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Research Article

Growth, Proline Accumulation and Ionic Relations of Tomato (*Lycopersicon esculentum* L.) as Influenced by NaCl and Na_2SO_4 Salinity

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Abstract: Salinity depresses ion activities, decreases the ratios of plant nutrients to Na and Cl ions, and consecutively suppresses plant growth. The objective of the present study was to distinguish the effects of NaCl and Na_2SO_4 salinity on the growth, ionic relations and proline accumulation of tomato plants. Tomato plants were grown for two months. Plant growth was reduced, but proline accumulation was enhanced by salinity. Total N and NO_3-N content of plants were decreased by both NaCl and Na_2SO_4 salinity. Sulphur content was not affected by the salt treatments. Salinity caused nutrient imbalances. The Na and Cl contents of plants increased while the K:Na ratio and NO_3-N:Cl ratio decreased. In addition, the nutrient uptake rate was depressed by salt treatments. All parameters measured were affected more adversely by Na_2SO_4 than by NaCl salinity. The depressing effect of Na_2SO_4 applied during the first month of the growing period was more deleterious than Na_2SO_4 applied during the second month of the growing period.

Key Words: NaCl salinity, Na_2SO_4 salinity, Proline accumulation, Ionic relations.

NaCl ve Na_2SO_4 Tuzluluğundan Etkilenen Domates (*Lycopersicon esculentum* L.) Bitkisinde Gelişim, Prolin Birikimi ve İyon İlişkileri

Özet: Tuzluluk iyonların aktivitelerini bozarak besinlerin Na iyonuna oranını daraltmak suretiyle bitki gelişimini geriletir. Bu çalışmada; NaCl ve Na_2SO_4 tuzluluğunun ayrı ayrı ve birlikte, domates bitkisinin gelişimi ile prolin birikimi, iyon kapsamı ve alımına etkisi araştırılmıştır. İki ay süresince büyütülen domates bitkilerinde tuzluluk, bitki gelişimini azaltırken bitkide prolin birikimini artırmıştır. Bitkinin toplam N kapsamı ile NO_3-N kapsamı hem NaCl hem de Na_2SO_4 tarafından azaltılmıştır. Tuz uygulamaları bitkinin S kapsamını etkilememiştir. Tuzluluk bitkide besin dengesizliklerine yol açmıştır. Bitkinin Na ve Cl kapsamı artarken K:Na oranı ve NO_3-N:Cl oranı azalmıştır. Tuz uygulamaları bitkinin besin maddesi alımını azaltmıştır. Tüm bu parametreler NaCl uygulamasına göre Na_2SO_4 uygulamasından daha fazla olumsuz şekilde etkilenmişlerdir. Buna ilaveten, bitkinin gelişim döneminin birinci ayında uygulanan Na_2SO_4 ikinci ayında uygulanan Na_2SO_4' tan daha fazla zararlı etki yapmıştır.

Anahtar Sözcükler: NaCl tuzluluğu, Na_2SO_4 tuzluluğu, Prolin birikimi, İyon ilişkileri.

Introduction

Irrigation agriculture tends to be characterized by varying degrees of crop injury as a result of salt accumulation in soil (Eaton et al., 1971). Most salinity studies have involved the determination of crop responses to NaCl salinity (Rogers et al., 1998). However, there is reason to suspect that responses to SO_4 salinity may differ from those observed in a Cl salt system. There have been comparatively few studies examining plant responses to situations where Na_2SO_4 salinity dominates (Curtin et al., 1993; Rogers et al., 1998). However, Na_2SO_4 is present in higher concentrations than NaCl in soil and groundwater in many parts of the world (Rogers et al., 1998). Research has shown that certain plants are less tolerant to Cl salinity than to SO_4 salinity due to the excessive accumulation of Cl in plant tissue or because of other Cl-induced nutritional disorders, such as the inhibition of phosphate uptake (Manchanda et al., 1982; Mor & Manchanda, 1992). Ion uptake, salt accumulation and parameters such as transpiration rates may also be affected to different degrees by Cl and SO_4 salts (Meiri et al., 1971).

As is known, Ca ions precipitate as gypsum where SO_4 salts predominate (Papadopoulos, 1984). One of the major differences between a Cl and SO_4 salt system is the concentration of Ca that may be relatively low in SO_4 solutions because of the low solubility of gypsum (Curtin et al., 1993). According to Marschner (1986), Ca plays a crucial role in controlling cell membrane permeability and selectivity. In salinity induced Ca deficiency, ion uptake and osmoregulation of plants is imbalanced, and ion toxicity, osmotic stress and nutritional disruption occurs.

