 1.092^c	41.87 ± 1.669^d	9.83 ± 1.093^d	2450.94 ± 88.385^a	687.91 ± 16.766^a
		10	79.97 ± 1.403^b	36.47 ± 1.403^b	67.34 ± 2.806^c	14.03 ± 1.403^c	690.92 ± 9.337^b	220.57 ± 5.165^b
LSD			1.723	1.068	2.149	1.235	36.428	7.367
0	$Ca(NO_3)_2$	0	64.27 ± 2.334^b	25.40 ± 1.294^b	44.46 ± 2.334^b	13.45 ± 1.942^b	513.33 ± 22.888^c	154.00 ± 3.494^c
		10	96.26 ± 2.310^a	43.84 ± 1.512^a	83.16 ± 1.512^a	28.72 ± 1.512^a	318.57 ± 4.305^d	86.82 ± 3.083^d
40	$Ca(NO_3)_2$	0	56.70 ± 1.978^c	22.81 ± 1.901^b	34.53 ± 1.452^d	9.82 ± 0.549^c	2352.82 ± 70.259^a	657.06 ± 14.556^a
		10	58.82 ± 2.136^c	23.25 ± 1.185^b	40.69 ± 2.136^c	12.31 ± 1.777^{bc}	606.66 ± 27.049^b	182.00 ± 4.129^b
LSD			1.791	1.223	1.549	1.259	32.172	6.463
0	$Mg(NO_3)_2$	0	80.70 ± 1.906^a	38.68 ± 2.162^a	67.80 ± 0.721^a	21.63 ± 0.721^a	694.67 ± 3.335^c	203.73 ± 2.356^c
		10	78.40 ± 5.614^a	35.11 ± 1.871^a	69.41 ± 1.871^a	20.00 ± 1.415^a	445.90 ± 4.491^d	129.44 ± 4.345^d
40	$Mg(NO_3)_2$	0	46.85 ± 1.795^b	20.41 ± 0.996^b	30.47 ± 1.795^c	10.92 ± 0.498^b	2073.42 ± 71.928^a	623.86 ± 24.373^a
		10	76.04 ± 1.796^a	36.45 ± 2.037^a	63.89 ± 0.679^b	20.38 ± 0.679^a	826.10 ± 3.966^b	229.85 ± 2.658^b
LSD			2.633	1.490	1.133	0.734	29.497	10.211

Table 3. Effects on foliar nutrient application on root macro element concentration of strawberry plant grown under with and without salinity stress

Salinity doses (mM NaCl)	Foliar nutrient (mM)	Doses	N	P	K	Ca	Mg	S
			(% DW)					
0	KNO_3	0	1.62 ± 0.026^{b}	0.41 ± 0.513	0.42 ± 0.019^{b}	0.32 ± 0.019^{a}	0.13 ± 0.013^{a}	0.016 ± 0.001^{b}
		10	1.70 ± 0.021^{a}	0.15 ± 0.015	1.82 ± 0.079^{a}	0.30 ± 0.018^{a}	0.12 ± 0.012^{a}	0.020 ± 0.001^{a}
40	KNO_3	0	0.61 ± 0.010^{d}	0.04 ± 0.002	0.22 ± 0.017^{c}	0.14 ± 0.006^{b}	0.05 ± 0.006^{b}	0.005 ± 0.000^{c}
		10	1.52 ± 0.025^{c}	0.40 ± 0.502	0.41 ± 0.019^{b}	0.31 ± 0.019^{a}	0.13 ± 0.012^{a}	0.015 ± 0.001^{b}
LSD			0.018	0.293	0.035	0.013	0.009	0.001
0	$Ca(NO_3)_2$	0	2.42 ± 0.474^{a}	0.39 ± 0.036^{a}	1.27 ± 0.045^{b}	1.59 ± 0.073^{b}	0.28 ± 0.020^{a}	0.018 ± 0.001^{b}
		10	2.84 ± 0.008^{a}	0.40 ± 0.004^{a}	1.35 ± 0.012^{a}	1.96 ± 0.038^{a}	0.26 ± 0.018^{a}	0.010 ± 0.000^{c}
40	$Ca(NO_3)_2$	0	0.35 ± 0.005^{b}	0.03 ± 0.003^{b}	0.24 ± 0.017^{d}	0.22 ± 0.009^{c}	0.11 ± 0.008^{c}	0.007 ± 0.001^{d}
		10	2.28 ± 0.448^{a}	0.37 ± 0.034^{a}	0.33 ± 0.023^{c}	1.54 ± 0.070^{b}	0.15 ± 0.011^{b}	0.021 ± 0.001^{a}
LSD			0.266	0.020	0.022	0.044	0.012	0.001
0	$Mg(NO_3)_2$	0	2.49 ± 0.591^{a}	0.30 ± 0.056^{b}	0.93 ± 0.499^{ab}	0.78 ± 0.407	0.96 ± 0.187^{ab}	0.021 ± 0.007^{ab}
		10	2.54 ± 0.494^{a}	0.45 ± 0.039^{a}	1.29 ± 0.080^{a}	0.46 ± 0.045	1.37 ± 0.545^{a}	0.025 ± 0.006^{a}
40	$Mg(NO_3)_2$	0	0.49 ± 0.124^{b}	0.06 ± 0.031^{c}	0.45 ± 0.338^{c}	0.32 ± 0.177	0.13 ± 0.037^{c}	0.010 ± 0.003^{c}
		10	2.35 ± 0.558^{a}	0.28 ± 0.053^{b}	0.62 ± 0.463^{ab}	0.43 ± 0.242	0.67 ± 0.036^{bc}	0.019 ± 0.007^{ab}
LSD			0.392	0.037	0.312	0.207	0.236	0.005

