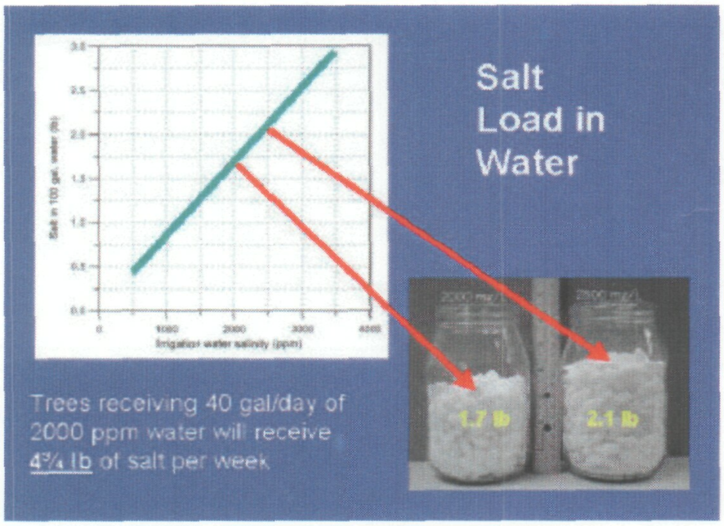
Special Publication SJ2001-SP12

Effects of Saline Irrigation Water on Florida Citrus

Leaf bronzing.

Canopy thinning.



Salt Load in Water

Trees receiving 40 gal/day of 2000 ppm water will receive 4¾ lb of salt per week

Brian Boman
University of Florida
Indian River Research Education Center
Ft. Pierce, Florida

IRREC Research Report 2001-09

Special Publication SJ2001-SP12

EFFECTS OF SALINE IRRIGATION WATER ON FLORIDA CITRUS

Final Report

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The St. John's River Water Management District provided
funding for this project under Contract No. 95G332.

by Brian Boman

University of Florida, IFAS
Indian River Research Education Center
2199 South Rock Road
Ft. Pierce, Florida 34945-3138.

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Executive Summary

Introduction

Flatwoods citrus growers often have only poor quality (high salinity) water available for irrigation. As early as 1900, damage to citrus on Florida's east coast was attributed to the high salinity in artesian wells (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 ppm total dissolved solids (TDS) per well. Many Flatwoods growers have no alternative other than to use this poor quality water for citrus irrigation. Therefore, knowing how to minimize the effects of saline irrigation water on citrus is an important production consideration.

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. Studies concerning growth and yield reductions due to excess salinity are difficult to extrapolate to the sub-tropical conditions of Florida's citrus belt. Actual salinity threshold values pertaining to growth and yield have not been established for Florida conditions. The objective of this investigation was to identify the effects of poor quality irrigation water on the growth of young citrus trees under Florida field conditions.

Two field experiments were initiated in the 1996/97 production season to meet the objectives of the study. One site was a 'Valencia' orange on rough lemon rootstock block and the other was a 'Marsh' grapefruit on sour orange rootstock block planted in 1969. In the 1997/98 season, an additional experiment was started in a 'Ruby Red' grapefruit block on Swingle citrumelo and Carrizo citrange rootstocks. In each experiment, trees were irrigated with water containing approximately 500, 1500, 2500, and 3500 ppm of total dissolved solids (TDS).

Results

The five seasons over which the studies were conducted encompassed a wide range of rainfall and irrigation conditions. Average rainfall for the area is about 56 inches per year. Rainfall at the IRREC for the study period was 51.8, 49.3, 52.6, 59.7, and 37.8 inches for 1996, 1997, 1998, 1999, and 2000, respectively. In the 1997-98 season, rainfall was generally adequate with little irrigation water applied. As a result, effects of salinity were minimal. Highest irrigation levels were applied in 1999 (when rainfall distribution was poor) and in 2000 (which was one of the driest years ever in Florida).

