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SOIL AND CITRUS TREE NUTRITION ARE AFFECTED BY SALINIZED IRRIGATION WATER

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Abstract. **The widespread use of micro-irrigation systems has greatly increased interest in fertigation. When irrigation water quality is poor, fertigation can add to any existing salinity problems. The objectives of this study were to investigate the effects of saline irrigation water on root and leaf mineral concentrations and root density of 'Valencia' orange trees on Carrizo citrange and sour orange rootstocks. Irrigation water salinity levels were increased by using a 3:1 ratio of NaCl:$CaCl_2$ to achieve total dissolved salts (TDS) values of about 210, 1,200, and 1,800 ppm. Weekly applications of liquid fertilizer with an additional TDS of 490 ppm was applied using a low volume drip system. We evaluated root dry weight per soil volume and soil nutrient concentrations directly under drippers in the top 12 inch depth soil. Salinity treatments increased root density, soil TDS, Na, and Ca concentrations but decreased concentrations of soil Cl. Salinity increased concentration of Na in the fibrous roots and decreased the concentration of root Ca, Mg, K, and Cu. Trees on sour orange had high foliar K and Ca but lower Mg and Cl than trees on Carrizo citrange. Although there were no nutrient deficiencies, foliar K in trees on Carrizo citrange and Mg in trees on sour orange were reduced by high salinity. These studies underscore the importance of rootstock, soil organic matter, and Ca concentration in determining nutritional characteristics of soil and citrus trees irrigated with saline water.**

Irrigation of citrus with artesian well water containing high salt content is common in parts of east Florida and may result in salinity stress to citrus trees (Calvert and Reitz, 1965; Syvertsen et al., 1989). *Citrus* spp. are very sensitive to salinity relative to many crop species (Bernstein, 1969; Bielorai et al., 1988; Shalhevet et al., 1974). Visible symptoms of salinity stress in citrus include small leaves, small fruit, leaf chlorosis, and die-back of young twigs (Bernstein, 1969; Cooper and Gorton, 1952). Irrigation water salinity also influences the choice of irrigation methods. Drip-irrigation system is advantageous as compared to either sprinkler or furrow irrigation when using high-salinity water (Bernstein and Francois, 1973; Calvert and Reitz, 1965).

The use of micro-irrigation systems for citrus production (Smajstrla et al., 1987) is becoming increasingly widespread (Bester et al., 1977; Bredell and Barnard, 1977; Greef, 1975; Koo, 1980). When irrigation water quality is poor, fertigation can add to existing salinity problems (Syvertsen et al., 1989). Salts in the soil solution can reduce citrus root growth and affect mineral nutrient concentrations in roots and leaves (Syvertsen and Yelenosky, 1988).

Under conditions in Florida, no information is available on how root growth and mineral nutrition of roots interact with salinity. In this study, we examined the effects of rootstock and salinity level in the irrigation water on soil characteristics, fibrous root density, and mineral nutrient concentrations in roots and leaves.

Materials and Methods

The study was conducted in central Florida using Candler fine sand soil in drainage lysimeter tanks, 11 ft in diameter and 3 ft deep. Four-inch diameter perforated plastic pipe was placed at the bottom of each tank to collect the leachate which was pumped out as it accumulated using a sump pump. At the time the thanks were installed, a sod grass cover was removed and the soil was back-filled to create a uniformly mixed profile, similar to the native sand which does not have a well-defined soil structure. Six-year-old 'Valencia' orange [*Citrus sinensis* (L.) Osbeck] trees on Carrizo citrange [*Poncirus trifoliata* (L.) Raf. x *C. sinensis*] rootstock or on sour orange (*Citrus aurantium* L.) rootstock were transplanted into each of 18 tanks using a tree spade in June 1988. Six additional trees (3 on each rootstock) were transplanted into adjacent undisturbed soil outside the lysimeter field which is referred to as no tank tree in this paper. The grass cover on this undisturbed soil had been herbicided and allowed to decompose *in situ*. All soil surfaces were maintained weed free with herbicide and trees were sprayed for pests as required.