Table 4. Effects on foliar nutrient application on root micro element concentration of strawberry plant grown under with and without salinity stress

Salinity doses (mM NaCl)	Foliar utrient mM)	Doses	Fe	Mn	Zn	Cu	Cl	Na
			(mg/kg DW)					
0	KNO_3	0	237.72 ± 0.727^{b}	124.74 ± 2.182^{b}	72.66 ± 4.050^{b}	27.72 ± 3.780^{b}	1174.40 ± 37.705^{c}	129.50 ± 5.398^{c}
		10	275.45 ± 2.143^{a}	147.78 ± 4.286^{a}	92.59 ± 1.403^{a}	33.20 ± 2.143^{a}	572.61 ± 7.581^{d}	64.09 ± 1.228^{d}
40	KNO_3	0	83.21 ± 4.774^{d}	42.09 ± 0.632^{d}	27.73 ± 0.414^{d}	10.76 ± 1.095^{c}	3218.16 ± 64.602^{a}	313.72 ± 2.530^{a}
		10	195.27 ± 0.598^{c}	102.46 ± 1.793^{c}	59.68 ± 3.327^{c}	22.77 ± 3.105^{b}	1565.86 ± 50.273^{b}	172.66 ± 7.197^{b}
LSD			2.171	2.111	2.222	2.226	36.923	3.848
0	$Ca(NO_3)_2$	0	283.99 ± 5.097^{a}	150.94 ± 2.903^{a}	94.34 ± 1.451^{a}	37.73 ± 2.903^{a}	839.08 ± 13.870^{c}	82.53 ± 1.353^{c}
		10	158.81 ± 2.229^{d}	91.21 ± 4.602^{c}	49.59 ± 2.343^{d}	20.36 ± 2.343^{b}	636.32 ± 25.646^{d}	64.37 ± 1.388^{d}
40	$Ca(NO_3)_2$	0	169.52 ± 2.805^{c}	94.86 ± 4.528^{c}	54.16 ± 0.918^{c}	19.27 ± 2.429^{b}	3883.91 ± 42.276^{a}	426.32 ± 8.914^{a}
		10	259.92 ± 4.665^{b}	138.15 ± 2.657^{b}	86.34 ± 1.328^{b}	34.53 ± 2.657^{a}	991.64 ± 16.392^{b}	97.53 ± 1.599^{b}
LSD			3.177	3.087	1.304	2.116	22.008	3.781
0	$Mg(NO_3)_2$	0	224.67 ± 45.442^{ab}	124.83 ± 23.597^{ab}	77.63 ± 17.626^{ab}	28.04 ± 7.824	1234.12 ± 78.940^{b}	132.32 ± 7.143^{bc}
		10	249.56 ± 8.315^{a}	169.21 ± 37.278^{a}	97.81 ± 13.081^{a}	36.64 ± 3.223	822.74 ± 28.557^{c}	87.57 ± 6.923^{c}
40	$Mg(NO_3)_2$	0	175.35 ± 30.560^{c}	104.75 ± 18.698^{c}	59.95 ± 13.293^{c}	24.10 ± 6.635	3773.14 ± 346.875^{a}	378.98 ± 56.160^{a}
		10	211.71 ± 42.821^{ab}	117.62 ± 22.236^{ab}	73.15 ± 16.609^{ab}	26.42 ± 7.373	1467.60 ± 93.874^{b}	149.29 ± 8.059^{b}
LSD			28.582	21.566	12.479	5.323	150.655	23.515