Salinity level typically had little effect on internal juice quality parameters for any of the experiments. Generally, there were no significant differences in any of the years on the solids per box produced or the Brix:acid ratio at time of harvest. One of the most visible effects of irrigation with high salinity water was the damage to leaves, which was expressed in elevated leaf Cl levels. With the exception of the 1997/98 season (when irrigation was limited), leaf Cl concentrations from trees receiving salinized irrigation water were considerably elevated above that in non-salinized trees. Elevated leaf Cl results in premature leaf drop and a requirement to divert tree resources to replace lost leaves.

'Valencia' orange

The 'Valencia' orange experiment was initiated in February 1996 in a block of mature trees on rough lemon rootstock planted on single-row beds at a 15 ft within-row by 30 ft across-row spacing (97 trees per acre). Trees were irrigated with microsprinklers with salinity levels of approximately 500, 1500, 2500, or 3500 ppm TDS. The higher salinity levels were achieved by injecting a brine mixture composed of NaCl, CaCl, and KCl (55%, 34%, and 11%, respectively, by weight) to the supply water.

Over the five seasons of the study, the leaf Cl levels increased an average of about 0.10% for each 1000 ppm increase in irrigation water TDS. With the exception on the 1997/98 season (when irrigation was limited), higher salinity levels in the irrigation water decreased both fruit number and fruit size. The fewer fruit and smaller fruit in the higher salinity level treatments resulted in significantly less yield for the higher salinity levels. Typically, fruit count decreased about 70 fruit/year for each 1000 ppm increase in TDS.

Average yields for the five years ranged from 490 box/ac for the non-salinized treatment trees to 335 boxes/tree for trees irrigated with 3500 ppm TDS water. Overall, yields decreased about 0.6 boxes/tree per year for each 1000 ppm increase in irrigation water salinity. At the planting density of 97 trees/ac, this amounts to about 60 boxes/acre per year reduction (about 11%) for each 1000 ppm increase in TDS. Average TSS during the five years of the study ranged from 3340 lb/ac/yr for the 500 ppm treatment to 2270 lb/ac/yr for the 3500 ppm TDS treatment. There was an average reduction of about 370 lb TSS per tree per year for each 1000 ppm increase in the salinity.

'Marsh Grapefruit

The 'Marsh' grapefruit on sour orange rootstock experiment was planted in 1969 on single-row beds. Salinized irrigation began in February 1996, with treatments receiving 500, 1500, 2500, or 3500 ppm TDS through microsprinkler irrigation. The higher salinity levels were achieved by injecting a brine mixture composed of NaCl, CaCl, and KCl (55%, 34%, and 11%, respectively, by weight) to the supply water.

The data collected in the 'Marsh' grapefruit block was from a commercial grove that was producing well below its potential due to minimal cultural inputs during all except the first year of the study. The trees in the study had the capacity to bear 5-8 boxes per tree, with the average production during the study being only 3 boxes per tree or less. Even though cultural practices were poor and little irrigation was applied (even in the critical periods in the 1999/00 season during the critical bloom, fruit set, and early development stages), significant observations of the effects of salinity were evident. High salinity levels were expressed in elevated leaf Cl levels, with leaf Cl levels increasing about 0.04% for each 1000 ppm increase in irrigation water TDS.

Cumulative yields for the 4 seasons were about 12.3 boxes/tree for the 500 and 1500 ppm treatments compared to around 11.0 for the 2500 ppm and 10.8 for the 3500 ppm treatments. These represent 12-13% decreases in production for the higher salinity levels compared to the non-salinized trees. The yield were decreased about a 6% for each 1000 ppm above the base of 1500 ppm. The effects of salinity on yield reductions would be expected to be greater on groves operated to achieve optimum production.

'Ray Ruby' Grapefruit

The experiment with 'Ray Ruby' grapefruit trees was planted in 1990 on 50 ft wide double-row beds at a spacing of 15 ft in-row by 24 ft across-row (116 trees/acre). Trees used in the study were on Swingle citrumelo and Carrizo citrange rootstocks. The control treatment was irrigated with water from a surficial aquifer well with a salinity concentration of about 500 ppm TDS. Higher levels of irrigation water salinity were achieved by injecting a sea water brine mixture into the supply water to achieve 1600, 2700, and 3800 ppm TDS.

