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INTERACTIVE EFFECTS OF SALINE WATER IRRIGATION AND NITROGEN FERTILIZATION ON TOMATO GROWTH AND YIELD

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ABSTRACT

Water is an important constituent of cell and plays an important role in almost all biochemical processes. High salt concentration in the root zone impedes the water movement from soil to aerial parts of the plant by reducing the available water for plant uptake. Salinity is among the major limitations for plant growth and productivity all around the globe and the damage caused by high salinity is witnessed as either loss of plant productivity or plant death. Soil salinization is the result of different soluble salts accumulation in the root zone. soil salinization is increasing at a rate of 10% annually and more than 50% of the arable land would be salinized by the year 2050. Approximately 4.5 million acres of cropland in California have been reported to be affected by saline soils or saline irrigation water. The scenario in Pakistan is also alarming where 1.89 out of 19.43 Mha irrigated cropland is salt affected. A pot experiment was carried out in the greenhouse at the University of California, Riverside. Tomato was used as the study plant and the experiment included nine treatments representing different combinations of three irrigation water salinity levels and three nitrogen fertilization rates. High salinity stress causes the stress on plant growth and productivity due to the effective increment in the osmotic stress, ion toxicity, and alterations in soil physical and chemical properties.

KEYWORDS:
Salinity, Stress, Tomato, Water, Yield

INTRODUCTION

Currently, world population of 7.5 billion is increasing at an alarming rate and expected to reach 8.5 billion by 2030, 9.7 billion by 2050 and 11.2 billion by 2100 [1], and there is a great need to increase the food production as much as 70 percent by 2050 [2] to feed this massive population. Increasing quantities of water are obligatory along with other provisions to accomplish this goal. It has been predicted that 60% of the global population will undergo water shortage by the year 2025 [3]. This increased demand of more water to irrigate crops to cope with the food security issue, especially when fresh-water resources are limited, has led to a rush of interest in the use of low-quality or saline water for irrigation in agriculture [4,5].

Salinity is among the major limitations for plant growth and productivity all around the globe and the damage caused by high salinity is witnessed as either loss of plant productivity or plant death. Soil salinization is the result of different soluble salts accumulation in the root zone. soil salinization is increasing at a rate of 10% annually and more than 50% of the arable land would be salinized by the year 2050 [6]. Approximately 4.5 million acres of cropland in California have been reported to be affected by saline soils or saline irrigation water [7]. The scenario in Pakistan is also alarming where 1.89 out of 19.43 Mha irrigated cropland is salt affected [8].

Water is an important constituent of cell and plays an important role in almost all biochemical processes. High salt concentration in the root zone impedes the water movement from soil to aerial parts of the plant by reducing the available water for plant uptake [9]. Accumulation of these injurious ions may inhibit photosynthesis by damaging chloroplasts, protein synthesis, and inactivate different enzymes [10]. Thus it is essential to develop suitable water management strategies in order to attain maximum yields from the crops irrigated with saline water and essential mineral nutrients. Therefore, it is very important to develop agricultural management practices to cope with salinity while at the same time, optimizing nitrogen use to improve nitrogen use efficiency and reduce nitrate leaching potential.

Various fertilizers play a significant role in crop production. An adequate supply of essential nutrients can considerably ameliorate plant growth, quality and their nutritional values [11]. Both nitrogen and water are vital factors for tomato growth and fruit quality [12]. Nitrogen is of prime importance for the plants as it is a major component of chlorophyll, the compound which plays a key role in photosynthesis to produce plant's food from water and carbon dioxide in the presence of sunlight [13]. On the other hand, nitrogen is one of the most limiting nutrients in vegetable production, especially in crops with high nitrogen demand like tomato [14].

Tomato is the second most valuable crop, 19% of all vegetable consumption only behind potato at 23% [15], as well as the second most commonly grown vegetable in the world after potato [16]. Tomato production requires enormous amount of water [17, 18] and nitrogen for optimal growth and yield. Tomato is sensitive to moderate salinity level up to 2.5 dS m^{-1} for most of the commercial cultivars [19].

Keeping in view the above discussion, no or little research work has been reported regarding the interactive effect of salinity and nitrogen on tomato growth, fruit yield and quality, the overall objective of this study was to evaluate the interactive effect of irrigation water salinity and nitrogen application rates on tomato growth, yield and fruit quality by greenhouse pot experiment.