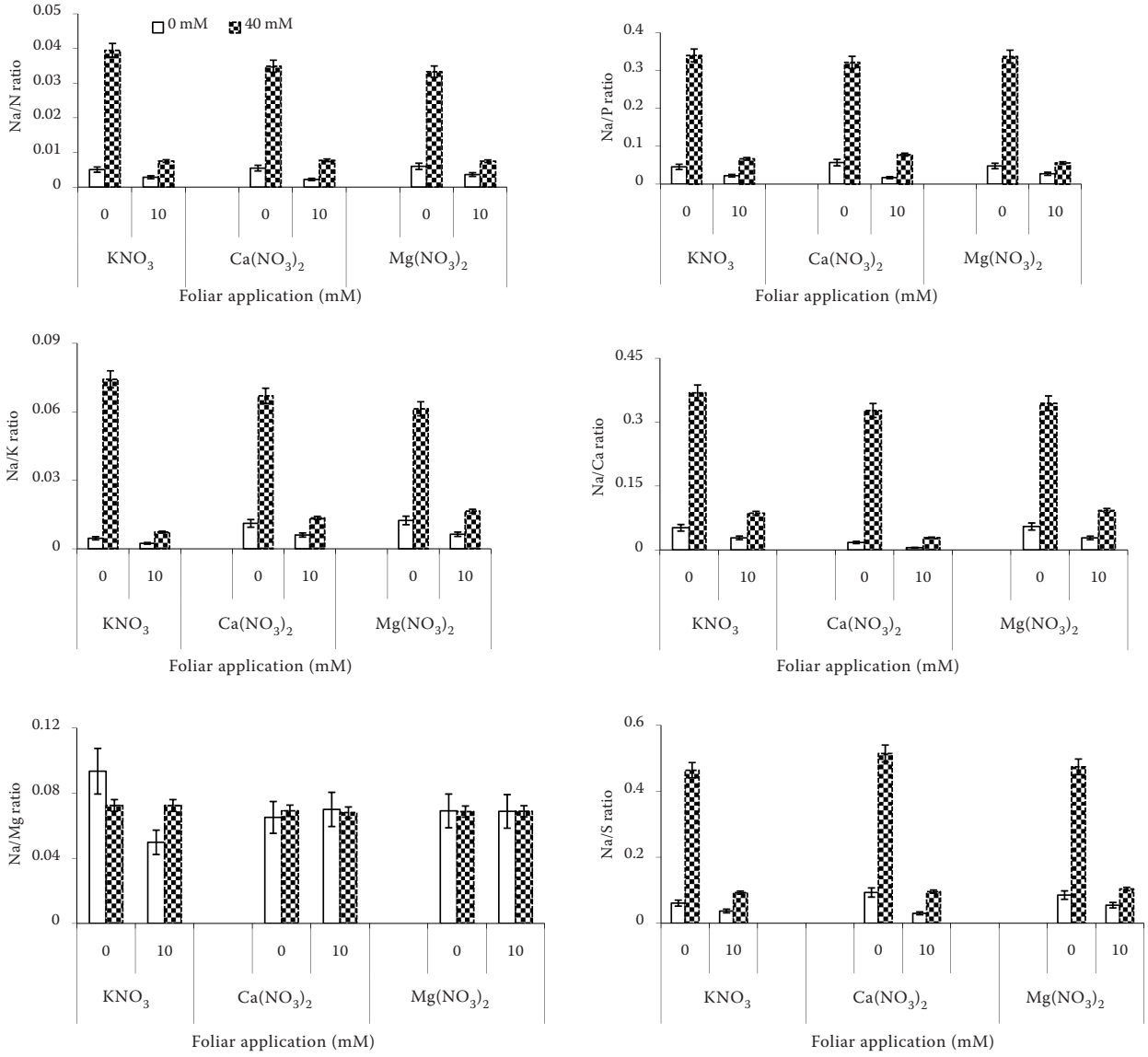

Figure 3. Effects of foliar nutrient application on Na and macro element ratio of strawberry plant shoot grown under with (40mM NaCl) and without salinity stress

in shoots and roots increased with FNA treatments and these values were still much lower than those of non-salt stress treatment. Sulphur, P, Fe and Zn contents of shoots reached similar values as in non-salt stress treatment when KNO_3 was applied, whereas Fe, Mn, Zn, and Cu contents of roots reached the values of non-salt stress treatment when $Ca(NO_3)_2$ was applied (Tables 1–4).

The application of N fertilizer was reported to mitigate significantly the adverse effects caused by salt stress on a number of crops (Leidi et al. 1991). Similarly, Cerda and Matinez (1998) found that the forms of N in the nutrient solution affected plant response to salinity. The higher concentration of cations generally observed under nitrate-N in the saline soil are in agreement with previous results for wheat (Irshad et al. 2002). Generally, NH_4-N reduces cation uptake and enhances anion uptake, while NO_3-N has the opposite effect in