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Response of Tomatoes to Nitrogen Supply Through Drip Irrigation System under Salt Stress Conditions

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Abstract: Salinity and low soil N availability are important growth limiting factors for most crops particularly under arid and semi-arid conditions. The proper use of N fertilizer in all soils is not only important for plant growth but it may also alter the salinity tolerance of plants depending on the level of salinity, plant growth stage and the extent by which the nutrient in the system is limiting. The present study was undertaken to determine the interaction effects of four N application rates (0, 120, 240 and 360) combined with two water salinity levels (2.5 and 4.8 dS/m) on growth rate, mineral composition and yield of drip irrigated tomato in a field experiment. A positive response of tomato to increasing N was obtained at the lower salinity level while at the higher salinity level increasing N was ineffective in alleviating adverse effects caused by salinity; further application of N beyond 240 kg N/ha under higher salinity interacted to reduce tomato fruit yield and worsened the situation. At low salinity, yield reduction caused mainly by reduction in the average fruit weight, whilst the declining number of fruits explains the main portion of yield reduction at high salinity. Medium and high N rates produced the maximum growth rate up to the first mature fruit stage and thereafter, the maximum growth rate was achieved with the high and the medium N rates under low and high salinity levels, respectively. Total N uptake was linearly increased with the N application rates but it was markedly suppressed by slowing down growth when associated with the higher salinity levels, irrespective of N rate. Leaf K, Ca and Mg concentrations were decreased significantly by increasing salinity levels and this was compensated by the accumulation of Na. The observed trend suggested that over fertilization may recover some of yield losses, whenever salinity is not so high to inhibit the response of the crop to the fertilizers. Salt stressed plants performed well when adequately fertilized, where N should be applied in amounts that increase with plant need over the growing season.

Key words: Nitrogen supply, Saline water, Salt tolerance, Tomatoes, Drip irrigation

INTRODUCTION

Salinity is a major problem that negatively impacts agricultural activities in many regions in the world, particularly in arid and semi-arid region. Salts inhibit plant growth by osmotic stress, nutritional imbalance, and specific ion toxicity (Gunes *et al.,* 1996; Cornillon and Palloix, 1997). Soil salinity is being progressively exacerbated by agronomic practices such as irrigation and fertilization, especially in arid regions. The proper use of N fertilizer in all soils is very important, but particularly so in saline soils where N object might reduce the adverse effects of salinity on plant growth and yield (Shen *et al.,* 1994; Flores *et al.,* 2001) depending on plant species, salinity level, or environmental conditions (Grattan and Grieve, 1999). On the other hand, over fertilization with N may contribute to soil salinization and increase the negative effects of soil salinity on plant performance. Studies of plant growth responses to N and soil salinity during the whole plant life cycle are important to reveal whether the amount of N applied alleviates or aggravates the detrimental effects of salinity during specific growth stages. In addition, examining plant growth during the whole growing season provides information about crop salt tolerance over time. Plant response to salinity changes with age, plant development and growth stage (Maas, 1993). For example, Del Amor *et al.,* (2001) reported that tomato plants are more sensitive during the seedling stage than during later stages of growth. Relative growth rate allows one to make more appropriate comparisons of plant growth among salinity treatments than absolute growth rate (Cramer *et al.,* 1994). The RGR gives a relative basis on which to compare growth rates of plants since it takes into account both the initial and ending plant weights over a specified time period (Hunt, 1990).

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Tomato is one of the important and widespread crops in the world, and is considered moderately sensitive to salt stress, since it can tolerates an EC of the saturated soil extract up to about 2.5 dS/m without any yield reduction and fruit yield decrease by 10% with each unit of EC increasing above the threshold value (Maas, 1986). Large amount of laboratory research and on-farm applied and adaptive research activities on tomatoes have been executed under saline water by numbers of researchers in many different countries. The results evidently revealed that if suitable management practices were adapted, it was feasible to irrigate tomato using relatively high saline water under arid conditions. These management practices included using drip irrigation, applying nitrogen daily by fertigation from the first day of irrigation and irrigating tomato five times per day, and so on (Pasternak and De Malach, 1995).

