Salinity Effects on Florida Grapefruit in the Indian River Region

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ADDITIONAL INDEX WORDS. *Citrus paradisi*, fruit size, irrigation, juice quality, yield

SUMMARY. A study was initiated in the 1997–98 production season to evaluate the effects of salinity on grapefruit yield and fruit quality in the Indian River area of Florida. The experiment was conducted on ‘Ray Ruby’ grapefruit (*Citrus paradisi*) planted in 1990 on ‘Carrizo’ citrange (*C. sinensis* × *Poncirus trifoliata*) and ‘Swingle’ citrumelo (*C. paradisi* × *P. trifoliata*) rootstocks. Trees were planted on 15.2-m-wide (50 ft) double-row beds at a spacing of 4.6 m (15 ft) in-row × 7.3 m (24 ft) across-row [286.6 trees/ha (116 trees/acre)]. The control treatment was irrigated via micro-sprinkler emitters with water from a surficial aquifer well with an electrical conductivity (EC) of 0.7 dS·m⁻¹. Higher irrigation water salinity levels were achieved by injecting a sea water brine mixture into the supply water to achieve ECs of 2.3, 3.9, and 5.5 dS·m⁻¹. A wide range of rainfall and irrigation conditions occurred during the years encompassed by these studies, with rain totaling 1262, 1294, 1462, and 964 mm (49.7, 50.9, 57.6, and 38.0 inches) for 1997, 1998, 1999, and 2000, respectively. Salinity level had little effect on internal juice quality parameters [total soluble solids (TSS), acid, or juice content] at time of harvest. One of the most visible effects of irrigation with high salinity water was the damage to leaves, with leaf chloride (Cl) levels increasing about 0.14% for each 1.0 dS·m⁻¹ increase in EC of the irrigation water for trees on ‘Carrizo’ citrange and 0.02% for trees on ‘Swingle’ citrumelo. For both rootstocks, the

number of fruit and the size of the fruit decreased with increasing salinity in the irrigation water. The non-salinized trees had significantly larger fruit compared to the rest of the treatments. In the very dry 2000–01 season, trees on ‘Carrizo’ irrigated with 0.7 dS·m⁻¹ water had about 50% more fruit size 36 [fruit count per 0.028-m³ (4/5 bu) carton] or larger than trees watered with 3.9 or 5.5 dS·m⁻¹ water. For trees on ‘Swingle’ rootstock, trees irrigated with 0.7 dS·m⁻¹ water had 150% to 200% more size 36 and larger fruit than trees watered with 2.3 dS·m⁻¹ water. Over the four seasons, average yields for ‘Carrizo’ were reduced 3200.0 kg·ha⁻¹ (2855 lb/acre) per year for each 1.0 dS·m⁻¹ increase in EC of the irrigation water. For ‘Swingle’ rootstock, the reduction was 2600.3 kg·ha⁻¹ (2320 lb/acre) per year for each 1.0 dS·m⁻¹ increase in EC of the irrigation water. These reductions averaged 7% (‘Swingle’) and 6% (‘Carrizo’) for each 1.0 dS·m⁻¹ increase in salinity of the irrigation water.

Citrus is classified as a salt-sensitive crop because growth and yield reductions can occur at relatively low salinity levels (Bernstein, 1969; Bielorai et al., 1978; Maas, 1993; Walker et al., 1983; Zekri and Parsons, 1989). However, citrus trees can withstand relatively moderate salinity levels depending on the climate, scion cultivar, rootstock, and irrigation-fertilizer management. In addition, many of the common citrus rootstocks differ in their tolerance to salinity (Bernstein, 1969; Cooper and Groton, 1952; Wutscher, 1979). Field studies in Texas (Chapman, 1968; Cooper, 1961) and California (Newcomb, 1978) tested salinity tolerance of rootstocks according to their ability to exclude Cl from leaves. In general, the decreasing order of salinity tolerance has been found to be: Cleopatra mandarin (*Citrus reshni*) > sour orange (*C. aurantium*) > sweet orange (*C. sinensis*) = ‘Swingle’ citrumelo > rough lemon (*C. limon*) > trifoliolate orange (*Poncirus trifoliata*). Details of citrus response to salinity and management of salinity in commercial citrus production are described in other papers from this workshop proceedings (Boman et al, 2005; Raveh, 2005; Syvertsen and Levy, 2005).