MATERIALS AND METHODS

Pot experiment A pot experiment was carried out in the greenhouse at the University of California, Riverside. Tomato was used as the study plant and the experiment included nine treatments representing different combinations of three irrigation water salinity levels and three nitrogen fertilization rates. Plastic pots were used in this experiment about 30 cm in height, 28 cm in diameter with a hole in the bottom center with the fiberglass wick to facilitate the drainage water collection. For each pot, a predetermined amount of soil (Amount of soil = Bulk density * Volume) for bulk density of 1.25 g cm^{-3} was added in small increments to obtain uniform packing. As a pretreatment, the soil was irrigated with equal amounts of 4% W/W water of EC = 1 dS m^{-1} one day before the tomato seedling transplantation.

Soil Collection, Packing, and its Basic Properties. Bulk soil was collected from the upper 30 cm of the experimental field from the Citrus Research Center, University of California Riverside. The collected bulk soil was air dried and passed through 10 mm sieve. Based on the soil particle size analysis (hydrometer method) the soil was classified as sandy loam. The electrical conductivity (µS m^{-1}) of soil was determined with an EC meter in an extract (1:5) after shaking for 3 mins.

Experimental Plan. Plants were irrigated with two saline water treatments (2 and 4 dSm^{-1}) and one control treatment (half-strength Hoagland solution). Three irrigation water treatments were factorial combined with the three levels of nitrogen fertilization and arranged in a completely randomized design with three replications. Saline water stock solution was added to the control treatment to raise the irrigation water salinity up to desired levels of EC = 2 and 4 dS m^{-1}, and the saline water stock solution was prepared by using NaCl, Na_2SO_4, $CaCl_2$,and $MgSO_4$ in molar proportion of 0.54, 0.33, 0.11, and 0.02 respectively. This composition is in line with the saline soil.Tomato crop was fertilized with three nitrogen rates; viz80, 100 and 120% of the recommendation for the pot experiment (100 mg Kg^{-1} soil) made by Novais et al. 1991. Nitrogen was applied in the form of Urea in three equal splits, i.e. with the first irrigation after transplantation, at the start of flowering and at the start of fruiting.

Irrigation. Plants were irrigated weekly for the first 7 weeks and every 4th day for the remaining growing season depending on the crop Water Use (ET_a). $Et_a$was measured gravimetrically by weighing the pot according to the method of FAO irrigation and drainage paper No. 56 and the required ET_awater plus extra water for leaching requirement (LR) was added to the pots. The leaching requirement was calculated by the equation developed by as a guideline for calculating LR based on irrigation water salinity and crop salt tolerance.

TABLE 1
Summary of experimental treatments

Treatments	Nitrogen Levels		
	80% N	100% N	120% N
Control	S1N1	S1N2	S1N3
2 dS m^{-1}	S2N1	S2N2	S2N3
4 dS m^{-1}	S3N1	S3N2	S3N3

TABLE 2
Chemical composition of different irrigation waters

Chemical composition of Irrigation Waters				
		Control	2 dS m^{-1}	4 dS m^{-1}
Sodium (Na^+)	(ppm)	1.79	295.12	711.80
Calcium (Ca^{++})	(ppm)	32.74	59.96	95.71
potassium (K^+)	(ppm)	28.32	26.80	21.63
Magnesium (Mg^{++})	(ppm)	7.74	8.77	10.38
Phosphorous (P^-)	(ppm)	2.98	2.46	1.68
Chloride (Cl^-)	(ppm)	2.58	364.12	978.47
Nitrate (NO_3^-)	(ppm)	230.03	167.18	113.63
Sulfate ($S0_4^=$)	(ppm)	35.78	459.44	1173.83

$$LR = \frac{EC_{iw}}{5EC_e - EC_{iw}} \quad (1)$$

Data Collection Plant height and the leaf area were measured three times during the mid-growing season before fruiting. Shoot fresh and dry biomass was determined at the end of the experiment when fruits were harvested. Total fruit yield per plant (g), the total number of fruits per plant and average fruit weight (g) were determined. The homogenized fruit's juice was subjected to the total soluble solids (TSS, expressed as °Brix at 20 °C) determination using a portable refract meter and the treatable acidity determination by titration against NaOH using phenolphthalein as indicator according to the method described in AOAC.

Statistical analysis Statistical analysis of the data (ANOVA) was conducted and differences between the means were compared for significance using a Revised Least Significant Difference (LSD) test at 0.05 levels.

RESULTS

Soil salinity is one of the most important abiotic factors controlling crop yields in the arid and semi-arid irrigated areas. Plant growth was significantly affected when the salinity concentration was increased from lower to higher with and without nitrogen application. Higher yields were recorded in the treatments with lower irrigation water salinity as compared to higher irrigation water salinity.