Nitrogen, in one form or another, accounts for about 80% of the total mineral nutrients absorbed by plants (Marschner, 1995). Inadequate nitrogen is often the growth-limiting nutritional stress in field soils. Consequently, addition of N usually improves plant growth and yield regardless of whether the crop is salt-stressed or not. In many field studies, horticulturists and agronomists set out to test the hypothesis that N-fertilizer additions alleviate, at least to some extent, the deleterious effect of salinity on plants. Most salinity and N interaction studies in the field were conducted on soils deficient in N. Therefore, additions of N improved growth and/or yield of apple, (El-Siddig and Ludders, 1994), bean, (Wagenet *et al.,* 1983), wheat and barley, (Badr, 2001), grape, (Taylor *et al.,* 1987), tomato, (Flores, *et al.,* 2001; Kutuk, *et al.,* 2004), pepper (Castorena, *et al.,* 2003) and spinach, (Langdale *et al.,* 1971) when the degree of salinity was not severe. Under dry land conditions, high rates of fertilization may not be economical and in many parts of the world availability of fertilizers is limited. Therefore, the objective of present work was to determine the interactive effects of different N rates and salinity levels on the growth rate, total yield and mineral composition of field grown tomato under drip irrigation system.

MATERIALS AND METHODS

The experiment was conducted at El Khatatba region, Monofia province west of Nile Delta of Egypt during the late summer growing season (August - November) 2007 using drip irrigation system. This area is a desert region, and the soil of the experimental site was deep, well-drained sandy composing of 85.5% sand, 10.2% silt and 4.3% clay, with an alkaline pH 8.2, EC 2.35 dS/m, $CaCO_3$ 2.5%, O.M 0.32%. The available N, P and K were 25, 8 and 47 mg/kg soil, respectively before the initiation of the experiment. Before cultivation, drip tubing (GR, 40 cm dripper spacing, 4l/h discharge rate and 1.5 m apart) was placed directly on surface of the soil beds. Twenty-five old seedlings of tomato cultivar 'TY 70/70' hybrid were transplanted to the main field (32 000 plants/ha) in double rows (40 cm apart), pre-furrowed to receive organic manure, at 50 m^3/ha, super phosphate at 250 kg/ha and potassium sulphate at 125 kg/ha prior to planting, as is customary in the region. Uniform irrigation was applied to the all seedlings through the drip tubing to encourage stand establishment. The experiment was randomized complete block factorial design consisting of combinations of four N rates (0, 120, 240 and 360 kg N/ha) and two salinity levels (2.5 and 4.8 dS/m) and was replicated three times in 4.5 m wide × 10 m long plots. The actual crop water requirement was estimated by multiplying reference evapotranspiration with crop coefficient ($ETc = ETo \times K_C$) for different months based on crop growth stages using the model suggested by Penman-Monteith's formula (Allen *et al.,* 1998). Amounts of irrigation water used after planting was 360 mm for the growing season. Irrigation frequency was running daily from two local well-water having EC 2.5 and 4.8 dS/m respectively. Soil salinity was monitored weekly to depths of 15 and 30 cm; when mean soil EC exceeded water EC by more than 0.5 dS/m, the daily amount of irrigation was increased by 25% until the next measurement to facilitate salt leaching.