All trees were irrigated as needed to avoid drought stress using 9 drippers per tree arranged evenly spaced in a ring around each tree below its canopy. The N, P, K, and Mg were supplied at the recommended annual rate (Koo et al., 1984) of about 0.71, 0.09, 0.40, and 0.02 lb per tree, respectively, as a liquid (6-2-6-0.5%, respectively, plus micronutrients) through the irrigation system in 50 (weekly) applications per year. The addition of nutrient solution to irrigation water contributed total dissolved salts (TDS) of 490 ppm. Three salinity treatments having TDS levels of about 210 (no salt added), 1,200, or 1,800 ppm, using a 3:1 ratio of NaCl and $CaCl_2$, were begun in June 1989 using 3 replicate trees each. Trees in the undisturbed soils outside lysimeters received the non-salinized irrigation water plus weekly fertigations. The experiment was conducted using completely randomized block design with

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3 single tree replications. Mean annual rainfall in the area is about 52 inches. Rainfall leached the lysimeter tanks periodically, especially in the summer.

Soil, root, and leaf sampling and analysis. Soil was sampled in May 1990 (when trees were 8 yr old) after salinity treatments had been in place for 11 months. Under each tree, 4 soil core (1 inch diameter) samples were taken at the 0 to 12 inch depth under 4 diagonally-opposite drippers in relation to trunk of the tree. The sampling locations under the drippers were about 3 ft from the tree trunk. The 4 replicate samples were bulked for analysis. Roots were separated by dry sieving, oven-dried at 140°F for 48 hr, and their dry weights recorded.

The soil samples were air-dried and soil pH was measured in 1:1 (w/v) soil:water suspensions. Extractable cations and P in the soil were measured using 1 M NH_4OAc at pH of 7.0 (Thomas, 1982). The concentrations of each element were measured by inductively coupled plasma emission spectroscopy (ICPES). Electrical conductivity of the saturation extract, and water-extractable NH_4-N, NO_3-N, and Cl, were measured following standard procedures described by Hanlon and DeVore (1989). Total soil N was predominantly NO_3-N (>90% of total N) so NH_4-N and NO_3-N were combined and discussed as total soil N. Soil organic matter was determined using a Walkley-Black method (Walkley and Black, 1934).

In July 1990, twenty 4-month-old leaves were sampled randomly from each tree canopy, surface-washed, dried at 140°F for 48 hr, ground, and bulked for analysis of nitrogen (Kjeldahl) and chloride (Buchler-Cotlove chloridometer). One-hundred milligrams of oven-dried ground leaf or root sample were ashed in a muffle furnace for 5 hr at 932°F. The ash was cooled and 10 mL of 1.0 M HCl was added. The concentrations of P, K, Na, Ca, and Mg in leaf samples and those of P, Ca, Mg, K, Na, Cu, Mn, Fe, and Zn in root samples were determined using ICPES. The data were subjected to analysis of variance, and mean separation between the salinity treatments was performed by Duncan's multiple range test.

Results and Discussion

Soil characteristics. Overall, organic matter averaged less than 0.8% but was much greater in the no tank soil than in the tank soil (Table 1). This was in part due to the lack of disturbance and in part due to the previous grass cover, which had not been removed from the no tank soil surfaces but herbicided 2 yr before. Soil pH was greater in the tank soil than that in the no tank soil. The highest salinity treatment significantly increased TDS in soil solution.

The concentration of Na was 18.4 lb/acre at the low salinity treatment in both the no tank and tank soils (Table 1). The Na concentration increased to 50.6 and 69.0 lb/acre with an increase in salinity treatments to 1,200 and 1,800 ppm, respectively. The concentration of Ca was increased by the salinity treatments but soil Ca level was much greater in the no tank soil than that in the tank soil. This could be due to dilution of surface Ca levels by soil mixing during back-filling of the tanks (Alva and Syvertsen, 1991).

Soil Cl concentrations decreased with an increase in salinity levels in spite of the added Cl. These soil samples were taken directly under the dripper. Since chloride is a very mobile element, much of the Cl applied in irrigation water was apparently transported away from the dripper (Alva and Syvertsen, 1991) or leached below 12 inches. No significant correlation was found between Cl and Na or Ca contents of the soil in spite of the fact that all 3 ions were added in the salinity treatments.

Soil N concentrations were not affected by the salinity treatments but, within the low salinity treatment, soil N was significantly greater in the no tank soil than that in the tank soil (Table 1). This decrease in N concentration in the tank soil would appear to be related to removal of organic matter with the sod cover during back-filling the tanks. Tank soils with lower organic matter would likely retain less N than no tank soils. In addition, tank trees tended to have higher root densities (Table 2) and may have had higher rates of nutrient extraction than no tank trees. Soil P concentrations showed slight but non-significant increase with increasing salinity levels.