Leaves from trees on Carrizo accumulated much higher Cl concentrations than leaves from Swingle trees. Typically, leaf Cl levels increased about 0.20% for each 1000 ppm increase in irrigation water TDS for Carrizo and 0.04% for Swingle.

For both rootstocks, both the number of fruit and the size of the fruit tended to decrease with increasing salinity in the irrigation water. The non-salinized trees had significantly larger fruit compared to the rest of the treatments In the 2000/01 season when drought necessitated numerous irrigation, trees on Carrizo irrigated with 500 ppm water had about 50% more size 36 and larger fruit season than trees watered with 2700 or 3800 ppm water. For trees on Swingle rootstock, trees irrigated with 500 ppm water had 1.5 - 2 times as many size 36 and larger fruit than trees watered with 1600 ppm TDS or more water.

Yields were significantly less for the higher salinity levels during each season. Over the 4 seasons, average yields for Carrizo were reduced about 50 boxes/ac per year for each 1000 ppm increase in TDS of the irrigation water. For Swingle rootstock, the reduction was about 40 boxes/acre per year for each 1000 ppm increase in TDS of the irrigation water. These reductions averaged 9% (Swingle) and 11% (Carrizo) for each 1000 ppm increase in TDS of the irrigation water.

All treatments had similar solids per box, averaging 4.7, 4.7, 4.6, and 4.8 pounds per box (Carrizo) and 4.8, 4.9, 5.0, and 4.9 pounds per box (Swingle) for the 500, 1600, 2700, and 3800 ppm TDS treatments, respectively. The two-season (1999/00 and 2000/01) reduction in total soluble solids due to salinity averaged 240 lb/ac for Swingle and 300 lb/ac for Carrizo per year for each 1000 ppm increase in TDS (at a density of 116 trees/acre).

Effects of Saline Irrigation Water on 'Valencia' Orange

Objective

The objective of the study is to measure and document the production and fruit quality changes that occur with the use of high salinity water for irrigation of 'Valencia' orange citrus trees under Florida conditions.

Methods

A field experiment was initiated in February 1996 in a block of 'Valencia' orange on rough lemon rootstock trees located at the Indian River Research Education Center. The trees were planted in 1986 on single-row beds with a tree spacing of 15 ft within-row by 30 ft across-row, resulting in a density of 97 trees per acre.

All trees were irrigated with spray-type microsprinklers (10.5 gph with 16.5 ft pattern at 20 psi) supplied by a surficial aquifer well. The control treatment trees received water with a salinity level of approximately 500 ppm TDS. The challenge treatments were irrigated with water having 3 higher levels of salinity. Each salinity treatment adds an increment of about 1000 ppm above the base rate of the control treatment (1500, 2500, and 3500 ppm). The higher salinity levels were achieved by injecting a brine mixture composed of NaCl, CaCl, and KCl (55%, 34%, and 11%, respectively, by weight) to the supply water. The brine mixture was applied during all irrigation events at a rate relative to the flow rate through the lateral line through the use of Dosatron™ proportional injectors.

Irrigation management of the 'Valencia' trees was accomplished using ET-based scheduling calculated from a weather station located at the IRREC. Irrigations were scheduled 3 days a week, with the amount applied based on accumulated ET since the last irrigation (with allowanced 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 kept to less than 15 cbar in the wetted area, and 20 cbar or less during the rest of the year.

The experiment was set up with a randomized block experimental design with 6 replications of each treatment. Each plot consisted of 5 in-row adjacent trees. Over the course of 5 seasons, many of the trees in the block began to exhibit symptoms of citrus blight. By the time the experiment was terminated in April 2001, over half of the trees had reduced productivity or were dead due to blight. In order to avoid confounding influences from blighted trees, trees that exhibited blight symptoms were excluded from the data analysis. Blight was first evident on the south side of the block, and all of the trees in replicate 1 were excluded. At the end of the study there were at least 2 trees in each plot that were unaffected by blight, so they were chosen to represent the plot. The data analyzed represents information collected from these two trees in each plot during each of the 5 seasons.