As early as 1900, damage to citrus trees on Florida’s east coast was at-

tributed to the high mineral content of artesian well water (Robinson, 1900). Wander and Reitz (1951) analyzed water samples from 160 east coast Flatwoods irrigation wells and found that most of them had high salinity levels, with an average of 2054 mg·L⁻¹ (ppm) of total dissolved solids (TDS). Summer rains in Florida quickly reduce soil salinity by leaching accumulated salts from the tree’s root zone. This annual natural flushing of accumulated salts by rainfall allows the use of much higher salinity levels on citrus in Florida than in arid areas. However, field studies of citrus salinity tolerance generally come from arid areas, making it difficult to extrapolate their findings to the subtropical conditions of Florida’s citrus belt. Actual salinity threshold values pertaining to growth and yield have not been established for Florida conditions.

Syvertsen et al. (1988) reported that citrus groves on well-drained soils in central Florida did not suffer significant salt damage even when irrigated with 4.6 dS·m⁻¹ water because periodic rainfall was adequate to leach salts below the root zone. The objective of this study was to assess the long-term impact of salinity on yield and total soluble solids (TSS) production for citrus grown on bedded groves of poorly drained soil in the Indian River citrus region of Florida.

Materials and methods

A field study using salinized irrigation water was conducted in a ‘Ray Ruby’ grapefruit block at the Indian River Research Education Center (IRREC) located near Fort Pierce, Fla. Trees were planted in 1990 on 15.2-m-wide double-row beds, with a tree spacing of 4.6 m in-row × 7.3 m across-row resulting in a tree density of 286.6 trees/ha. Nearly all commercial citrus plantings in Florida coastal areas are planted on raised beds in order to expedite drainage following high-intensity rainstorms and to provide additional elevation above the shallow water tables that are prevalent in the area. The beds in this experiment were constructed in an Oldsmar fine sand soil (sandy, siliceous, hyperthermic, Alfic Arenic Haplaquods). The soil was characterized by a surface 10.2-cm (4 inches) dark gray sand A horizon overlying a light gray sand E horizon that turned to white at a depth of 45.7–61.0 cm (18–24 inches). A spodic (black

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Florida Agricultural Experiment Station Journal Series No. R-10231. This project was supported in part by grants from the Florida Citrus Production Research Advisory Council (FCPRAC) and the St. Johns River Water Management District.

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organic) B horizon about 10.2–15.2 cm (4–6 inches) thick was located at a depth of 76.2–91.4 cm (30–36 inches) below the surface. The subsoil below the spodic layer was a slowly permeable clay. During the bedding operation, a grader was used to cut drainage swales (water furrows) on 15.2-m centers to a depth of about 81.3 cm (32 inches). The soil excavated was brought up to the bed tops to increase the tree row elevation 10.2–15.2 cm (4–6 inches) above the natural ground level.

Trees used in the study were budded on ‘Carrizo’ citrange and ‘Swingle’ citrumelo rootstocks. Each plot contained four trees on each rootstock, with four replications of each water salinity and rootstock combination arranged in a randomized block experimental design. Irrigation with salinized water began about 2 months after planting. Additional details on the planting can be found in Boman (1993).

All trees were irrigated with microsprinkler emitters on stake assemblies with discharge rates of 38.61 L·h⁻¹ (10.2 gal/h) and 360° wetting patterns about 4.6 m in diameter. The control treatment was irrigated with water from a surficial aquifer well with an EC of about 0.7 dS·m⁻¹. Higher levels of irrigation water salinity were achieved by injecting a sea water brine mixture into the supply water. Each salinity treatment added an increment of about 1.6 dS·m⁻¹ above the base rate of the control treatment (2.3, 3.9, and 5.5 dS·m⁻¹). The brine mixture was applied during all irrigation events at a rate proportional to the flow rate through the lateral line.

Irrigation management was based on evapotranspiration (ET) calculated from a weather station located at the IRREC. When irrigations were required, they were applied at 2-d intervals, with the amount applied based on accumulated ET since the last irrigation (with allowances made for rainfall). Tensiometers in selected plots were used to monitor irrigation system performance throughout the season. During February through June, soil moisture tension was maintained at less than 15 kPa (cbar) in the wetted area, and 20 kPa or less during the rest of the year.

FERTILIZATION. Fertilizer applications to all plots were made at typical times and rates for the Indian River area. Application times were

typically in February, May/June, and October/November. Dry, granular materials were broadcast on bed tops with a bulk spreader. The spreader used a “turkey tail” to direct fertilizer into the tree rows and avoid application in the bed middles. The fertilizer blend was typically derived from ammonium nitrate, muriate of potash, and diammonium phosphate. Applications were made with a broadcast spreader to both sides of tree rows, at the following rates and times:

1997. Three applications (20 Feb., 16 June, 15 Oct.) with 2.27 kg/tree (5.0 lb/tree) of 8N–1.8P–6.6K material applied. A total of 156.9 kg·ha⁻¹ (140 lb/acre) of N was applied during the year.