Salinity treatments had no effect on the concentration of K in the soil, but Mg tended to decrease with increasing salinity level (Table 1). A strong negative correlation ($r = -0.575^{**}$) was found between the concentrations of Mg and Na. This reduction in Mg concentration was likely due to the addition of Na and Ca in conjunction with the salinity treatment. The addition of Ca as gypsum ($CaSO_4$) has been shown to decrease Mg concentration in topsoil, primarily due to displacement of Mg from the soil exchange complex (O'Brien and Sumner, 1988; Sumner et

Table 1. Effects of irrigation water salinity on soil organic matter, total dissolved solids (TDS), and composition of various mineral elements in 0 to 12 inch depth of soil either in lysimeter tanks or outside (no tank).

Soil treatment	Salinity levels TDS	Soil organic matter	Soil pH	TDS	Na	Ca
	(ppm)	(%)		(ppm)	lb/acre	
No tank	210	0.73 a[z]	5.78 b	70 b	18.4 c	525.0 a
Tank	210	0.23 b	5.93 a	77 b	18.4 c	276.6 c
Tank	1200	0.27 b	5.96 a	84 b	50.6 b	332.6 b
Tank	1800	0.32 b	6.04 a	105 a	69.0 a	346.8 b
		Cl	N	P	K	Mg
		lb/acre				
No Tank	210	28.2 a	3.0 a	24.8 a	23.4 a	56.0 a
Tank	210	21.2 a	1.8 b	24.8 a	7.8 b	29.2 b
Tank	1200	14.2 b	1.6 b	31.0 a	7.8 b	19.4 c
Tank	1800	14.2 b	1.9 b	31.0 a	7.8 b	14.6 c

[z]Means followed by similar letters within each column are not significantly different according to Duncan's multiple range test at P = 0.05.

Table 2. Effects of irrigation water salinity on root density in the 0 to 12 inch depth of 8-yr-old 'Valencia' orange trees on 2 rootstocks, sour orange and Carrizo citrange.

Soil treatment	Salinity levels TDS (ppm)	Root density (mg/cc)	
		Sour orange	Carrizo citrange
No tank	210	1.24 b[z]	1.14 b
Tank	210	1.85 a	1.12 b
Tank	1200	1.40 b	1.26 b
Tank	1800	1.92 a	2.39 a

[z]Means followed by similar letters within each column are not significantly different according to Duncan's multiple range test at P = 0.05.

al., 1986; Syed, 1987). The concentrations of Mg and K were greater in the no tank soil than in the tank soil. Since the concentrations of these elements were much greater in the topsoil than in the soil below (Alva and Syvertsen, 1991), this again may have been due to differences in the previous surface organic matter levels and in the mixing of profile samples during refilling of the lysimeter tanks.

Root density and mineral composition. The root density in soil was calculated on the basis of air-dry weight of the soil and the oven dry weight of roots per core (soil bulk density = 1.5 g/cm^3). Root density of sour orange in the top 12 inch depth soil was greater than that of Carrizo citrange rootstock except in the highest salinity treatment (Table 2). At the lowest salinity treatment, root density of sour orange was significantly greater in the tank soil than that in the no tank soil. An increase in salinity from 210 to 1,800 ppm in the tank soil had no significant effects on root density of sour orange. In the case of Carrizo citrange rootstock, root density was significantly greater at high salinity treatment than at the lower salinity treatments. Thus, root growth can be enhanced by salinity stress and may be reflected in an increase of root:shoot ratio (Wilson, 1988).

The concentration of Ca in the roots decreased whereas Na increased at the 2 high salinity treatments (Table 3). Since salinity treatments comprised both $CaCl_2$, and NaCl at a ratio of 1:3, the supply of Ca also increased with increasing salinity treatments. It appears, however, that a large excess of Na in the root environment may have effectively decreased the Ca uptake by roots despite a significant increase in soil Ca from high salinity treatments. The concentrations of K and Mg in the roots also decreased with an increase in salinity levels but, salinity had no effect on the concentration of P in the roots. In general, micronutrient contents of the roots were much greater in trees grown in the no tank soil than that in the tank soil. Since soil organic matter is an important component in complexing micronutrients, such patterns could have been due to the effect of profile mixing during back-filling the lysimeter tanks. In the no tank soil where the soil profile was not disturbed, organic matter remained in the top 6 to 12 inches of soil. During back-filling the lysimeter tanks, the profile was uniformly mixed to a meter in depth. Therefore, organic matter in the top 12 inch soil in samples from the tank soil was lower than that in the no tank soil (Table 1). As a result, it appears that the availability of micronutrients in the top 12 inch soil was lower in the tank soil than that in the no tank soil.