Rain and Irrigation

Rainfall in the 1996/97 citrus season (April through March) was less than the previous 2 seasons, especially during the late summer (Table 1). Rainfall was scarce in April and the first part of May (Fig. 1). Late July and early August had much less than normal rainfall, and several irrigations were made in late July and throughout most of August when summer thunderstorms consistently failed to produce adequate rainfall. Rainfall was lower than normal in December, when only 1.7 inches fell. Rainfall was also less than 1.5 inches per month in February and March, but nearly 8 inches in April (Table 1). Most of the irrigation was in late January and through much of February, a period which was generally rainless with above normal temperatures.

Rainfall in the 1997/98 citrus season was adequate throughout most of the year (Table 1). For the period from April 1997 through March 1998, rainfall was 56.6 inches in the 'Valencia' block. The rain was well distributed, resulting in only 42 hours of irrigation applied to the oranges. There was not a prolonged dry period with significant irrigation during the 1997/98 season.

The 1998/99 season was characterized by very high rainfall in February and March and about half the normal rainfall in June and July. And nearly 30 inches of rain falling from mid-August to November. Little irrigation was required during the normal dry season months, but irrigation was required in the normally wet months of June, July, and August. Total irrigation for the season was 156 hours.

Dry weather in the spring of 1999 made considerable irrigation necessary in March and April (131 hours). Rains began in May, and nearly 11 inches of rain was recorded in June. July was again a dry month, and irrigations were required. Hurricanes Floyd and Irene in September and October resulted in several inches of rainfall. 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 oranges off the trees. Rainfall was well below normal during the winter of 1999/00 and continued throughout the spring of 2000.

The 7-month period beginning in November 1999 received only 11 inches of rain, compared to normal rainfall of 21 inches. Rainfall for 2000/01 season was nearly 20 inches below normal, and irrigations were required throughout the year. Nearly 550 hours of irrigation was required, with applications on 3 or 4 days a week for many weeks continuously.

Seasonal irrigation ranged from 42 hours in 1997/98 to 548 hours in 2000/01, averaging 221 hours per year (Table 2). In the 1999/00 season, irrigation applications were just slightly higher than the 5-season average. The seasonal irrigation application (in hours) for the 1996/97, 1997/98, 1998/99, and 2000/01 seasons was 60%, 20%, 70%, and 250% of the average annual irrigation amount (in hours), respectively.

Table 1. Rainfall (inches) for 'Valencia' orange block by season (April through March).

Month	Season					1952-1999 Avg
	1996/97	1997/98	1998/99	1999/00	2000/01	
Apr	0.74	7.67	2.41	3.43	2.59	2.49
May	3.90	1.80	2.37	4.59	0.54	4.81
Jun	4.99	6.94	3.45	11.11	7.47	6.92
Jul	5.56	5.74	2.97	1.04	6.72	6.93
Aug	4.56	13.24	11.20	9.39	2.96	7.09
Sep	7.21	3.63	7.38	9.80	3.95	7.93
Oct	6.35	2.49	2.21	11.89	7.16	6.51
Nov	2.55	3.74	8.71	1.72	0.26	2.91
Dec	1.65	0.57	0.91	1.16	2.94	1.97
Jan	3.07	2.15	3.08	1.89	1.00	2.25
Feb	1.54	4.46	0.67	1.50	0.31	2.87
Mar	1.28	4.80	0.59	1.92	1.45	3.44
Total	43.40	57.23	45.95	59.44	37.35	56.12