Nitrogen application improved tomato growth and yield parameters while this increment was not significantly different. Fruit firmness was the only parameter that was significantly differed with the different levels of nitrogen application. The effect of nitrogen along with the saline water irrigation showed the prominent effects on tomato plant growth and yield. Data obtained on the total soluble solids (TSS) of tomato fruit as influenced by various levels of salinity and nitrogen showed that the effects of salinity, nitrogen, and their interactions were highly significant ($P < 0.01$). For the salinity effect (Table 1.6), it is clear that all three levels of salinity differed significantly from one another. Total soluble solids of tomato fruits were increased linearly as the salinity level increased ($p < 0.01$). Our observations about the effect of salinity levels on the total soluble solids agreed with the findings by [20] Ahmed et al. (2017) who reported that the total soluble solids increased linearly with salinity levels of irrigation water. Likewise, our results were similar to the findings obtained by [21-, 23]. It is obvious from our work that the salinity levels of irrigation water reduced the fruit water content which in turn increased the total soluble solids of tomato fruit. [24] Reported a positive relationship between the fruit soluble solids and irrigation water salinity and observed the increase in tomato fruit total soluble solid under the saline water irrigation (5.5 dS m^{-1}) treatment in their study. Our observations about the effect of salinity levels on the total soluble solids agreed with the findings by [25] who reported that the total soluble solids increased linearly with salinity levels of irrigation water.

Effect of treatments on tomato growth parameters According to the data recorded regarding the tomato plant fresh and dry biomass, plant height and growth parameter were significantly altered among the salinity and nitrogen applications levels (Tab.1 and tab. 2). It can be explained that salinity might have decreased the photosynthetic activities and prepared insufficient food for plant growth and fruit enlargement. According to the present study, results suggested that the stress caused by the excess of ions might reduce CO_2 assimilation, stomatal conductance, transpiration and photosynthesis which consequently tend to hamper plant development. Mostly Plant growth is affected by the soil salinities due to a reduction in the osmotic potential of the soil solution, along with the possibility of the occurrence of ionic toxicity and/or nutritional imbalance due to unnecessarily higher accumulation of certain ions in plant tissues. [26] found that the values of the fresh seedling weight of the three different tomato cultivars were generally lowered with the increasing salinization comparing with the control. [27]) reported that the plant height decreased with increasing irrigation water salinity and this decrease became more significant when irrigation water of electrical conductivity equal or higher to 3.5 dS m^{-1} was used. The findings of [28] support the present results as they reported that the plants irrigated with fresh-water produced longer fruits than the plants irrigated with waters of higher irrigation water salinity. [29] reported an increment in different growth parameters of tomato plants with the increase in N fertilization, even under moderate salinity conditions while [30] found interaction in salinity and nitrogen fertilization only for the leaf area. On the other hand, [31] reported the significant effect of salinity and nitrogen level for different growth parameters while the interaction was significant only for the number of leaves and seedling fresh and dry weight.

By comparing the leaf areas in treatments of three salinity levels (Table 3), it was found that the leaf area of 2dSm^{-1}treatment (133.60 cm^2) was comparable with that of the control treatment (145.48 cm^2). However, the leaf area in the 4dS m^{-1}(89.99 cm^2) was significantly lower than that of the control (38.14 % decrease). [32] observed that the leaf area of cherry tomato decreased linearly with the increase in irrigation water salinity and reduction of 9.21% per unit increase in EC_{iw}. The excess of salts in the root zone might have negative effects on plant growth, because of the higher osmotic effect outside the roots and restriction in the water flow from the soil to the plants, which is necessary for survival and production under saline stress conditions [33]

Effect of treatments on fruit yield and quality. Our results about the total tomato fruit yield per plant showed that the effect of salinity levels on the total fruit yield per plant was highly significant ($P< 0.01$), while the effects of nitrogen levels and the salinity × nitrogen interaction on the total fruit yield of tomatoes per plant were found non-significant.

It can be seen that the total fruit yield of tomatoes per plant in various levels of salinity treatments differed significantly from one another (Table 4). The significantly highest total fruit yield of tomatoes per plant (2259.7 g per plant) was recorded in control treatment as against the total yield of 1988.1 and 1211.9 g per plant, respectively, in 2 and 4 dS m^{-1} irrigation water salinity treatments, which represent 12.1 and 46.36% reductions, compared with the control treatment. There was a significant and linear decrease in the total fruit yield of tomatoes per plant as the salinity level increased from control to 4 dS m^{-1}.

Our results regarding the effects of salinity levels are in agreement with the work of other researchers who reported that salinity levels above 2 dS m^{-1} reduced the total fruit yield of tomato significantly. [34] also indicated that the tomato yields reduced when the plants were irrigated with a nutrient solution of EC 2.5 dS m^{-1} or higher, and they attributed the yield reduction to the decrease in average fruit weight and/or number of fruits.