1998. Applications in 1998 included 2.27 kg/tree of 8N–1.8P–6.6K applied on 9 Apr., 23 July, and 24 Nov. Total for the year was 156.9 kg·ha⁻¹ of N.

1999. In 1999, 2.27 kg/tree of 8N–1.8P–6.6K was applied on 24 Feb. and 4 June. In addition, 2.40 kg/tree (5.3 lb/tree) of 8N–1.8P–6.6K was applied on 4 Oct. The total annual N applied was 159.2 kg·ha⁻¹ (142 lb/acre).

2000. Fertilizer applications in 2000 were made on 3 Feb. with 2.59 kg/tree (5.7 lb/tree), 20 June with 2.40 kg/tree, and 17 Nov. at 2.50 kg/tree (5.5 lb/tree) of 8N–1.8P–6.6K material. The total annual N applied was 159.2 kg·ha⁻¹.

LEAF ANALYSIS. Spring flush leaves were sampled from non-fruiting terminals during July of each season. Leaves were washed, dried, and ground. Subsamples were then acid-digested for nitrogen analysis and additional subsamples were ashed for the analysis of other minerals. Solutions were prepared from the samples and they were analyzed for N, P, K, calcium (Ca), magnesium (Mg), and sodium (Na) by the University of Florida, Institute of Food and Agricultural Sciences Analytical Research Laboratory, Gainesville (1997–99), or Pioneer Labs, Ft. Pierce, Fla. (2000). Leaf Cl concentrations were determined at the IRREC with a chloridometer (Labconco model 4425000, Kansas City, Mo.).

JUICE ANALYSIS. The ‘Ray Ruby’ grapefruit plots were only sampled for juice analysis in Dec. 1999 and 2000. Fruit were randomly picked from positions all around the trees, with a total of 50 fruit per plot. The fruit were

analyzed at the Florida Department of Citrus Lab in Lake Alfred with standard methods for juice content, acid, and total soluble solids. TSS produced per tree was calculated by multiplying yield (kg/tree) by the percent TSS measured in the juice sample for each plot.

SIZE DISTRIBUTION AND YIELD. Trees were harvested individually during the commercial harvest in mid- to late-December of each year. At harvest, all of the fruit from each tree was picked and then volumetrically measured (1997 and 1999) or run through a portable sizing unit that used optical imaging (infrared) and load cells to measure the diameter and weight of each piece of fruit.

Commercially, fruit are sized at the packing house based on how many fit in a 0.028-m³ carton. Due to considerable overlap in the allowable diameters for adjacent fruit sizes specified by the USDA standards for Florida grapefruit, some fruit diameters may be classified in more than one size category. Therefore, the diameter vs. pack size data for grapefruit were used to develop a regression curve that was used to estimate yields from fruit number and fruit size. Most years, there is little demand for grapefruit smaller than size 48 (count per carton). The most common grapefruit sizes packed in Florida are 27, 32, 36, 40, and 48.

The value of a fresh fruit crop is determined by the number of fruit in each size category, the price of each size fruit, and the number of eliminations due to peel defects and misshapen fruit. In the 2000 season, the gross packed value (GPV) for each treatment was calculated by multiplying the number of fruit in each of the commercial size categories by the average free on board (FOB) price from the *Market News Bulletin* (Florida Citrus Mutual, 2002) published for the first date following harvest. The GPV assumes no grade-lowering defects, no eliminations, and no reductions that would typically be incurred by the grower for items such as pick and haul, drench, elimination charges, marketing, packing charges, taxes, or other charges incurred in fruit harvesting and packing operations. Nevertheless, the GPV can provide relative comparisons between treatments and give an economic indication of the relative potential to increase the producer’s net income.

STATISTICAL ANALYSIS. Leaf mineral concentrations, fruit size, yield,

TSS, and GPV data were statistically analyzed using SAS software (SAS Institute Inc., Cary, N.C.). The data were subjected to analysis of variance procedures with a randomized complete-block design experimental procedure. Means were separated using Duncan's multiple range test at $P \leq 0.05$.