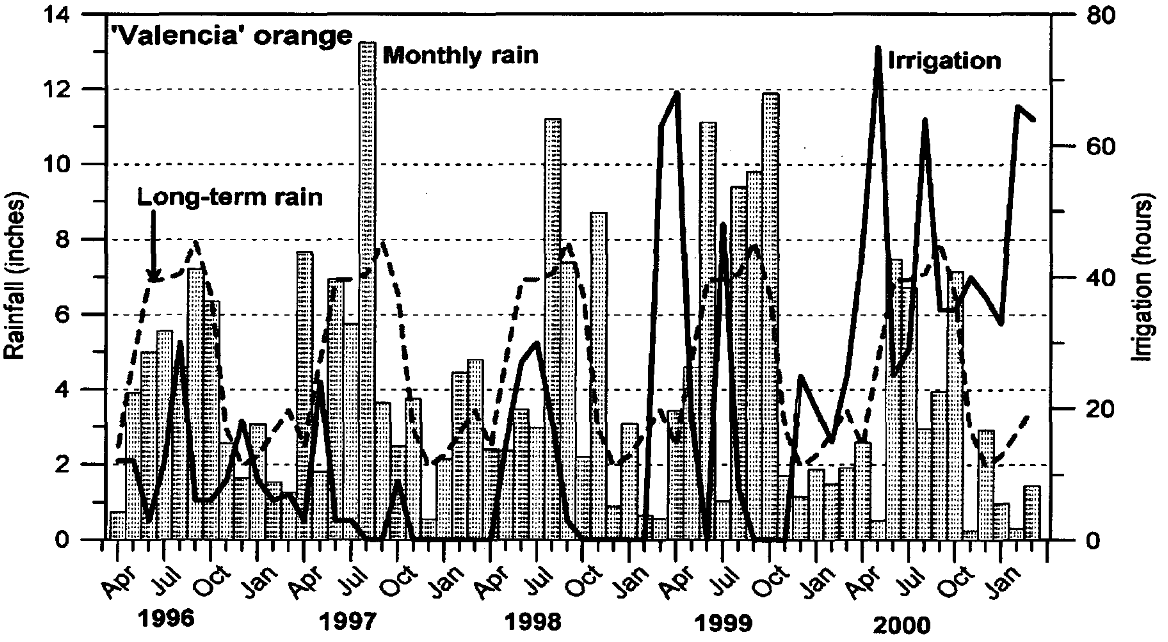

Figure 1. Monthly rainfall, irrigation, and long-term rain for 'Valencia' orange block.

Table 2. Irrigation (hours with 10.5 gph emitters) for 'Valencia' orange block.

Month	Season					Avg
	1996/97	1997/98	1998/99	1999/00	2000/01	
Apr	12	3	0	68	45	26
May	12	24	15	18	75	29
Jun	3	3	27	0	25	12
Jul	12	3	30	48	29	24
Aug	30	0	18	8	64	24
Sep	6	0	3	0	35	9
Oct	6	9	0	0	35	10
Nov	9	0	0	0	40	10
Dec	18	0	0	25	37	16
Jan	9	0	0	20	33	12
Feb	6	0	0	15	66	17
Mar	7	0	63	25	64	32
Total	130	42	156	227	548	221

Fertilization

All plots were fertilized with granular materials applied three times per year, normally in February, May, and October. 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:

1996

Three applications of granular material were made during the 1996/97 season. During each of the applications (Feb., July, and Oct.), 4.0 lb/tree of 10-10-10 material was applied, for a total of 144 lb N per acre for the year.

1997

Three applications of granular material were made during 1997. During each of the applications (Feb., July, and Nov.), 7.5 lb/tree of 8-4-8 material was applied (for a total of 172 lb N per acre).

1998

Applications in 1998 included 5.0 lb/tree of 8-4-8 applied on April 9 and 7.5 lb/tree of 8-4-8 on July 16 and Oct. 12. Total for the year was 154 lb N per acre.

1999

In 1999, 7.5 lb/tree of 8-4-8 was applied on Feb. 17, June 3, and October 3. The total annual N applied was 173 lb/acre.

2000

Fertilizer applications in 2000 were made on Feb. 3, June 20, and Nov. 17. At each application, 5.25 lb/tree of 8-4-8 material was applied. Total for the year was 154 lb N per acre.

2001

On Feb 5, 5.25 lb/tree of 8-4-8 material was applied with a broadcast applicator to each tree.

Leaf Mineral Concentrations

Spring flush leaves were sampled from 'Valencia' plots during July or August 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 other minerals. Solutions were prepared from the samples and they were analyzed (N, P, K, Ca, Mg, and Na) by the IFAS Analytical Research Laboratory in Gainesville (1997 -2000) or Pioneer Labs, Ft. Pierce (2001). Leaf Cl concentrations were determined at the IRREC with a chloridometer.

