POTASSIUM EFFECT ON ION LEAKAGE, WATER USAGE, FRUIT YIELD AND BIOMASS PRODUCTION BY STRAWBERRY PLANTS GROWN UNDER NaCl STRESS

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A B S T R A C T

Strawberry plants were grown in soilless culture under greenhouse conditions to investigate the effect of supplementary potassium fertilization on growth and development of plants exposed to high NaCl concentration (35 mmol/L). Treatments included: 1) nutrient solution alone (N); 2) N + 35 mmol/L NaCl (NS); 3) NS + 5 mmol/L K_2SO_4 (NSK1); 4) NS + 10 mmol/L K_2SO_4 (NSK2). Results showed that leaf area, ion leakage (EC), chlorophyll contents, biomass production and water usage were negatively affected by NaCl stress. Moreover, fruit set and fruit number decreased under stress condition. Mineral content (Na, Cl, Ca and K) in various plant parts increased upon NaCl stress. Although supplementary potassium fertilization positively influenced the leaf area development, chlorophyll contents and reproductive parameters, it had a negative effect on biomass production. On the other hand, in addition to K and Ca, supplementary potassium increased Na and Cl content. These results showed that potassium reduces some negative effects of NaCl stress in strawberry.

Key words: ion leakage, growth and development, NaCl salt, potassium, yield

INTRODUCTION

Saline water occupies 71% of the earth area and as much as a quarter of the whole pedosphere, amounting to 950×10^6 ha, is affected by salts (Glenn and O'Leary, 1985; Flowers and Yeo, 1995), whereas 23% of the 1.5×10^9 ha of cultivated land is considered as saline (Rhoades and Loveday, 1990).

Farmers often must use low quality water (Awada et al., 1995). Salinity is the basic environmental factor accounting for decreased crop productivity in many areas, mainly in arid and semi-arid regions (Greenway and Munns, 1980). Studies show that Iran is ranked fifth in the world having more than 25 million ha of saline soils, which is in progress.

Plant responses to excessive NaCl concentration are complex and involve several changes in their morphology, physiology and metabolism (Halil et al., 1998). Salinity stress can lead to shoot dehydration due to low water potential (Kaya et al., 2002), nutrient imbalances (Qadar, 1998) and specific toxicity due to high accumulation of Na^+ and Cl^- in the cytoplasm (Greenway and Munns, 1980). Researches on the salt tolerance mechanism frequently pointed out at limited ion accumulation and organic solutes synthesis as a major adaptation mechanism in glycophytes (Greenway and Munns, 1980). An important negative effect of salt stress is the leaf senescence, which differs with plant growth stages and tends to be more pronounced at flowering than at mature stages (Lutts et al., 1995). Leaf senescence corresponds with the reduction of chlorophyll content (Chen et al., 1991) and increase of membrane permeability at high NaCl concentrations (Dhindsa et al., 1981). Cachorro et al. (1995) have found that salinity induces the structural changes in bean plant roots by increasing the cell membranes permeability and thus ions leakage. It is also known that high NaCl levels in the soil induce potassium deficiency in strawberry (Kaya et al., 2002), tomato (Adams, 1991) and cucumber plants (Sonneveld and Kreij, 1999). The main objectives of the research were:

(1) To assess the effects of high NaCl concentration (35 mM) in the growing medium on strawberry growth and development.

(2) To evaluate the effect of supplementary potassium fertilization on reducing plant injuries due to high NaCl level in the growing medium.

MATERIAL AND METHODS

Plant growth conditions

A pot-experiment was conducted using strawberry cv. 'Selva' grown in soilless culture under greenhouse condition. Cold-stored and bare-rooted daughter plants, uniform in height and leaf number, each having strong crown 8-10 mm in diameter, were planted in 2.5 L plastic pots filled with perlite. Plants were supplied with a nutrient solution consisted of 0.1% of "Melspray" water-soluble fertilizer (20% N, 20% P_2O_5, 20% K_2O, 0.1% Fe, 0.01% B, 0.0075% Cu, 0.032% Mn, 0.0230% Zn) using open-system with nutrient recirculation during the whole experimental period (from April

till October). The pH of solution was maintained at 5.5-6.0 by adding 1 M nitric acid when necessary. Day/night tem-peratures and humidity ranged between 20-24/14-16˚C and 50-65%, respectively. Light period was 16 h.