Also [35] reported that total fruit yield of tomato reduced by 11% upon each unit increase in the salinity of the irrigation water. Reduction in total fruit yield (49.7%) of tomato has also been observed at higher salinity levels (12 dS m^{-1}) in comparison with the control (1.2 dS m^{-1}), while a moderate salinity level (2.4 dS m^{-1}) of irrigation water had no significant effect in this regard [36]. According to [37] increasing EC of irrigation water from 1.5 to 3.2 dS m^{-1} reduced about 45% tomato yield. Also [38] reported yield reduction in plants irrigated with water of 3.6 dS m^{-1} as compared with that of irrigated with

TABLE 3
Effect of irrigation water salinity and nitrogen fertilization on tomato growth parameters.

Treatments		Shoot length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Leaf area index
Control	80% Nitrogen	41.67	848.72	113.07	143.92
	100% Nitrogen	42.50	897.07	114.54	141.45
	120% Nitrogen	43.00	921.30	118.10	151.06
	Mean	42.39a	889.03a	115.24a	145.48a
EC 2 dS m^{-1}	80% Nitrogen	41.00	816.89	105.58	134.13
	100% Nitrogen	41.33	840.44	109.36	129.33
	120% Nitrogen	41.67	906.18	112.69	137.34
	Mean	41.22a(-2.76%)	854.50a(-3.88%)	109.21a(-5.23%)	133.60a(-8.17%)
EC 4 dS m^{-1}	80% Nitrogen	37.33	419.72	61.19	91.59
	100% Nitrogen	38.17	508.00	71.55	89.58
	120% Nitrogen	39.17	527.82	77.44	88.79
	Mean	17.19b (-59.44%)	485.18b (-45.43%)	70.06b (-39.21%)	89.99b (-38.14%)
Mean	80% Nitrogen	40.00	695.11ab	93.28a	123.21a
	100% Nitrogen	40.67	748.50a	98.48a	120.12a
	120% Nitrogen	41.28	695.11ab	102.74a	125.73a

Means followed by similar letter(s) in respective row or column do not differ significantly from one another.
Number in the parenthesis shows the percent increase or decrease.

TABLE 4
Effect of irrigation water salinity and nitrogen fertilization on tomato fruit yield and quality.

Treatments		Total fruit yield per plant (g)	Number of fruits per plant	Average fruit weight (g)	Fruit length (mm)	Fruit volume (cm^3)	Fruit water content (%)	Fruit firmness (pound force, lbf)	Fruit TSS (°Brix)
Control	80% Nitrogen	2122.49	77.67	27.42	50.16	38.79	93.02	1.01	5.81
	100% Nitrogen	2255.62	81.67	27.68	50.40	39.04	93.66	1.09	5.50
	120% Nitrogen	2400.89	84.00	28.84	50.56	39.24	93.72	1.12	5.34
	Mean	2259.70a	81.11a	27.98a	50.37a	39.02a	93.45a	1.07c	5.55c
EC 2 dS m^{-1}	80% Nitrogen	1920.98	65.67	29.97	50.47	39.14	92.67	1.07	6.15
	100% Nitrogen	1989.51	69.67	28.94	51.05	39.99	92.69	1.28	6.10
	120% Nitrogen	2053.84	74.33	27.81	52.61	41.29	92.74	1.33	6.10
	Mean	1988.10b (-12.01%)	69.89b (-13.83%)	28.90a (-3.65%)	51.38a	40.14a	92.70b (-0.81%)	1.23b (14.95%)	6.11b (10.09%)
EC 4 dS m^{-1}	80% Nitrogen	1115.70	58.00	20.12	40.74	30.43	92.11	1.22	6.97
	100% Nitrogen	1246.99	60.67	20.60	41.08	30.84	91.56	1.39	6.58
	120% Nitrogen	1273.02	62.67	20.73	42.14	31.43	91.24	1.62	7.02
	Mean	1211.90c (-46.36%)	60.44c (-25.48%)	20.49b (-26.77%)	47.12b (-6.45%)	30.90b (-20.81%)	91.64c (-1.94%)	1.41a (31.78%)	6.85 (23.42%)
Mean	80% Nitrogen	1719.70a	67.11a	25.84a	47.12a	36.12a	92.11a	1.10c	6.31a
	100% Nitrogen	1830.70a	70.67a	25.74a	47.51a	36.62a	91.56a	1.25b (13.63%)	6.06b
	120% Nitrogen	1909.20a	73.67a	25.80a	48.44a	37.32a	91.24a	1.36a (23.63%)	6.15b