Because of limited information and apparent contradictions in the literature concerning the effects of high sulphate and chloride waters on plants (Curtin et al., 1993; Rogers et al., 1998), the present study was undertaken to observe the effects of Na_2SO_4 and NaCl salts on growth, ion absorption, proline accumulation and ionic relations in tomatoes grown in nutrient solution under greenhouse conditions.

Materials and Methods

The seeds of a tomato (*Lycopersicon esculentum* L.) were germinated on a tray containing a peat:perlite mixture (1:1). Seedling transplantation was made at the three leaf stage, at a rate of one seedling per plastic pot holding 0.5 L of peat:perlite mixture (1:1). The plants were then grown for 2 months under greenhouse conditions and were irrigated with a nutrient solution containing NaCl or Na_2SO_4 salts. Six treatments were applied: 1) Control; 2) 30 mM NaCl; 3) 30 mM NaCl for the first month and 15 mM Na_2SO_4 for the second month of the growting period; 4) 15 mM Na_2SO_4; 5) 15 mM Na_2SO_4 for the first month and 30 mM NaCl for the second month of the growing period; and 6) 1:1 mixture of 30 mM NaCl and 15 mM Na_2SO_4 salts. The composition of the nutrient solution was as follows: macronutrients in mM: 1.25 KH_2PO_4, 2.00 $MgSO_4.7H_2O$, 4.25 $Ca(NO_3)_2.5H_2O$, 4.00 KNO_3, 1.75 K_2SO_4, 1.25 NH_4NO_3: micronutrients in µM: 15 FeEDDHA, 10 $MnSO_4.H_2O$, 5 $ZnSO_4.7H_2O$, 30 $Na_2B_4O_7.10H_2O$, 0.75 $CuSO_4.5H_2O$, 0.50 $Na_2MoO_4.2H_2O$ (Sonneveld, 1992). The pH of the nutrient solution was adjusted to 5.9-6.10 with 0.1 Eq. NaOH. Treatments were replicated four times (24 pots, each containing one plant) and arranged in a completely randomized design.

Plants were harvested 2 months after transplanting. The fresh and dry weight of the plants were measured. The dried tissue was powdered and dry ashed in a muffle furnace. In the extract solutions, Na and K were determined by flamephotometry, P spectrophotometrically by using the phosphomolibdate yellow method (Kitson & Mellon, 1944), and Ca titrimetrically by the method of Johnson & Ulrich (1975). Total N was determined by micro-Kjeldahl procedure. Chloride and NO_3 were extracted from dried tissue with water and determined by using the methods of Johnson & Ulrich (1975) and Cataldo et al. (1975), respectively. Sulphur assayed in acid (HNO_3:$HClO_4$, 4:1) digested extract solution turbidimetrically by the method of Tabatabai & Bremner (1970). Tissue water content was calculated on dry weight basis.

The data were analysed by ANOVA using a MINITAB (Minitab Inc., USA) and treatment means were compared by LSD test ($p < 0.05$).

Results and Discussion

The fresh and dry weights of tomato plants were decreased by saline treatments (Table 1). For fresh weight, salt treatments introduced as Na_2SO_4 in the first or second month of the growing period were found to be more detrimental than those of the other salt treatments. Plant growth reductions caused by salinity have been reported in the literature (Gunes et al., 1996; Caines & Shennan, 1999; Alpaslan & Gunes, 2001).

Plant water content was increased by treatment 3 (Table 1). Ruiz et al. (1999) reported that salinity achieved by Na, Cl, NaCl, and macronutrients increased plant tissue water content. It seems from Table 1 that Na_2SO_4 salinity is more detrimental for plant growth than is NaCl salinity.

Proline accumulation was increased by salinity regardless of the salt source (Table 1). When the plants were given NaCl+Na_2SO_4, proline accumulated in the tissue at the highest rate. In salt stress conditions, proline accumulation in plants increased for the osmoregulation (Gunes et al., 1996; Aziz et al., 1999).

When compared to the control, the total N content of plants was decreased by salinity (Table 2). Salt treatments from Na_2SO_4 applied in the first or second month of the growing period were more pronounced in

Table 1. Fresh (FW) and dry (DW) weights, and water and proline contents of tomato plants affected by NaCl and Na_2SO_4 salinity (means followed by same letters are not significant at $p < 0.05$, n = 4).