several plant species (Barker and Mills 1980). For both saline and non-saline treatments, Na/N, Na/K, Na/Ca, Na/Mg and Na/P ratios were highest in the FNA-untreated plants. Lower Na/K, Na/Ca and Na/Mg ratios of shoot were determined in KNO_3, $Ca(NO_3)_2$ and $Mg(NO_3)_2$ applications at 10mM concentration, respectively; but it is not surprising that supplementary KNO_3, $Mg(NO_3)_2$, $Ca(NO_3)_2$ applications decreased these parameters (Figure 3, 4). The lowest Na/N and Na/P ratios of shoots were determined for $Mg(NO_3)_2$ at 10mM concentration (Figure 4). But it was not effectively on root parts of plant. On the other

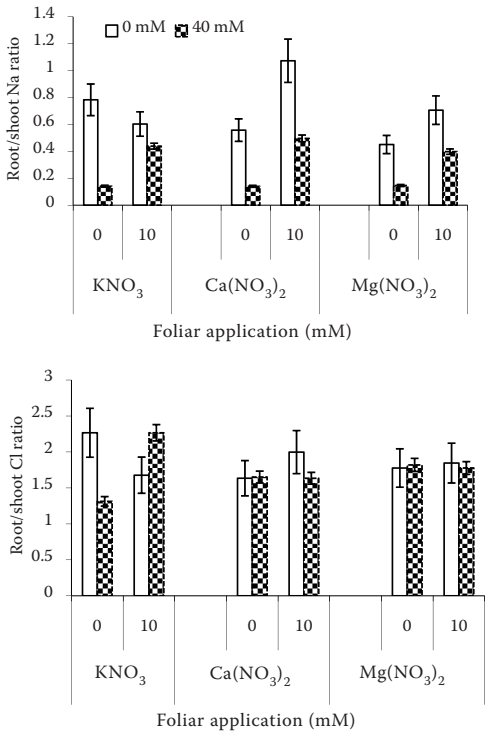

Figure 4. Effects of foliar nutrient application on root and shoot Na and Cl ratio of strawberry plant grown under with (40mM NaCl) and without salinity stress

hand, the highest $root_{(Na)}/shoot_{(Na)}$, and $root_{(Cl)}/shoot_{(Cl)}$ ratio were obtained from $Ca(NO_3)_2$ at 10mM concentration (Figure 4). These high ratios indicate that Ca, K and Mg transport was impaired by Na under saline conditions and could disturb plant metabolism and reduce plant growth.