With the exception of Cl, the 'Valencia' samples showed little differences in leaf mineral concentrations with respect to salinity treatments (Tables 3-7). Leaf N and K concentrations were generally at or slightly below the optimum IFAS recommended range (2.5-2.7% for N and 1.2-1.7% for K).

The lack of need for irrigation in the 1997/98 season was reflected by little differences in leaf mineral concentrations. The only significant effect was a lowering of leaf Mg in the highly salinized trees (Table 4). Leaf Cl concentrations were elevated in the highly salinized (3500 ppm) treatment trees in each of the other years.

In the 1996/97, 1997/98, and 1998/99 seasons, leaf Ca and/or Mg concentrations were diminished in the high-salinity treatments compared to the less-salinized trees. This phenomenon is typically attributed to Na displacement of the bi-valent cations in the tree.

In the 1999/00 and 2000/01 seasons, significantly more irrigation was required than in the other years. As a result, Leaf Cl concentrations in the 3500 ppm treatment trees was double that of the non-salinized trees (Tables 6 and 7). Leaf Ca and Mg concentrations were again slightly depressed compared to the less-salinized trees. When leaf Cl concentrations were averaged over the five seasons, there was a definite trend of increased Cl concentration with increasing salinity level (Fig. 2). Leaf Cl levels increased an average of 0.10% for each 1000 ppm increase in irrigation water TDS.

Table 3. Mean leaf mineral concentrations for 'Valencia' orange trees sampled in August 1996 (n=5).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	2.60	0.15	1.36	4.1 ab	0.28 ab	0.15 a	0.23 a
1500	2.69	0.15	1.39	4.2 ab	0.29 ab	0.15 a	0.22 a
2500	2.63	0.15	1.44	3.9 bc	0.30 a	0.15 a	0.22 a
3500	2.76	0.16	1.48	3.7 c	0.24 b	0.23 b	0.53 b

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 4. Mean leaf mineral concentrations for 'Valencia' orange trees sampled in August 1997 (n=5).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	2.38	0.14	0.83	4.16	0.27 ab	0.20	0.16
1500	2.55	0.14	0.85	4.19	0.25 ab	0.18	0.19
2500	2.55	0.14	0.79	4.40	0.28 a	0.17	0.18
3500	2.55	0.14	0.84	4.05	0.23 b	0.18	0.19

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 5. Mean leaf mineral concentrations for 'Valencia' orange trees sampled in July 1998 (n=5).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	1.96	0.13	0.98	4.00 ab	0.24 ab	0.13	0.18 b
1500	1.89	0.13	0.96	4.08 a	0.24 ab	0.16	0.28 ab
2500	1.84	0.12	0.92	4.04 ab	0.29 a	0.12	0.24 ab
3500	1.96	0.13	1.00	3.73 b	0.21 b	0.17	0.48 a

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 6. Mean leaf mineral concentrations (%) for 'Valencia' trees sampled in July 1999 (n=5).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	1.92	0.15	1.32	3.69	0.37	0.10	0.24 b
1500	1.96	0.17	1.38	3.73	0.32	0.10	0.35 ab
2500	1.88	0.16	1.28	3.46	0.32	0.10	0.39 ab
3500	1.96	0.16	1.23	3.73	0.34	0.09	0.41 a

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 7. Mean leaf mineral concentrations (%) for 'Valencia' trees sampled in July 2000 (n=5).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	2.66	0.15	1.24	3.69	0.24	0.06 b	0.35 b
1500	2.78	0.15	1.14	3.64	0.19	0.11 a	0.38 b
2500	2.67	0.15	1.40	3.59	0.21	0.06 b	0.40 ab
3500	2.70	0.15	1.41	3.52	0.21	0.07 b	0.72 a