Treatments		FW	DW	H_2O	Proline
1st month	2nd month	(g)	(g)	($g\ g^{-1}$ DW)	($mg\ g^{-1}$ FW)
1) Control	Control	55.29 a	4.91 a	10.31 bc	0.44 c
2) NaCl	NaCl	45.74 ab	3.41 b	12.76 ab	4.37 b
3) NaCl	Na_2SO_4	33.33 c	2.25 c	14.16 a	5.48 ab
4) Na_2SO_4	Na_2SO_4	32.29 c	3.35 b	8.75 c	5.75 ab
5) Na_2SO_4	NaCl	37.47 bc	3.47 b	9.92 bc	6.04 ab
6) NaCl+Na_2SO_4	NaCl+Na_2SO_4	43.97 abc	3.96 b	10.00 bc	6.98 a
F-test[a]		**	**	*	**

a: ** = $p < 0.01$, * = $p < 0.05$

Table 2. Effects of NaCl and Na_2SO_4 salinity on total N, NO_3-N, Cl, S contents, and NO_3-N:Cl ratio of tomato plants (means followed by same letters are not significant at $p < 0.05$, n = 4).

Treatments		Total N	NO_3-N	Cl	NO_3-N:Cl	S
1st month	2nd month	(% DW)	(% DW)	(% DW)	ratio	(% DW)
1) Control	Control	3.44 a	2.03 a	1.31 c	1.56 a	1.00
2) NaCl	NaCl	3.11 ab	1.82 a	7.21 a	0.24 cd	0.88
3) NaCl	Na_2SO_4	2.03 c	0.29 b	6.71 a	0.05 d	1.04
4) Na_2SO_4	Na_2SO_4	2.79 b	1.87 a	1.39 c	1.35 b	1.13
5) Na_2SO_4	NaCl	3.06 ab	1.64 a	4.49 b	0.36 c	1.01
6) NaCl+Na_2SO_4	NaCl+Na_2SO_4	3.09 ab	1.66 a	5.27 b	0.33 c	1.11
F-test[a]		**	**	**	**	ns

a: ** = $p < 0.01$, ns = non significant

reducing the total N content of plants. The decrease in the total N content of plants can be explained by the antagonism between Cl and SO_4 ions (Perez-Alfocea et al., 1993; Santamaria et al., 1998).

All saline-stressed plants gave lower NO_3-N content compared to control plants. The lowest NO_3-N content was reached by the treatment in which Na_2SO_4 was applied in the second month of the growing period (Table 2). Chloride absorption by plants was increased by the NaCl-containing treatments (Table 2). The highest Cl absorptions were reached in NaCl treatments which were applied throughout the growing period. Since Cl absorption increased, the ratio of NO_3-N to Cl decreased. In addition, all salt treatments decreased the NO_3-N:Cl ratio. Sulphate salt (Na_2SO_4) applied during the second month of the growth period caused the lowest NO_3-N:Cl ratio. Similar results have been reported by Inal et al. (1995) and Perez-Alfocea et al. (1993). As reported by Cusido et al. (1987) salinity inhibits both water absorption, nitrogen assimilation and protein biosynthesis. It was reported that salinity produces extreme ratios of Cl:NO_3 ratios (Grattan & Grieve, 1999). Antagonism between Cl and NO_3 causes lower NO_3:Cl ratios (Santamaria et al., 1998).

Sulphur (S) absorption by plants was not affected (Table 2) by the treatments ($p > 0.01$). In one study that compared the effects of both chloride and sulphate salinity on peas, Mor & Manchanda (1992) found that chloride salinity reduced the sulphur content in the straw.

When compared to the control treatment, all the treatments increased the Na content of plants (Table 3). Only treatment 4 (Na_2SO_4 applied for two months) decreased the K contents of plants. But, as seen from Table 3, the K:Na ratio and uptake rates of K (Figure) were decreased by the salt treatments. Similar results heve been reported by Alpaslan & Gunes (2001) and Adams (1991) on Na, K and Cl contents of tomato plants.

Table 3. Effects of NaCl and Na_2SO_4 salinity on Na, K, P and Ca contents and K:Na ratio of tomato plants (means followed by same letters are not significant at $p < 0.05$, n = 4).