Nitrogen as NH_4NO_3 was applied on weekly basis through drip fertigation in split equal doses and commenced after two weeks of planting. This was done along with phosphorus (160 kg P/ha), as phosphoric acid (85%) and potassium (200 kg K/ha) as K_2SO_4 respectively. All N, P and K fertilizers were injected directly into the irrigation water using venture-type injector. Plants were sampled vive times (30, 45, 60, 75 and 90 days of transplant) at three representative plants from the experimental plots on each sampling date, and then dried and weighed to determined absolute growth rate. After being collected, the ground leaf sample materials were wet digested with H_2SO_4 in the presence of H_2O_2 for analysis of total N by the micro-Kjeldahl method (Bremner and Mulvaney, 1982), K, Ca, Mg and Na using the atomic absorption spectrophotometer. Total P was determined on the same digest by colorimetric molybdenum blue method (John, 1970). Nitrate and Cl^- were extracted by hot water and NO_3^- was determined by the micro-Kjeldahl method as decried above and Cl^- was determined by titration against $AgNO_3$ (Eaton *et al.,* 1995). Tomato fruits were collected periodically and at last pick of fruits all aboveground biomass in each plot were collected and weighed to determined total yield of shoots and fruits. Average fruit weight, number of fruits per plant and total yield per plant were also evaluated for at least four plants.

RESULTS AND DISCUSSIONS

Crop Response:

Both salinity and N rate affected tomato fruit yield and an interaction was detected between these factors (Table 2). At lower salinity level of 2.5 dS/m, increasing N supply promoted tomato yield and its components and the maximum yield (78.74 t/ha) was obtained at 360 kg N/ha, confirming the impact of higher nitrogen input on the aboveground production. Increase in yield was due to improvement in growth parameter reflected in dry matter production of the vegetative growth, number of fruits per plant and the mean fruit weight. On the other hand, increasing salinity to 4.8 dS/m reduced fruit yield much more in soils treated with highest N rate of 360 kg/ha which worsened the situation; the efficiency of N fertilizer decreased considerable when combined with higher salinity level. The effect of salinity on the yield was particularly pronounced at low N rate of 120 kg/ha because N starvation and salinity combined to depressed the yield under both salinity levels.

Table 1: Ionic composition of the well water used at the experimental field site.

EC (well water) dS/m	Concentration (mg/l)						
	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	SO_4^{2-}	HCO_3^-
2.5	311	144	45	23	621	278	92
4.8	637	236	73	94	1250	566	114

Table 2: Yield and yield components of tomato plants as influenced by N application rates under different salt stress conditions.

Salinity level dS/m	Nitrogen kg/ha	Total yield (t/ha)		No. of fruits per plant	Mean fruit weight (g)	Fruit yield kg/plant
		Fruits	Shoots			
Low (2.5)	0	25.19	2.19	8.8	90	0.79
	120	54.27	4.73	17.2	108	1.70
	240	70.34	5.65	17.7	124	2.21
	360	78.74	6.27	18.2	135	2.46
High (4.8)	0	18.34	1.87	7.2	81	0.58
	120	45.63	4.95	16.4	88	1.45
	240	58.76	5.16	17.5	105	1.84
	360	55.35	5.87	16.9	102	1.73

LSD ($P = 0.05$) fruit yield, N =3.32; salinity = 4.55; N × salinity = 7.27.

This result indicated that over fertilization during plant growth periods may contribute to salinity and decreased fruit yield as also reported by (Alam, 1994; Castorena, *et al.,* 2003). Thus, fertilization above plant requirements not only increases costs, but can also have detrimental effects on the environment such as soil salinity accumulation or conversely, ground water contamination by leaching. The interaction between salinity and N rates on tomato yield was significantly; at lower salinity level, all N application rates were additive, but highest N rate of 360 kg/ha decreases the effect of the fertilizer on tomato yield when combined with higher salinity level. Yield reduction under saline conditions was due to a reduction in fruit size, which agrees with literature indicating that, at relatively low salinity, yield reduction is mainly caused by reduction in fruit weight whilst fruit number remains almost unchanged (Sanchez *et al.,* 2005). Salinity reduced both fruit number and mean fruit weight at the higher level (4.8 dS/m), but still had its major effect on fruit weight. Differences in fruit size may result from the reducing water transport towards the fruit, retarding fruit growth rate or the numbers of cells determined in the first phase of fruit growth or the extent of cell expansion through the second phase of fruit growth (Cuartero and Fernandez-Munoz, 1999; Saure, 2001). The extended fruit development period is most probably the reason for the increased fruit size.