Results and discussion

RAIN AND IRRIGATION. The study period encompassed years requiring little irrigation (1997 and 1998) and extended drought requiring very high irrigation applications (2000). Rainfall in the 1997 citrus season was adequate throughout most of the year (Table 1), with 1262 mm for the year. The rain was well distributed, resulting in only 57 h of irrigation applied, mainly in the period from late March to early May. There was no prolonged dry period requiring significant irrigation during the 1997 season.

In 1998, there was very high rainfall in February and March and about half the normal rainfall in June and July. Nearly 740 mm (29.1 inches) of rain fell from mid-August to November. Total irrigation for the season was 78 h, mainly occurring in April–June. Dry weather in Spring 1999 made considerable irrigation necessary from March to early May (212 h). Rains began in mid-May, and 270 mm (10.6 inches) of rain was recorded in June. July normally receives over 170 mm (6.7 inches) of rain, but only 27 mm (1.1 inch) fell in 1999, requiring summer irrigations. Hurricanes Floyd and Irene

in September and October resulted in several large rainfall events. Hurricane Irene, which crossed the state from southwest to northeast, passed over the area in mid-October. The winds were high enough to blow a small percentage of the fruit off the trees.

The 7-month period beginning in Nov. 1999 received only 180 mm (7.1 inches) of rain, compared to normal rainfall of 533 mm (21.0 inches). Rainfall for the 2000 season was 426 mm (16.8 inches) below the 50-year average for the area, and irrigations were required throughout the year. Over 700 h of irrigation were required, with applications on 3 or 4 d per week continuously for several weeks at a time.

Over the 4 years of the study, rainfall averaged 1245 mm (49.0 inches) and irrigation averaged 290 h per year. During 1997 and 1998, only 20% and 27% of the average irrigation hours were required, respectively. The 304 h of irrigation in 1999 was 6% above the 4-year average. During the extended drought in 2000, the 713 h of irrigation was about 2.5 times the 4-year average.

LEAF MINERAL CONCENTRATIONS. With the exception of Na and Cl, no differences were noted in leaf mineral concentrations among rootstocks or salinity levels. Leaf N, P, and K concentrations averaged 2.2%, 0.15%, and 1.09%, respectively, for the 5 years of the study. These values were slightly below the optimum recommended range for N (2.5% to 2.7%) and K (1.2% to 1.7%) and in the optimum range for

P (0.12% to 0.16%) as recommended by the University of Florida (Hanlon et al., 1995). There were also no trends in leaf Ca or Mg with respect to salinity level, with leaf Ca concentration averaging 3.6%. Leaf Mg concentration averaged 0.56% in 'Carrizo' trees, slightly higher than the 0.46% average for trees on 'Swingle'.

Both rootstocks demonstrated good ability to exclude Na, with highest levels less than 0.2% and average concentrations about 0.09% (Table 2). During 1997 and 1998, when few irrigations were required, there were only minor differences in leaf Cl among salinity levels (Table 2). Due to the high irrigation levels in 1999 and 2000, even the lowest salinity levels produced leaves on 'Carrizo' that had close to 1.0% Cl concentration.

Leaves from trees on 'Carrizo' accumulated nearly twice as much Cl as those on 'Swingle', even at lower levels of salinity in irrigation water. Trees on 'Carrizo' receiving elevated salinity levels had higher leaf Cl levels in 3 of the 4 years. In both the 1999 and 2000 seasons when significantly more irrigation was required than in the other years, leaf Cl concentrations for 'Carrizo' trees in the 5.5 dS·m⁻¹ treatment were almost double that of the non-salinized trees. Trees on 'Swingle' showed much less accumulation of Cl than found on 'Carrizo' trees. Leaf Cl accumulations were only significantly different among salinity treatments during one of the four seasons. In 2000, leaf Cl concentrations in 'Swingle' trees averaged 0.71% for

Table 1. Monthly irrigation [hours with 38.61-L·h⁻¹ (10.2 gal/h) emitters] and rainfall for 1997–2000 in grapefruit block and 50-year (1952–2002) average monthly and total rainfall at the Indian River Research and Education Center (IRREC), Ft. Pierce, Fla.

Month	1997		1998		1999		2000		IRREC avg for 1952–2000 (mm)
	Irrigation (h)	Rain (mm) ^z	Irrigation (h)	Rain (mm)	Irrigation (h)	Rain (mm)	Irrigation (h)	Rain (mm)	
January	2	76	0	0	0	25	36	46	54
February	5	35	0	114	16	37	25	33	69
March	10	31	0	124	60	14	68	68	83
April	17	188	20	63	112	89	80	60	64
May	18	54	18	61	40	132	88	21	120
June	9	170	30	80	0	270	32	161	177
July	0	170	6	87	32	27	48	149	171
August	0	287	0	299	0	253	64	91	175
September	0	95	0	178	0	252	68	97	196
October	5	54	0	45	0	293	64	160	156
November	0	86	0	220	20	41	80	6	74
December	0	16	4	23	24	29	60	72	52
Total	66	1262	78	1294	304	1462	713	964	1390

^z25.4 mm = 1.0 inch.