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

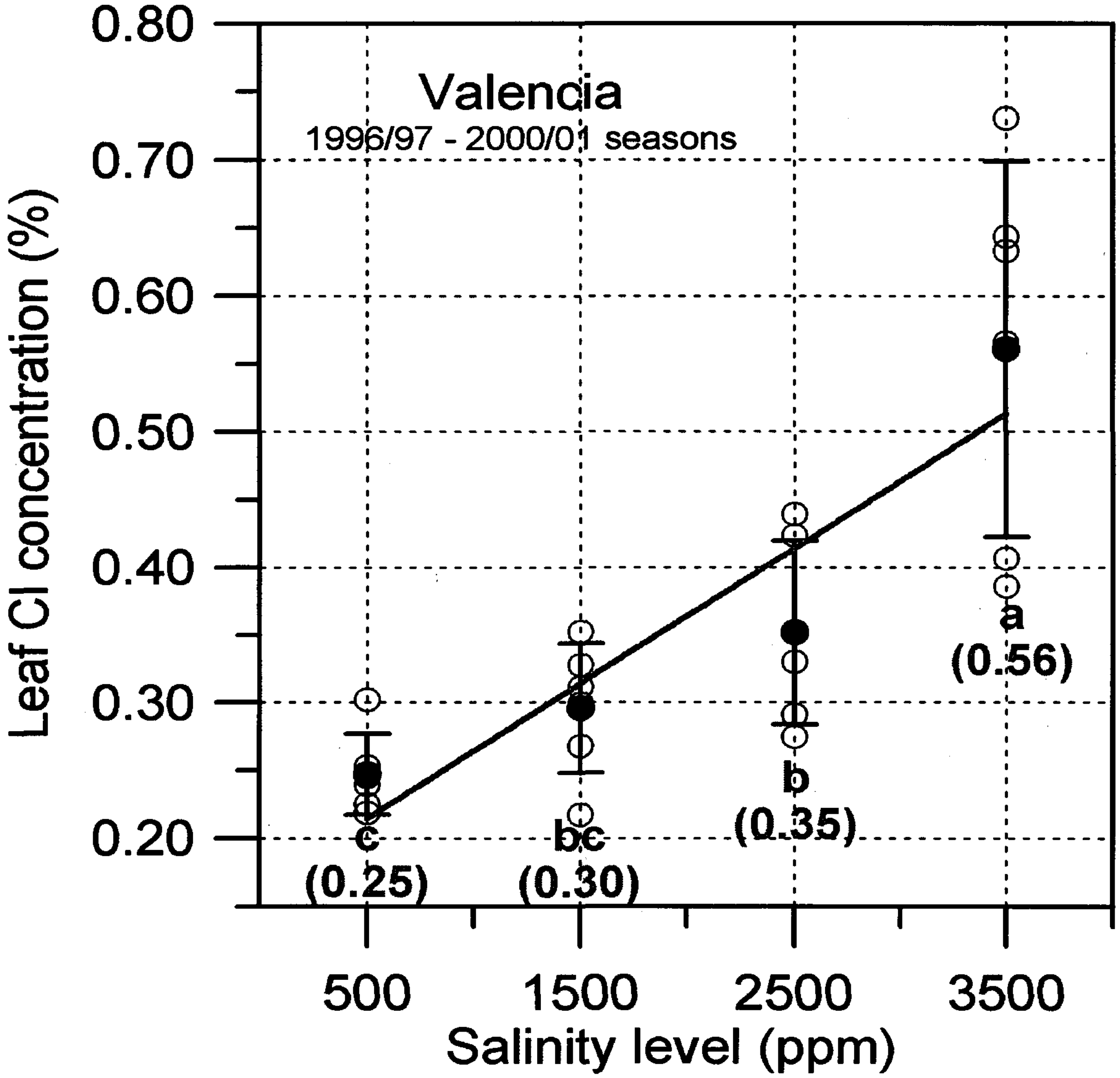

Figure 2. Mean leaf Cl concentrations for 1996/97 through 2000/01 seasons. Means followed by the same letter are not significantly different according to Duncan's multiple range (P=0.05). Error bars represent 1 standard deviation from the mean.

Juice Quality

The 'Valencia' plots were sampled in March or April of each year prior to harvest. Fruit were randomly picked from locations all around the trees, with a total of 50-60 fruit per plot. The fruit were analyzed at the Florida Department of Citrus Lab in Lake Alfred with standard methods for juice content, Brix, acid content and solids (lbs) per box.