Treatments included:

1. Nutrient solution (N),
2. N + 35 mmol/L NaCl (NS),
3. NS + 5 mmol/L K_2SO_4 (NSK1),
4. NS + 10 mmol/L K_2SO_4 (NSK2).

Measurements

Leaf area was measured with leaf area meter (Delta T-Devices models) on six plants from each treatment, having three fully expanded leaves consisted of 3 leaflets.

Chlorophyll content was measured on 9 plants in each treatment using chemical method according to A.O.A.C. (1975) and chlorophyll meter (SPECTRONIC – 20 model). However, because chemical method is more precise than the other one, results from chemical method are only presented.

Ion leakage was used to evaluate membrane permeability in the leaves. It was determined with electrical conductivity (EC) meter. Six plants were selected from each treatment and from each four leaves were taken. 1-cm^2-large segment were cut out at random from each leaf, washed three times with distilled water in order to remove surface contaminants and then placed individually in stoppered vials containing 10 ml of distilled water. The vials were incubated at room temperature (25ºC) on a shaker (100 rpm) for 24 h. EC of the bathing solution was measured after incubation (EC1). Then the same vials with leaf samples were placed in an autoclave at 120ºC for 20 min and the second measurement of electric conductivity (EC2) was done after cooling the solution to room temperature. The ion leakage was calculated as EC1/EC2 and expressed in percents (Lutts et al., 1995).

Water usage (WU) was calculated in three replications as a difference between water supplied to the plants and drained from the pots (Kaya et al., 2001a).

Number of healthy leaves as well as shoot and root fresh weights were recorded at the end of the experiment.

Ions analysis was carried out in oven-dried shoots and roots. Ground samples were ashed in porcelain crucibles at 550ºC for 6 h. The white ash was taken up in 2 M hot HCl, filtered into a 50 ml volumetric flask and made up to 50-ml with distilled water. Concentration of sodium and potassium were analyzed using a flame photometer and calcium was determined by atomic absorption spectrophotometer. Chlorine was determined by titration according to Chapman and Pratt (1982).

Experimental design and statistical analysis

The experiment was done in a completely randomized design with 4 treatments and 9 replications in each, where the replication consisted of one plant/pot. Data were analyzed statistically using MSTAT-C programme. Differences between means

of the treatments were compared by Duncan's multiple range tests at $p \leq 0.05$.

RESULTS AND DISCUSSION

Vegetative characters

Strawberry plants grown on the medium with high NaCl level had significantly reduced leaf area (Tab. 1), which was in agreement with earlier studies done by Saied et al. (2003) and Turhan and Eris (2007). Such behaviour is a typical earliest response of glycophytes exposed to salt stress. Potassium supplied via the root system did not counteract NaCl effect and at higher concentration (NSK2) caused further decrease of leaf area, as compared with other treatments, which contradicts findings of Sultana et al. (2001) on rice plants. Munns and Termeat (1986) reported that growth inhibition due to the long-term exposure to salt stress resulted in decrease of photosynthetic area. In our experiments decrease in photosynthetic area was not only due to growth inhibiting effects of NaCl, but was also correlated with the injurious effects of salinity resulting in defoliation (Tab. 1).

Membrane permeability increased in plants exposed to salinity as compared to non-stressed plants (Tab. 1), which confirms earlier findings of Kaya et al. (2002) on strawberry. Potassium application at lower dose did not have a significant effect on electrolyte leakage and at higher concentration significantly increased it (Tab. 2), which contradicts the result obtained by Kaya et al. (2002).

Chlorophyll content in the leaves was not affected by salinity (Tab. 1), which is in agreement with results obtained on pepper by Gunes et al. (1996). Supplementary potassium fertilization at a lower dose had a stimulatory effect on this trait but at higher dose it did not have a significant impact, which confirms results obtained by Kaya et al. (2003).