An apparent increase in salt tolerance has been reported when N levels supplied under saline conditions exceeded those that were optimum under non-saline conditions and it has been suggested that increased fertilization may overcome some of the inhibitory effects of salinity. For tomatoes and several other vegetables, excess salinity or serious N deficiency tend to control plant growth and yield regardless of the levels of the other (Shen *et al.,* 1994; Flores *et al.,* 2001) depending on plant species, salinity level, or environmental conditions (Grattan and Grieve, 1999). In the present experiment, adverse effects of high salinity level on plant growth were enhanced by increasing N fertilization up to 360 kg N/ha. However, over-fertilization apparently reduced yield reduction at lower salinity level but otherwise, when salinity severely depressed growth, the applied N could not be effective. Fertilization under saline condition may follow the same requirements for crops under non-saline condition whenever salinity is not so high as to inhibit response of the crop to fertilization, by its direct limiting effect on growth or sever restriction of root growth and consequent poor recovery of soil nutrients, added fertilizers or both.

Effects on Growth Rate:

The growth rate of tomato was affected by salinity and N rates during all plant growth stages with positive response between these two factors detected at lower salinity level (Fig. 1, A&B). Absolute growth rates for tomato increased from 0.007 g/plant/day to a maximum rate of 14.7 g/ plant/day at 70 days after transplanting with 360 kg N/ha, for lower salinity level and from 0.005 to 11.4 g/plant/day for the corresponding period with 240 kg N/ha for higher salinity level. This translates to maximum dry matter accumulation rates of 470 and 394 kg/ha day for low and high salinity level, respectively. During the first growth period, from transplanting to flowering onset (45 days), increasing N level promotes growth rate at lower salinity level greater than under higher salinity level; a little marked increase in the growth rate was obtained, with no further response with N applications. Reductions in growth rate due to moderate N stress became obvious only toward the end of the growing season, when N depletion in the soil started to affect plant growth.

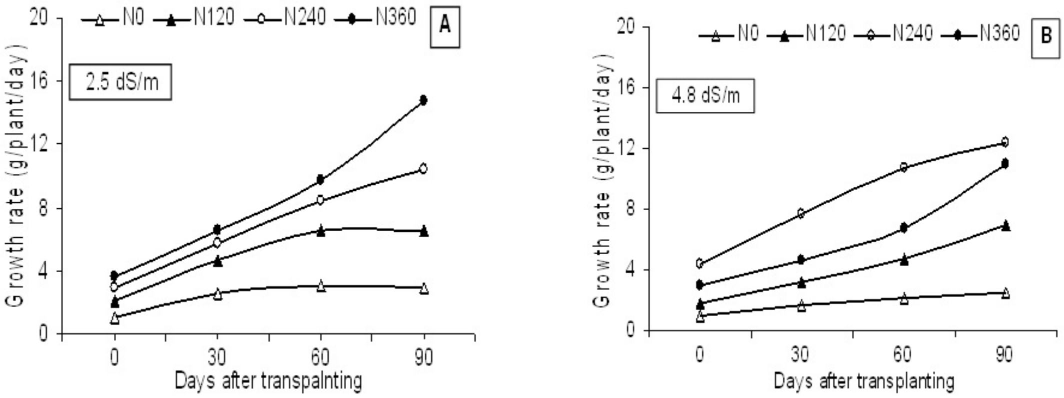

Fig. 1: Absolute growth rate of tomato plants in response to different N rates and salinity levels during the growing season.