Plant inorganic ions were negatively related to salt doses. From the results of this experiment, it can be concluded that NO_3^- with K, Ca and Mg counteracted the deleterious effects of salinity stress on the investigated parameters, helped the strawberry plants to avoid Na toxicity and improved cell membrane stability and nutrient uptake under salinity stress. Improvement of plant growth, water status of salt-stressed strawberry plants makes it possible to recommend the treatment of plants grown under saline conditions with the above chemicals. FNA significantly improved the variables affected by high salinity and also increased plant mineral nutrient balance, enhanced plant growth by nutrients uptake of plant as needed. The addition of FNA could offer an economical and simple solution to problems in production of salt-sensitive strawberry plants aridisol caused by high salinity. Further studies are nonetheless required in order to determine the efficiency of these materials under natural field condition.

REFERENCES

AOAC Association of Official Analytical Chemists (2005): Official Methods of Analysis. 18th ed. Arlington.

Barker A.V., Mills H.A. (1980): Ammonium and nitrate nutrition of horticultural crops. Horticultural Reviews, *2*: 395–423.

Bhandal I.S., Malik C.P. (1988): Potassium estimation, uptake, and its role in the physiology and metabolism of flowering plants. International Review of Cytology, *110*: 205–254.

Cerda A., Martinez V. (1998): Nitrogen fertilization under saline conditions in tomato and cucumber plants. Journal of Plant Nutrition, *63*: 451–458.

FAO Food and Agriculture Organization (2006): FAO-STAT-Agricultural Statistics.

Grattan S.R., Grieve C.M. (1999): Mineral nutrient acquisition and response by plants grown in saline environments. In: Pessarakli M. (1999): Handbook of Plant and Crop Stress. Marcel Dekker, New York, 203–229.

Irshad M., Honna T., Eneji E.A., Yamamoto S. (2002): Wheat response to nitrogen source under saline conditions. Journal of Plant Nutrition, *25*: 2603–2612.

Kaya C., Ak B., Higgs D. (2003): Response of salt-stressed strawberry plants to supplementary calcium nitrate and/or potassium nitrate. Journal of Plant Nutrition, *26*: 543–560.

Kaya C., Higss D., Saltali K., Gezerel O. (2002): Response of strawberry grown at high salinity and alkalinity to supplementary potassium. Journal of Plant Nutrition, *25*: 1415–1427.

Leidi E.O., Silberbush M., Lips S.H. (1991): Wheat growth as affected by nitrogen type, pH and salinity. I. Biomass production and mineral composition. Journal of Plant Nutrition *14*: 235–243.

Lutts S., Kinet J.M., Bouharmont J. (1996): Effects of salt stress on growth, mineral nutrition and proline accumulation in relation to osmotic adjustment in rice (*Oryza sattiva* L.) cultivars differing in salinity resistance. Journal of Plant Growth Regulation, *19*: 207–218.

Marschner H. (1995): Mineral nutrition of higher plants. Academic Press, London.

Martinez V., Cerda A. (1999): Influence of N source on rate of Cl, N, Na, and K uptake by cucumber seedlings grown in saline conditions. Journal of Plant Nutrition, *12*: 971–983.

Neufeld H., Chappelka A.H., Somers G.L., Burkey K.O., Davison A.W., Finkelstein P. (2006): Visible foliar injury caused by ozone alters the relationship between SPAD meter readings and chlorophyll concentrations in cut leaf coneflower. Photosynthesis Research, *87*: 281–286.

Pirlak L., Esitken A. (2004): Salinity effects on growth, proline and ion accumulation in strawberry plants. Acta Agriculturae Scandinavica, Section B-Soil and Plant Science, *54*: 189–193.

Shi Q., Bao Z., Zhu Z., Ying Q., Qian Q. (2006): Effects of different treatments of salicylic acid on heat tolerance, chlorophyll fluorescence, and antioxidant enzyme activity in seedlings of *Cucumis sativa* L. Plant Growth Regulation, *48*: 127–135.

Yildirim E., Turan M., Guvenc I. (2008): Effect of foliar salicylic acid applications on growth, chlorophyll and mineral content of cucumber (*Cucumis sativus* L.) grown under salt stress. Journal of Plant Nutrition, *31*: 593–612.

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