Treatments		Na	K	K:Na	P	Ca
1st month	2nd month	(% DW)	(% DW)	ratio	(% DW)	(% DW)
1) Control	Control	0.09 b	6.40 a	70.58 a	0.57 c	2.80 a
2) NaCl	NaCl	1.19 a	6.82 a	5.95 b	0.58 c	2.71 a
3) NaCl	Na_2SO_4	1.10 a	6.83 a	7.33 b	0.26 d	2.66 a
4) Na_2SO_4	Na_2SO_4	1.40 a	5.14 b	3.72 b	0.73 a	1.68 b
5) Na_2SO_4	NaCl	1.16 a	6.16 a	5.33 b	0.69 ab	2.08 b
6) NaCl+Na_2SO_4	NaCl+Na_2SO_4	1.48 a	6.67 a	4.71 b	0.62 bc	2.64 a
F-test[a]		**	**	**	**	**

a: ** = $p < 0.01$

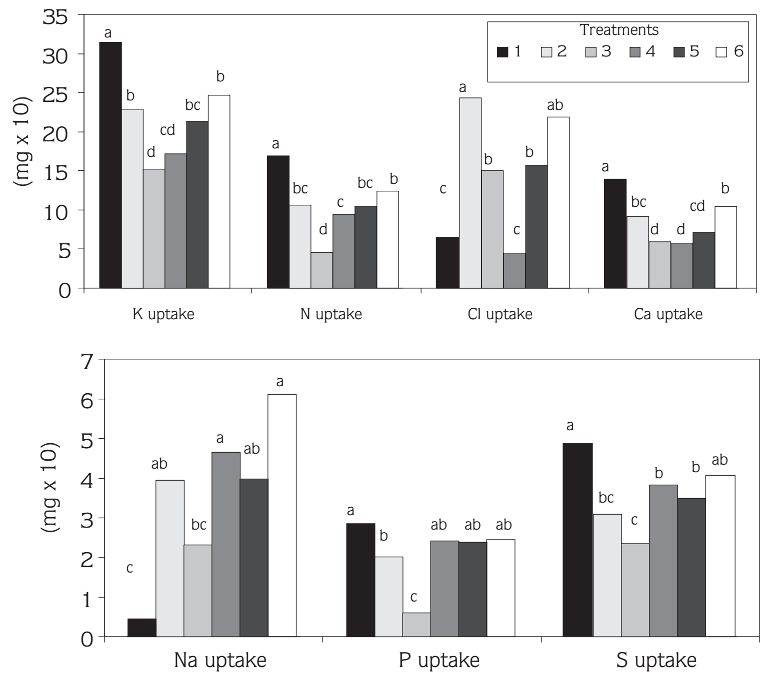

Figure. Uptake rates of K, N, Cl, Ca, Na, P and S ions by tomato plants affected by NaCl and Na_2SO_4 salinity.

Only the third treatment caused a reduction in the P content of plants. Salt treatments decreased the Ca content of plants. However, significant decreases occurred in the treatments where Na_2SO_4 was applied during the full growth period or the second month of the growth period (Table 3). According to Adams & Ho (1989) salinity reduces the Ca content of tomato plants. As a result of salinity, increases in Cl and Na but decreases in Ca and K contents and the K:Na ratio in plants have widely been reported in the literature (Gunes et al., 1996; Santamaria et al., 1998; Ruiz et al., 1999). It has been reported that the dilution effect may increase or decrease the concentrations of ions in plant tissues (Bergmann, 1992).

Potassium, N and Ca uptake by plants decreased under all salt treatments (Figure). The decreases in K and N uptake were more pronounced in the treatments where Na_2SO_4 was introduced in the first or second month of the growth period. Generally, mixed salinity (NaCl+Na_2SO_4) applied throughout a full growing period gave higher K and N uptake rates. Chloride uptake was increased by treatments in which the Cl ion was included.

When compared to the control, the Na uptake of plants was increased by salt treatments. Slight decreases in P and S uptake were seen as a result of saline treatment (Figure). Similar results on the uptake rate of mineral ions have also been reported widely in the literature (Ruiz et al., 1999; Pardossi et al., 1999; Savvas & Lenz, 2000). In a review on salinity-mineral nutrient relations in horticultural crops, Grattan & Grieve (1999) and Alpaslan & Gunes (2001) stated that a large number of studies demonstrate that salinity reduces nutrient uptake and accumulation as well as partitioning within the plant.

In conclusion, the present experimental results have shown the depressing effect of NaCl and Na_2SO_4 salinity on growth, ionic imbalance, ion accumulation and uptake rates of tomato plants. In general, the two salt sources (NaCl and Na_2SO_4) affected the performance of tomato plants in similar ways, but Na_2SO_4 affected the parameters examined in this experiment more adversely than NaCl. In addition, the effects of Na_2SO_4 differed depending on when it was introduced. Therefore, as well as salt concentration, salt composition or accompanying anion should be taken into consideration in salinity-plant growth and plant nutrition studies. It is reasonable to believe that numerous salinity-nutrient interactions occur simultaneously, but whether they ultimately affect crop yield or quality depends upon both the salinity level and composition of salts and the crop species. Therefore, further experimentation on other crop species and different salt compositions is needed.

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