Increasing the N rate from 120 to 240 kg/ha increased the growth rate during transplanting to flowering onset and from flowering onset to first mature fruits (75 days). But at the end of growing season, an increase from 240 to 360 kg N/ha was needed to produce the highest growth rate indicating that 120 and 240 kg N/ha were enough to satisfy plant N requirements from transplanting to first mature fruits and from first mature fruits to leaf senescence period, respectively. Thus, it may be possible to improve tomato plant yields by supplying N fertilizer in amounts that cope with plant size instead of equal application doses throughout the growing season, since salt stress was intensified by lower-fertilization during times of high fertilizer requirements (last stage). From flowering onset to first mature fruits, the growth rate was reduced at higher salinity level while, N had a positive effect on growth rate in the last development period, from first mature fruits to leaf senescence. However, this apparent beneficial effect of N on growth rate late in the plant's life cycle may be because salt-stressed plants delayed their early growth and development and subsequently continued growing longer into the season, resulting in a higher growth rate while lower stressed plants had already reached full vegetative growth. It is known that salinity stress retards plant growth due to osmotic and specific ion effects on metabolic processes such as nutrient uptake, assimilation and photosynthesis (Alam, 1994).

Other studies have also pointed out the differences in salt tolerance among plant growth periods (Cuartero and Fernandez-Munoz, 1999). The growth response to added N was most pronounced between 120 and 240 kg N/ha, and fruit set was prolonged and these last formed fruits are typically smaller and of lower quality. Similar results have been reported by (Scholberg, *et al.,* 2000) who reported that N stress resulted in a decrease in partitioning of dry matter to stems and leaves and increased transfer of assimilates to fruits near the end of the growing season.

Effects on Mineral Composition:

Because all N fertilizer was applied through fertigation, this typically results in relatively low N concentrations early in the season, followed by an increase at flowering onset and then followed by a steady decrease in N concentration of the leaf tissue over time with similar findings reported by (Scholberg, 1996). The N concentration of leaf blades decreased from 4-6 % at 30 days after transplanting to 2-4% near the end of the growing season (Fig. 2, A&B). The linear decrease in N concentration of leaves with time is attributed to leaf aging and N translocation to the fruits. Under N-limiting conditions, nitrogen stress affected N concentrations of leaves most drastically, whereas concentrations in N treated plants were relatively small, but became more pronounced as plants entered the rapid growth stage. According to standard values for tissue analysis (Hochmuth *et al.,* 1991), leaf tissue for the drip irrigated crops tested high (5%) until initial flowering and adequate (2-3%) depending on stage of growth throughout the remainder of the growing season. Except with 120 kg/N ha, which tested deficient (2.60-1.15%) after initial flowering as indicated by leaf yellowing and stunted growth, all N treated plants tested sufficient during the entire growing season.