Table 2. Effect of irrigation salinity level and rootstock on mean leaf sodium (Na) and chloride (Cl) concentrations for 'Ray Ruby' grapefruit samples taken in July of each year.

Irrigation salinity (dS·m ⁻¹) ^a	Na concn [mg·kg ⁻¹ (ppm)]				Cl concn [mg·kg ⁻¹ (ppm)]			
	1997	1998	1999	2000	1997	1998	1999	2000
<i>'Carrizo' citrange</i>								
0.7	0.18	0.11	0.08 ab ^y	0.03 a	0.08 b	0.69	1.02 b	0.90 b
2.3	0.16	0.07	0.07 b	0.04 ab	0.11 ab	0.71	1.87 a	1.14 ab
3.9	0.15	0.08	0.09 ab	0.05 a	0.11 ab	0.75	1.57 ab	1.77 a
5.5	0.15	0.08	0.12 a	0.05 a	0.14 a	0.80	1.95 a	1.61 ab
<i>'Swingle' citrumelo</i>								
0.7	0.16 b	0.10 a	0.07	0.03	0.34	0.35	0.51	0.26 b
2.3	0.15 b	0.07 b	0.06	0.04	0.21	0.22	0.55	0.35 b
3.9	0.15 b	0.07 b	0.09	0.04	0.23	0.24	0.42	0.47 ab
5.5	0.17 a	0.08 ab	0.10	0.04	0.39	0.29	0.71	0.71 a

^a1.0 dS·m⁻¹ is approximately equal to 700 mg·L⁻¹ (ppm) for Florida waters.

^yMeans in the same column for the same rootstock followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

the 5.5 dS·m⁻¹ treatment, nearly three times that of the 0.7 dS·m⁻¹ treatment (0.26%).

When leaf Cl concentrations were averaged over the four seasons, there was a definite trend of increased Cl concentration with increasing salinity level for both rootstocks. Leaf Cl concentration in 'Carrizo' increased an average of 0.14% for each 1.0 dS·m⁻¹ increase in irrigation water salinity (Fig. 1). For 'Swingle', the increase in leaf Cl concentration was considerably less, averaging of 0.02% for each 1.0 dS·m⁻¹

increase in irrigation water salinity (Fig. 2). Elevated leaf Cl results in premature leaf drop (normally, leaves last about 2 years) and a requirement to divert tree resources to replace lost leaves.

FRUIT SIZE. In the 1998 season, when adequate rainfall negated the need for irrigations through much of the year, there was little difference in the size distribution of fruit among salinity treatments (Table 3). However, in the 2000 season, the number of larger fruit tended to decrease on both rootstocks as the salinity level increased

(Table 4). Trees on 'Carrizo' irrigated with 0.7 dS·m⁻¹ water had about 50% more size 36 and larger fruit during the 2000 season than trees watered with 3.9 or 5.5 dS·m⁻¹ water. The results were even more dramatic for 'Swingle' rootstock, as the trees irrigated with 0.7 dS·m⁻¹ water had 150% to 200% more size 36 and larger fruit than trees watered with 2.3 dS·m⁻¹ TDS or higher salinity. For both rootstocks, both the total number of fruit and the number of larger-sized fruit tended to decrease with increasing salinity in the irrigation water.

JUICE ANALYSIS. No differences in juice quality parameters were noted for fruit from 'Swingle' trees in either year when juice was analyzed. In 1999, the highest salinity rate produced higher TSS per box for fruit from 'Carrizo' trees (Table 5). In 2000, there were no differences in any of the juice parameters for either rootstock. The fruit sampled in 2000 from 'Carrizo' had slightly higher juice content (58% vs. 60%) and TSS:acid ratio (9.1 vs. 8.5) than 'Swingle', while fruit on 'Swingle' had a slightly higher acid content (1.13% vs. 1.05%). In both years, the TSS:acid ratio was slightly higher for fruit from 'Carrizo' trees as compared to 'Swingle'.

On a TSS per tree basis, the 5.5 dS·m⁻¹ treatment produced 30% to

Fig. 1. Mean leaf chloride (Cl) concentrations for 'Ray Ruby' grapefruit trees on 'Carrizo' citrange rootstock trees for the 1997 through 2000 seasons. Means followed by the same letter are not significantly different according to Duncan's multiple range ($P \leq 0.05$). Error bars represent 1 SD from the mean.