NaCl treatment significantly reduced fruit set. Results showed (Tab. 2) that under this condition, fruit setting decreased by as high as 60%. In addition, inflorescence and flower production were significantly suppressed by the stress, which is in agreement with results obtained by Awang and Atherton (1995) on strawberry plants. Supplementary potassium fertilization decreased flower number in comparison to NS and N treatments (Tab. 2). However, potassium could ameliorate the negative effect of NaCl on fruit set and thus total yield was less affected (Tab. 3), which is in agreement with findings of Kaya et al. (2003). We suggest that higher yield may have resulted from higher fruit set and heavier fruit produced in NSK treatments under stress condition.

Shoot fresh weight was negatively affected by NaCl stress compared with the control (Tab. 3), which is in agreement with results of experiments done by Gunes et al. (1996) on pepper and by Turhan and Eris (2007) on strawberry plants. As opposite to results obtained by Kaya et al. (2001b) on spinach plants, supplementary potassium fertilization did not ameliorate the harmful effects of NaCl stress

Table 1. Effects of NaCl stress and supplementary potassium fertilization on vegetative parameters of strawberry plants

Treatment	Leaf area [cm^2]	Electrolyte leakage [%]	Chlorophyll content [mg g^{-1} f.w.]	Healthy leaves [%]
N	290.40a*	0.41c	1.08ab	100.00
NS	195.50b	0.56b	1.03b	17.19
NSK1	175.90c	0.53b	1.10a	35.90
NSK2	149.20d	0.62a	1.03b	39.06

*Within each column, same letter indicates no significant difference between treatments at $p \leq 0.05$

Table 2. Effects of NaCl stress and supplementary potassium fertilization on reproductive parameters of strawberry plants

Treatment	Fruit set [%]	Inflorescence number per plant	Flower number per plant	Fruit number per plant
N	*100.00a	4.88a	20.67a	6.00a
NS	37.50d	3.44b	10.89b	1.33c
NSK1	49.20c	0.53b	1.10a	2.00c
NSK2	75.90b	0.62a	1.029b	4.00b

*Explanations, see Table 1

Table 3. Effects of NaCl stress and supplementary potassium fertilization on total yield, fresh weights and water usage of strawberry plants

Treatment	Total fruit yield [g]	Shoot fresh weight [g]	Root fresh weight [g]	Water usage [ml $plant^{-1}$]
N	*723.40a	226.20a	174.70a	234.30a
NS	221.00d	60.78b	61.50d	149.30b
NSK1	310.20c	26.27d	81.68b	122.10c
NSK2	497.70b	44.35c	68.81c	116.80c

*Explanations, see Table 1

on this trait (Tab. 3). An increase in concentration of potassium has led to higher shoot fresh weight, which consequently resulted in lower root fresh weight (Tab. 3).

Water usage was significantly reduced in strawberry plants grown in media with high concentration of NaCl (35 mmol/L) (Tab. 3), which is in agreement with result obtained by Sonneveld and Voogt (1990) on tomato plants. Potassium supplied to the root medium at both concentrations reduced further water usage, which does not corroborate results of experiments done by Kaya et al. (2001a), who

Table 4. Effects of NaCl stress and supplementary potassium fertilization on nutrient content in roots

Treatment	Na [mg g^{-1} f.w.]	K [mg g^{-1} f.w.]	Cl [mg g^{-1} f.w.]	Ca [mg g^{-1} f.w.]
N	*7.06c	5.24b	19.64d	4.48b
NS	11.00b	5.78b	29.94c	3.72c
NSK1	13.16a	8.23a	62.57a	3.50d
NSK2	9.99b	8.61a	35.14b	5.35a

*Explanations, see Table 1

Table 5. Effects of NaCl stress and supplementary potassium on nutrient content in shoot

Treatment	Na [mg g^{-1} f.w.]	K [mg g^{-1} f.w.]	Cl [mg g^{-1} f.w.]	Ca [mg g^{-1} f.w.]
N	*3.66c	19.98c	26.98d	4.76a
NS	10.45a	28.02b	34.67c	4.82a
NSK1	8.95b	22.60bc	50.76b	4.34b
NSK2	11.55a	40.86a	55.73a	4.68a

*Explanations, see Table 1

Table 6. Effects of NaCl stress and supplementary potassium on K : Na ratio in strawberry shoots and roots

Treatment	K : Na ratio in shoots	K : Na ratio in roots
N	* 5.48a	0.75ab
NS	2.70bc	0.53c
NSK1	2.53c	0.62bc
NSK2	3.53b	0.85a

*Explanations, see Table 1

Table 7. Effects of NaCl stress and supplementary potassium on Ca : Na ratio in strawberry shoots and roots

Treatment	Ca : Na ratio in shoots	Ca : Na ratio in roots
N	1.31a*	0.64a
NS	0.46b	0.34c
NSK1	0.48b	0.26c
NSK2	0.40b	0.53b

*Explanations, see Table 1

reported that supplementary potassium could ameliorate the negative effect of NaCl on plant water usage.