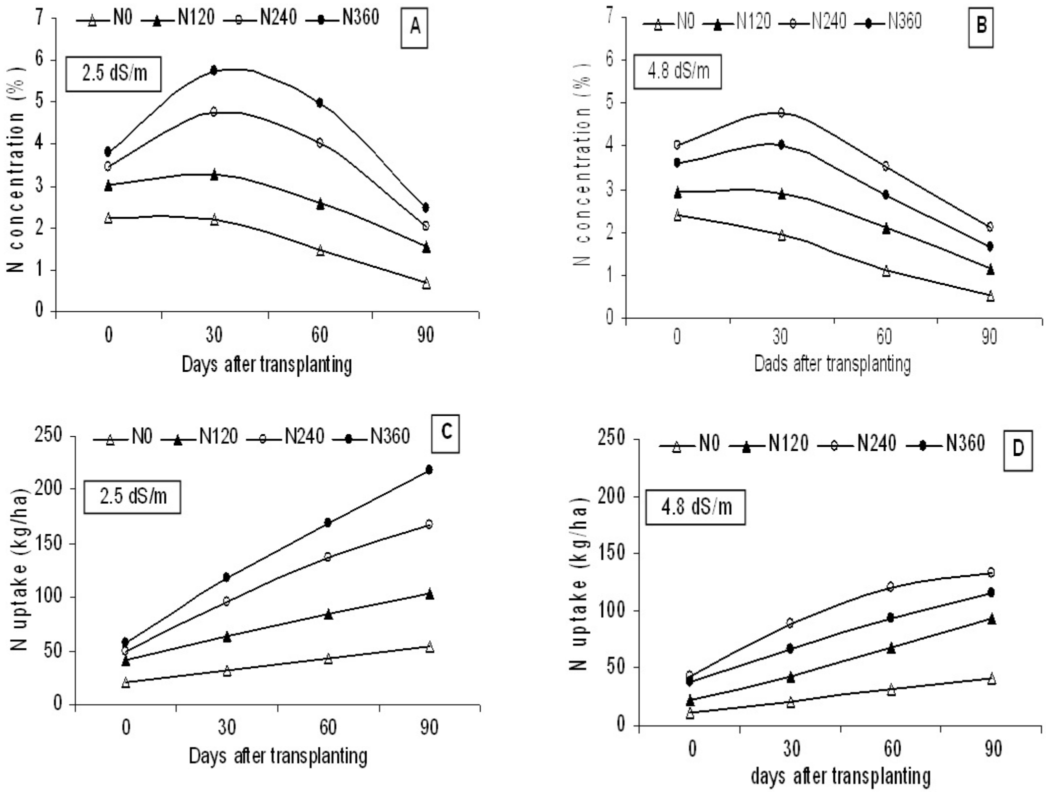

Fig. 2: Nitrogen concentration in the leaves of tomato (A&B) and total N uptake (C&D) in response to different N rates and salinity levels during the growing season.

At the lower salinity level (2.5 dS/m), there was a significant leaf N increase associated with the increasing N applied at all sampling dates. Increasing N from 240 to 360 kg N/ha in the irrigation solution was ineffective in restoring the decrease in the leaf N caused by higher salinity at 4.8 dS/m, indicating that the effect of salinity was independent from that of N which was not a limiting factor. However, in evaluating effects of salinity on leaf N content it should be stressed that the response is not the same during the entire growing period. The saline treatments induce a variety of effects on leaf N concentration where at 30 days after the treatments were started, both salinity levels increased leaf N, but had a decreasing effect on leaf N at the 60 days sampling particular at higher salinity level.

A likely explanation is that salinity increased leaf N indirectly at the first sampling by suppressing growth, and decreased leaf N at the 60 days sampling directly by restricting N uptake from the soil. In other studies (Feigin *et al.,* 1991), it has been found that the effect of salinity on leaf N and total N uptake was mainly through the suppressing effect of salinity on root growth and water uptake. Total N uptake by tomato plants was affected by salinity and N interactions (Fig. 2, C&D). Since, for the plants grown in soil to which saline water was applied, the growth limiting factor was the salinity rather than N; the total N uptake at lower level of salinity was significantly higher compared with the N uptake at the higher salinity level. The decrease in total N uptake by increasing salinity, apart from the effects of salinity on root growth, has been partly attributed to a probable substitution of Cl^- for NO_3^- (Feigin *et al.,* 1987; Martinez and Cerda, 1989). Under salt stress, nitrate uptake is slowed down and salinity reduces nitrate assimilation with the possible consequence of N deficiency in the plant.

Table 3: Mineral composition of tomato leaves in response to different N and salinity levels at 30 and 60 days after transplanting.