Fig. 2. Mean leaf chloride (Cl) concentrations for 'Ray Ruby' grapefruit trees on 'Swingle' citrumelo rootstock trees for the 1997 through 2000 seasons. Means followed by the same letter are not significantly different according to Duncan's multiple range ($P \leq 0.05$). Error bars represent 1 SD from the mean.

Table 3. Effect of irrigation salinity level and rootstock on size distribution (number of fruit in each size class) for 'Ray Ruby' grapefruit harvested Dec. 1998.

Irrigation salinity (dS·m ⁻¹) ^z	Fruit size [no. per 0.028-m ³ (4/5 bu) carton]			Total no. fruit	Mean fruit diam (mm)
	Smaller than 48 (<94 mm) ^y	48 and 40 (94–107 mm)	36 and 32 (107–118 mm)		
<i>‘Carrizo’ citrange</i>					
0.7	157	103	17 ab ^x	277	91
2.3	138	89	11 b	238	92
3.9	143	101	18 a	262	91
5.5	128	109	19 a	256	92
<i>‘Swingle’ citrumelo</i>					
0.7	224 a	126	13 b	363 a	90 b
2.3	150 b	112	16 ab	278 b	91 a
3.9	168 b	124	17 ab	309 b	91 a
5.5	144 b	120	21 a	287 b	92 a

^z1.0 dS·m⁻¹ is approximately equal to 700 mg·L⁻¹ (ppm) for Florida waters.

^y25.4 mm = 1.0 inch.

^xMeans in the same column for the same rootstock followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

Table 4. Effect of irrigation salinity level and rootstock on size distribution (number of fruit in each size class) for 'Ray Ruby' grapefruit harvested Dec. 2000.

Irrigation salinity (dS·m ⁻¹) ^z	Fruit size [no. per 0.028-m ³ (4/5 bu) carton]				Total no. fruit	Mean fruit diam (mm)
	Smaller than 48 (<94 mm) ^y	48 and 40 (94–107 mm)	36 and 32 (107–118 mm)	Larger than 32 (>118 mm)		
<i>‘Carrizo’ citrange</i>						
0.7	52	85	92 a ^x	39	268 a	101
2.3	84	67	70 ab	45	266 ab	101
3.9	83	84	54 b	32	253 b	99
5.5	60	60	51 b	35	206 b	102
<i>‘Swingle’ citrumelo</i>						
0.7	45 b	88	112 a	62 a	307	104 a
2.3	94 a	100	81 ab	28 b	303	98 b
3.9	66 ab	82	78 ab	40 b	266	101 ab
5.5	84 ab	90	63 b	25 b	262	99 b

^z1.0 dS·m⁻¹ is approximately equal to 700 mg·L⁻¹ (ppm) for Florida waters.

^y25.4 mm = 1.0 inch.

^xMeans in the same column for the same rootstock followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

Table 5. Effect of irrigation salinity level and rootstock on mean juice quality parameters for 50-fruit samples picked at random from each four-tree plot of 'Ray Ruby' grapefruit in Dec. 1999.

Irrigation salinity (dS·m ⁻¹) ^z	Avg wt (g)	Juice content (%)	Acid (%)	Total soluble solids (TSS) (%)	TSS:acid ratio	TSS per 40.8-kg (90 lb) box (kg) ^y
<i>'Carrizo' citrange</i>						
0.7	435 a ^x	58.2	1.02 b	9.2 b	9.1 a	2.1 b
2.3	390 ab	57.1	1.14 a	9.4 b	8.3 b	2.1 b
3.9	375 ab	56.0	1.06 ab	9.4 b	8.9 ab	2.1 b
5.5	359 b	58.4	1.09 ab	9.8 a	9.0 a	2.2 a
<i>'Swingle' citrumelo</i>						
0.7	383	59.0	1.32	9.6	7.7	2.2
2.3	367	58.9	1.17	9.7	8.4	2.2
3.9	354	60.4	1.17	10.0	8.6	2.3
5.5	351	57.1	1.15	9.9	8.5	2.2

^z1.0 dS·m⁻¹ is approximately equal to 700 mg·L⁻¹ (ppm) for Florida waters.

^y1.0 kg = 2.20 lb.