Leaf nutrition. Concentrations of both macronutrients (Table 4) and micronutrients (data not shown) in leaves of trees on both rootstocks revealed neither excesses nor deficiencies relative to standards for citrus (Koo et al., 1984). In contrast to salinity effects on root Ca, leaf Ca was relatively high and was further elevated by the added Ca salinity in trees on Carrizo citrange. Leaf K and Mg of trees on Carrizo citrange and Mg of trees on sour orange were reduced by high salinity, reflecting the low concentrations of K and Mg in soil (Table 1) and roots (Table 3) in the lysimeter tanks. Since leaf Mg concentration was strongly related to soil Mg levels (R^2 = 0.522**), Mg may be an important consideration when dealing with saline irrigation water. Francois and Clark's (1980) study did not show any effects of salinity treatments on leaf Mg levels since they used $MgSO_4$, along with $CaCl_2$ and Na_2SO_4 to attain desired salinity levels.

High Na in the irrigation water and roots reduced root K and leaf K of trees on Carrizo citrange (Syvertsen et al., 1988). There was no evidence, however, that leaf Na levels (Table 4) responded to high Na levels in soil (Table 1) and roots (Table 3) with the application of saline irrigation water. The relatively high concurrent leaf and soil Ca levels may have been a factor, as there were no visible Na-toxicity symptoms. The beneficial effects of increased Ca levels in minimizing injury due to high salinity are well-known (Chapman, 1968) and have been confirmed by Zekri and Parsons (1990). Salinization did result in Cl accumulation to toxic levels (0.2%) in leaves of trees on Carrizo but not on sour orange.

These studies underscore the importance of soil organic matter and Ca concentration in determining nutritional characteristics of soil irrigated with salinized water. Citrus rootstocks not only influence root density but also leaf nutritional responses to salinity stress.

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Table 3. Nutrient concentrations of citrus fibrous roots (sampled from 12 inch depth) as influenced by salinity treatments. All concentrations are means across 2 rootstocks, sour orange and Carrizo citrange, and 3 replicate trees (n = 6).

Soil treatment	Salinity levels TDS (ppm)	P	Ca	Mg	K	Na	Cu	Mn	Fe	Zn
		percent on dry weight basis					ppm			
No tank	210	0.19 a[z]	2.10 a	0.58 a	0.74 a	0.24 c	135 a	573 a	601 a	920 a
Tank	210	0.19 a	2.05 a	0.49 a	0.69 a	0.27 c	74 b	255 b	465 b	243 b
Tank	1200	0.17 a	1.79 b	0.20 b	0.55 b	0.71 b	33 c	296 b	488 ab	129 b
Tank	1800	0.15 a	1.72 b	0.20 b	0.46 b	1.08 a	33 c	290 b	552 ab	293 b

[z]Means followed by similar letters within each column are not significantly different according to Duncan's multiple range test at P = 0.05.

Table 4. Effects of irrigation water salinity levels on concentrations of cations and P and Cl in 4-month-old 'Valencia' orange leaves of trees on sour orange or Carrizo citrange rootstocks (Alva and Syvertsen, 1991).

Soil treatment	Salinity levels TDS (ppm)	N	P	K	Na	Cl	Ca	Mg
		percent on dry weight basis						
					Sour orange			
No tank	210	3.0	0.15	1.2	0.12	0.11	4.3	0.41 a
Tank	210	2.8	0.16	1.3	0.09	0.10	4.0	0.37 a
Tank	1200	2.8	0.16	1.4	0.12	0.08	4.9	0.28 b
Tank	1800	2.8	0.17	1.4	0.09	0.10	5.1	0.26 b
	Mean	2.8	0.16	1.3 A[y]	0.10	0.10 B	4.6 A	0.33 B
					Carrizo citrange			
No tank	210	2.9	0.16 a[z]	1.3 a	0.06	0.08 b	3.6 b	0.56 a
Tank	210	2.8	0.16 a	1.1 ab	0.12	0.12 b	3.9 ab	0.48 ab
Tank	1200	2.8	0.18 b	1.0 ab	0.12	0.88 a	4.4 ab	0.46 b
Tank	1800	2.6	0.16 a	0.8 b	0.08	1.08 a	4.9 a	0.43 b
	Mean	2.8	0.17	1.1 B	0.10	0.54 A	4.2 B	0.48 A

[z]Elemental values within a rootstock followed by unlike letters (lower case) differ significantly ($P < 0.05$).
[y]Rootstock means followed by unlike letters (upper case) differ significantly ($P < 0.05$).

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