Data presented in Tables 4 and 5 show that NaCl in the growing medium can alter the nutrients content in shoots and roots, which supports findings of Saied et al. (2003) who reported that salt stress increased Na and Cl level in roots and shoots of strawberry. Supplementary potassium fertilization increased content of these elements in plant parts, which contradicts findings of Kaya et al. (2002). Potassium content in the roots was enhanced by addition of NaCl to the nutrient solution (Tab. 4), which was in agreement with results of other workers, who reported that potassium uptake by the roots increased when the plants were exposed to NaCl (Kaya et al., 2001a). Moreover, supplementary potassium fertilization induced potassium uptake, which was in agreement with findings of Kaya et al. (2001a). Silva et al. (2003) reported that NaCl stress decreased Ca^{2+} uptake by roots and its accumulation in shoots. In our experiments, Ca uptake was reduced by salinity, but shoot calcium content was not affected. Ca uptake was increased by high rate of supplementary potassium fertilization, but it did not have a significant effect on shoot calcium content (Tab. 4 and 5).

Increased salinity reduced K/Na and Ca/Na ratios in the roots and shoots of strawberry (Tab. 6 and 7). Chauhan et al. (1980) observed that in saline stress-sensitive cereals, K^+/Na^+ ratio decreased upon salt treatment whereas high potassium level in nutrient solution ameliorated this effect. Ca^{2+}/Na^+ also decreased significantly. In our experiments, supplementary potassium increased this ratio in plant parts (Tab. 7) and there was also a positive correlation between Ca^{2+}/Na^+ ratio and water usage by plant.

CONCLUSION

In the light of this experiment, we concluded that:

1. High NaCl concentration in nutrient solution strongly influences the vegetative parameters, fruit yield, and ionic content of 'Selva' strawberry.
2. Supplementary potassium sulphate can partially ameliorate the negative effects of high NaCl concentrations.

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WPŁYW POTASU NA WYPŁYW JONÓW, ZUŻYCIE WODY, PLON OWOCÓW I PRODUKCJĘ BIOMASY TRUSKAWEK UPRAWIANYCH W WARUNKACH STRESU SOLNEGO

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S T R E S Z C Z E N I E

Truskawki uprawiano w kulturze bezglebowej uzupełnionej dodatkowo nawozem potasowym i w warunkach wysokiego zasolenia NaCl (35 mmol/L) i określano wpływ tych czynników na wzrost i rozwój roślin. Traktowania obejmują pożywki: 1) kontrolną (N); 2) N + 35 mmol/L NaCl (NS); 3) NS + 5 mmol/L K_2SO_4 (NSK1); 4) NS + 10 mmol/L K_2SO_4 (NSK2). Stwierdzono, że powierzchnia liści, wypływ jonów (EC), zawartość chlorofilu, produkcja biomasy i zużycie wody były obniżone w warunkach stresu solnego. Poza tym zawiązywanie owoców i liczba owoców były niższe w warunkach stresu solnego. Zawartość składników mineralnych (Na, Cl, Ca i K)

w różnych częściach roślin była wyższa w warunkach stresu solnego. Dodatkowe uzupełnienie pożywki nawozem potasowym w warunkach stresu solnego wpłynęło pozytywnie na rozwój liści, zawartość chlorofilu i rozwój owoców, ale miało ujemny wpływ na produkcję biomasy. Wykazano, ze potas powoduje obniżenie negatywnego wpływu powodowanego przez stres solny na wzrost i rozwój truskawki.

Słowa kluczowe: wypływ jonów, wzrost i rozwój, NaCl, potas, plon