Salinity dS/m	Nitrogen kg/ha	Mineral elements (% dry weight)						
		Ca	Mg	K	Na	P	Cl^-	NO_3^-
				30 days after transplanting				
Low (2.5)	0	2.0	0.24	2.2	0.71	0.32	2.5	0.023
	120	3.1	0.36	3.9	0.78	0.37	1.9	0.031
	240	3.5	0.57	4.3	0.65	0.35	1.7	0.065
	360	3.8	0.65	4.7	0.46	0.38	1.4	0.083
High (4.8)	0	1.8	0.21	2.0	2.86	0.25	3.5	0.046
	120	2.4	0.28	3.1	2.32	0.30	2.9	0.052
	240	2.7	0.42	3.6	2.54	0.34	2.7	0.078
	360	3.1	0.49	3.9	2.65	0.38	2.4	0.096
				60 days after transplanting				
Low (2.5)	0	2.4	0.26	2.0	0.45	0.25	3.2	0.019
	120	2.7	0.39	2.5	0.74	0.32	2.7	0.031
	240	3.2	0.61	3.3	0.69	0.37	2.4	0.049
	360	3.7	0.67	3.7	0.57	0.35	2.1	0.071
High (4.8)	0	2.2	0.28	1.9	2.84	0.19	4.5	0.023
	120	2.4	0.42	2.4	1.48	0.23	3.7	0.054
	240	2. 8	0.48	2.6	1.34	0.28	3.3	0.065
	360	3.2	0.52	2.8	1.22	0.25	2.8	0.079

However, application of N has a positive effect on salt-stressed plants probably due to the additional uptake of nitrogen and consequently, a higher N concentration was found in salt stressed leaves . Considerable differences in the content of cations in leaves of the tomato plants were induced by the different salinity and N levels (Table 2). An increase in Cl^- uptake and accumulation is often accompanied by a decrease in leaf NO_3^- concentration as also reported by Martinez and Cerda, (1989). Many attributed this reduction to Cl^- antagonism of NO_3^- uptake (Bar *et al.,* 1997; Badr, 2001) while others attributed the response to salinity effect on reduced water uptake (Lea-Cox and Syvertsen, 1993). Apparently, the counter-ions may influence Cl^- antagonism of NO_3^- uptake. In contrast to the effect of Cl^- on NO_3^- uptake, others have reported that increased NO_3^- in the substrate decreased Cl^- uptake and accumulation in tomato (Flores, *et al.,* 2001).

The increasing concentrations of leaf Cl^- were found to be associated with decreasing leaf P, possibly because of competition between Cl^- and P uptake. It appears that when Cl^- concentration in leaves increased the P concentration decreased, where P at the 60 days sampling reduced sharply when $C1^-$ concentration was reached to about 4.5% in leaf dry weight. High Ca concentrations in the saline soils would probably cause P precipitation and consequently reduction of P availability to plants. Sharpley, *et al.,* (1992) suggested phosphate availability is reduced in saline soils not only because of ionic strength effects that reduce the activity of phosphate but also because phosphate concentrations in soil solution are tightly controlled by sorption processes and by the low-solubility of Ca±P minerals. With increasing N application, the concentrations of cations in the leaves were generally increased. Leaf K, Ca and Mg concentrations were decreased significantly by increasing salinity levels and this was compensated by the accumulation of sodium. Although, salinity raises Na concentration in the leaves but the ability of tomato to regulate Na in older leaves was observed in the second sampling date which seems to be related to salinity tolerance. A slight reduction in K content in tomato plants, in spite of a very high Na/K ratio in the soil solutions, and it was suggested that K was being selectively accumulated. Reduction in K uptake in plants by Na is a competitive process and sodium induced K deficiency has been implicated in growth and yield reductions of various crops, including tomato (Lopez and Satti, 1996).

Finally, at lower salinity level the addition of excess N as NH_4NO_3 fertilizer could alleviate adverse affects caused by salinity as hypothesized by some authors, but at higher salinity the applied N may contributed to the overall soil salinity and aggravated the situation. The N nutrition to levels required to maximize yields under non-saline conditions is likely to yield poor return when salinity is high enough to depress yield under optimal fertility conditions. Whereas, salt stressed tomato performed well when adequate N was applied; N should be applied in amounts that increase with plant need over the growing season.

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