^xMeans in the same column for the same rootstock followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

35% less solids than the non-salinized treatment trees for both rootstocks (Table 6). The average decrease in TSS due to salinity was 179.3 kg·ha⁻¹ (160 lb/acre) for 'Swingle' to 213.0 kg·ha⁻¹ (190 lb/acre) 'Carrizo' per year for each 1.0 dS·m⁻¹ increase above the base of 0.7 dS·m⁻¹.

FRUIT YIELD. Yields were reduced by the highest salinity rate in all years for 'Carrizo' rootstock trees, and in 3 of 4 years for 'Swingle' rootstock trees (Table 7). Even in 1997 and 1998, when irrigations were minimal, yield was reduced with increased irrigation water salinity for the trees on 'Carrizo'. Increasing the irrigation water salinity from 0.7 to 5.5 dS·m⁻¹ reduced 'Carrizo' yields by 28% in 1997, 23% in 1998, 35% in 1999, and 41% in 2000.

There were no significant yield reductions with increased salinity for trees on 'Swingle' during the 1997 season. However, the 'Swingle' yields were reduced 27% in 1998, 16% in 1999, and 42% in 2000 when salinity increased from 0.7 to 5.5 dS·m⁻¹.

Over the four seasons, the relationships between cumulative yield and salinity levels were similar for both rootstocks. Total yield for the 0.7 dS·m⁻¹ salinity treatment averaged 616.9 kg/tree (1360 lb/tree) for the 'Carrizo' trees compared to 621.4 kg/tree (1370 lb/tree) for the 'Swingle' trees. Total 4-year total yields were reduced 42.2 kg/tree (93 lb/tree) for 'Swingle' and 36.3 kg/tree (80 lb/tree) for 'Carrizo' for each 1.0 dS·m⁻¹ increase in salinity (7% and 6%, respectively, for 'Swingle' and 'Carrizo'). This translates to yield reductions of 2600.3 kg·ha⁻¹ for 'Swingle' and 3200.0 kg·ha⁻¹ for 'Carrizo' for each 1.0 dS·m⁻¹ increase in salinity at the planting density of 286.6 trees/ha.

In the 2000 season, the FOB price for grapefruit during the second week of December (Fig. 3) ranged from \$5.23 per carton for small fruit (size 48) to \$8.94 per carton for size 27 (Florida Citrus Mutual, 2002). Due to the higher fruit count and larger-sized fruit, the GPV for non-salinized trees on both rootstocks was significantly

Table 6. Effect of irrigation salinity level and rootstock on total soluble solids (kg/tree)^z for 'Ray Ruby' grapefruit by season.

Irrigation salinity (dS·m ⁻¹) ^y	1999–2000	2000–01	Total
<i>'Carrizo' citrange</i>			
0.7	7.7 a ^x	11.3 a	19.1 a
2.3	7.1 ab	9.4 ab	16.5 ab
3.9	4.7 b	7.5 ab	12.2 b
5.5	5.4 ab	6.6 b	12.0 b
<i>'Swingle' citrumelo</i>			
0.7	7.2	12.0 a	19.2 a
2.3	8.0	7.9 ab	15.9 ab
3.9	6.7	7.1 b	13.9 b
5.5	6.1	7.1 b	13.2 b

^z1.0 kg/tree = 2.20 lb/tree.

^y1.0 dS·m⁻¹ is approximately equal to 700 mg·L⁻¹ (ppm) for Florida waters.

^xMeans in the same column for the same rootstock followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

higher than for other treatments. With a GPV of \$56/tree, fruit on 'Swingle' trees had about 20% more value than fruit from 'Carrizo' trees for the 0.7 dS·m⁻¹ treatment. The reduction in GPV ranged from \$2.80/tree (6%) for 'Carrizo' to \$4.70/tree (8%) for 'Swingle' for each 1.0 dS·m⁻¹ increase in salinity.

Salinity negatively affected returns by the combination of reduced fruit count and smaller fruit size. Even with good management practices, salinity can result in severe reductions in gross returns during dry years when substantial irrigation is required. In the 2000 season, the reduction in GPV was \$803.06/ha (\$325/acre) for 'Carrizo' and \$1349.15/ha (\$546/acre) for 'Swingle' for each 1.0 dS·m⁻¹ increase in salinity. Cultural practices that maintain good tree health and irrigation management practices that minimize accumulation of salts in the root zone are recommended to minimize the effects of salinity (Boman et al., 2005).

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Table 7. Effect of irrigation salinity level and rootstock on 'Ray Ruby' fruit yield (kg/tree)^z by season.