Means followed by similar letter(s) in respective row or column do not differ significantly from one another.
Number in the parenthesis shows the percent increase or decrease.

water of 0.9 dS m^{-1}. [39] published their work reporting that the significantly highest total fruit yield was recorded in plants irrigated with fresh-water and significant yield reduction was observed in plants irrigated with saline water of EC = 4 dS m^{-1} and higher. [40] observed that the most sensitive plants may suffer physiological damages, with subsequent significant yield loss, while moderately sensitive to tolerant plants are still able to produce acceptable yields. [41] observed the 11.51% and 25.84% decrease in yield when irrigation water salinity was 6.3 and 9.1 dS m^{-1} as compared with fresh-water (EC = 0.38 dS m^{-1}). [42] also reported that that the tomato fruit yield per plant significantly reduced with the application of saline irrigation water of EC = 3.0 and 4.5 dS m^{-1} as compared to irrigation water of EC = 0.55 EC = 2 dS m^{-1}. Yield reduction has been attributed to reduced photosynthesis, high energy and carbohydrate expenditure in osmoregulation under salt stress conditions [43].

The results regarding the effect of nitrogen levels on the total fruit yield of tomatoes per plant (Table 4) showed that 80% of the recommended level of nitrogen seems better as there was no significant increase in yield at higher N application rates.

Comparing the salinity levels with one another (Table 4), it was observed that all the three EC levels differed significantly from one another as regards their effect on the number of fruits per plant. The control treatment was found with the significantly highest number of fruits per plant (81) and it decreased linearly as the salinity level was increased at a significant level of $p < 0.01$. The reduction in the number of fruits per plant was 13.83 and 25.48% at 2 and 4 dS m-1, respectively.

Though the results for nitrogen levels were non-significant, (Table 4), there was a little linear increase in the number of fruits per plant as N application rate increases from 80% of recommended nitrogen to 120% of recommended nitrogen. However, it can be visualized from these results that the application of 80% of the recommended level of nitrogen seems better under the greenhouse conditions.

Inconsistencies have been found in the literature regarding the number of fruits per plant as influenced by the salinity. [44] reported that moderate salinity had no effect on the number of fruits per plant and the yield reduction was entirely due to smaller fruit size. However, their results are inconsistent with the study of [45] who reported that the decline in number of fruits per plant was a result of increasing salinity. The reduction in number of fruits per plant in this study might be related to the reduced number of flower per truss and per plant in higher salinity treatments [46] who indicated that the number of tomato fruits/plant depended on the number of trusses/plant, and the number of flowers/truss and the number of trusses/plant decreased as irrigation water salinity, as well as salinization period increased.

Comparing the various levels of salinity with one another (Table 4), it can be visualized that all three levels of irrigation water salinity were significantly different from one another. The fruit firmness of tomato was significantly and linearly increased with the increase in the salinity level. The increase in fruit firmness over control was 14.95 and 31.78 %, respectively due to 2 and 4 dS m^{-1} treatments. As regards the effect of various levels of nitrogen on the fruit firmness (Table 4), it can be seen that all three levels of nitrogen were significantly different from one another. The fruit firmness was increased linearly as the nitrogen level was increased from 80 % to 120 % N. The interactions between salinity levels and nitrogen levels on the fruit firmness of tomato (Fig.1.1) showed that the highest level of nitrogen produced tomatoes with significantly greater fruit firmness at three levels of irrigation water salinity. Similarly, the significant results were observed for the fruit water content (93.45%) and the significantly lowest fruit water content of 91.64% were recorded in control treatment and irrigation water salinity of 4 dS m^{-1} treatment respectively. This decrease in fruit water content due to the use of saline water can be explained on the basis of making osmotic adjustments [47]. Soluble salts lower the osmotic potential of the soil water, thus lower leaf water potential is required to sustain transpiration [48]. In other words, plants spend more energy on the uptake of water.

Looking at the various levels of salinity on the fruit volume of tomato (Table 4), it can be visualized that the 2 dS m^{-1} (40.14) was at par with control treatment (39.02) and both of these treatments were significantly different from 4 dS m^{-1} (30.92). The reduction in fruit volume at 4 dS m^{-1} was 20.81 % over the control treatment. This reduction might
be due to the adverse effect of salinity on the number of leaves per plant and disruption of chloroplasts resulting in reduced photosynthetic activity of tomato plants and synthesis of food. High salinity stress causes the stress on plant growth and productivity due to the effective increment in the osmotic stress, ion toxicity, and alterations in soil physical and chemical properties[49]), as well as triggering an imbalance of nutritional cations in plant tissues [50].

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