Irrigation salinity (dS·m ⁻¹) ^y	1997–98	1998–99	1999–2000	2000–01	Four-season total
<i>'Carrizo' citrange</i>					
0.7	135 a ^x	135 a	143 a	205 a	618 a
2.3	124 ab	116 ab	131 ab	170 ab	541 ab
3.9	97 b	112 ab	89 b	135 bc	433 b
5.5	97 b	104 b	93 b	120 c	414 b
<i>'Swingle' citrumelo</i>					
0.7	124	158 a	128 ab	213 a	623 a
2.3	124	135 b	139 a	139 b	537 ab
3.9	116	124 b	112 bc	124 b	476 b
5.5	100	116 b	108 c	124 b	448 b

^z1.0 kg/tree = 2.20 lb/tree.

^y1.0 dS·m⁻¹ is approximately equal to 700 mg·L⁻¹ (ppm) for Florida waters.

^xMeans in the same column for the same rootstock followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

Fig. 3. Mean gross packed value (GPV) for grapefruit harvested from trees on Carrizo citrange and Swingle citrumelo rootstocks in the 2000 season based on the free on board (FOB) prices for the second week of December (prices from Florida Citrus Mutual, 2002 are listed in the Carrizo citrange panel). Bars with the same letter for the same rootstock are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

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How Salinity Damages Citrus: Osmotic Effects and Specific Ion Toxicities

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ADDITIONAL INDEX WORDS. sodium, chloride, boron

SUMMARY. There are two ways salinity can damage citrus: direct injury due to specific ions, and osmotic effects. Specific ion toxicities are due to accumulation of sodium, chloride, and/or boron in the tissue to damaging levels. The damage is visible as foliar chlorosis and necrosis and, if severe enough, will affect orchard productivity. These ion accumulations occur in two ways. The first, more controllable and less frequent method, is direct foliar uptake. Avoiding irrigation methods that wet the foliage can easily eliminate this form of specific ion damage. The second way specific ion toxicity can occur is via root uptake. Certain varieties or rootstocks are better able to exclude the uptake and translocation of these potentially damaging ions to the shoot and are more tolerant of salinity. The effect of specific ions, singly and in combination, on plant nutrient status can also be considered a specific ion effect. The second way salinity damages citrus is osmotic effects. Osmotic effects are caused not by specific ions but by the total concentration of salt in the soil solution produced by the combination of soil salinity, irrigation water quality, and fertilization. Most plants have a threshold concentration value above which yields decline. The arid climates that produce high quality fresh citrus fruit are also the climates that exacerbate the salt concentration in soil solution that produces the osmotic effects. Osmotic effects can be slow, subtle, and often indistinguishable from water stress. With the exception of periodic leaching, it

is difficult to control osmotic effects and the cumulative effects on woody plants are not easily mitigated. This review summarizes recent research for both forms of salinity damage: specific ion toxicity and osmotic effects.

Salinity has been a problem since irrigated agriculture began thousands of years ago. It is most common in the arid and semiarid areas where evapotranspiration, the combination of evaporation from the soil with transpired water from plants, exceeds annual precipitation, making irrigation necessary. Salts occur naturally in soils, and they accumulate further as they are introduced in irrigation waters and fertilizers. The combination of the three in irrigated agriculture in arid zones, particularly if water is limited in quantity and quality, will eventually produce salinity problems. As most citrus is produced in arid climates, and since citrus and its commercial rootstocks are classified as salt sensitive, salinity damage is a problem in citrus production (Maas, 1993). This problem manifests in two forms: specific ion damage and osmotic effects.

Salinity tolerance of citrus

The general term “salinity” refers to the presence of the dissolved cations sodium, calcium, boron, magnesium and potassium, and the anions: chloride, sulfate, and carbonate in the soil solution in concentrations high enough to reduce crop growth.

The salinity tolerance of any crop is defined as the ability to endure the effects of excess salt in the root zone. The crop salt tolerance is best described by plotting its relative yield as a function of increasing soil salinity (Maas, 1990). This relationship between relative yield and soil salinity is described by the following equation:

$$Y = 100 - B(EC_e - A)$$

where Y is relative yield; A is the threshold value or the maximum soil salinity, in $dS \cdot m^{-1}$, at which 100% yield is still realized; B is the slope or percent reduction in yield per unit increase in soil salinity ($dS \cdot m^{-1}$); and EC_e is the average root zone salinity expressed as the electrical conductivity of the saturated soil paste, in $dS \cdot m^{-1}$. This formula describes the level of soil salinity where plant productivity begins to decline (A) and how rapidly it declines in productivity (B) as soil salinity in-

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