No substantial differences were noted with respect to salinity treatment for any of the juice parameters in any of the seasons (Tables 8-12). Although non-significant, the fruit in the 3500 ppm treatment tended to have slightly higher juice content and solids per box compared to the other treatments.

Table 8. Mean juice quality parameters for 50 'Valencia' oranges picked at random on April 11, 1997.

Salt level (ppm)	Avg weight (g)	Juice content (%)	Acid (%)	Brix	Solids per box (lb)	Brix:acid ratio
500	184 ab	58.1	0.79	12.4	7.0	15.7
1500	192 ab	64.3	0.81	12.2	7.1	15.1
2500	179 b	64.1	0.79	12.4	7.1	15.7
3500	197 a	62.8	0.81	12.6	7.1	15.6

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 9. Mean juice quality parameters for 50 'Valencia' oranges picked at random on March 9, 1998.

Salt level (ppm)	Avg weight (g)	Juice content (%)	Acid (%)	Brix	Solids per box (lb)	Brix:acid ratio
500	168	61.9	0.96	12.4	6.6	12.9
1500	171	62.8	0.95	12.4	7.0	13.2
2500	175	61.4	0.96	12.2	6.8	12.8
3500	169	63.3	0.98	12.5	7.1	12.8

All means are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 10. Mean juice quality parameters for 50 'Valencia' oranges picked at random on March, 1999.

Salt level (ppm)	Avg weight (g)	Juice content (%)	Acid (%)	Brix	Solids per box (lb)	Brix:acid ratio
500	168	61.9	0.96	12.4	6.9	12.9
1500	171	62.8	0.95	12.4	7.0	13.2
2500	175	61.5	0.96	12.2	6.8	12.8
3500	169	63.3	0.98	12.5	7.1	12.8

All means are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 11. Mean juice quality parameters for 50 'Valencia' oranges picked at random on March, 2000.

Salt level (ppm)	Avg weight (g)	Juice content (%)	Acid (%)	Brix	Solids per box (lb)	Brix:acid ratio
500	175	60.8	0.91	11.9	6.5	13.2
1500	174	60.3	0.91	11.7	6.4	12.9
2500	180	59.3	0.90	11.6	6.2	12.9
3500	179	60.8	0.89	11.5	6.3	13.0

All means are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 12. Mean juice quality parameters for 50 'Valencia' oranges picked at random on March 29, 2001.

Salt level (ppm)	Avg weight (g)	Juice content (%)	Acid (%)	Brix	Solids per box (lb)	Brix:acid ratio
500	173	59.4 b	0.87	11.9	6.4	13.8
1500	195	60.6 ab	0.79	11.9	6.5	15.1
2500	184	61.2 a	0.85	11.8	6.5	13.9
3500	185	61.0 a	0.87	11.8	6.5	13.6

All means are not significantly different according to Duncan's MRT (P=0.05).

Size Distribution and Yield

In the 1996/97 season, the major-axis diameters of 30 fruit selected at random within each plot were measured with calipers on May 8. Fruit volume was calculated assuming the fruit were spheres. The weight of fruit picked from each tree was measured when the trees were harvested on May 23, 1997. During the normal commercial harvest of the block in each of the other seasons, fruit from each tree in the experiment were picked and run through a portable optical fruit sizing machine. Data collected from each tree included the total number of fruit and the weight and diameter of each individual fruit harvested.

Fruit are sized at the packing house based on how many fit in a 4/5 bushel carton. Due to some overlap in the allowable diameters for adjacent fruit sizes specified by the USDA Standards for Florida oranges, some fruit may be classified in more than one size category (Fig. 3). Therefore, the diameter versus pack size data for oranges were used to develop a regression curve which was used to estimate boxes from fruit number and fruit size. Solids per tree were calculated by multiplying yield (in boxes/tree) by the solids per box measured in fruit sampled from the plot. Harvest dates were April 30, 1998, April 13, 1999, March 31, 2000, and April 10, 2001.

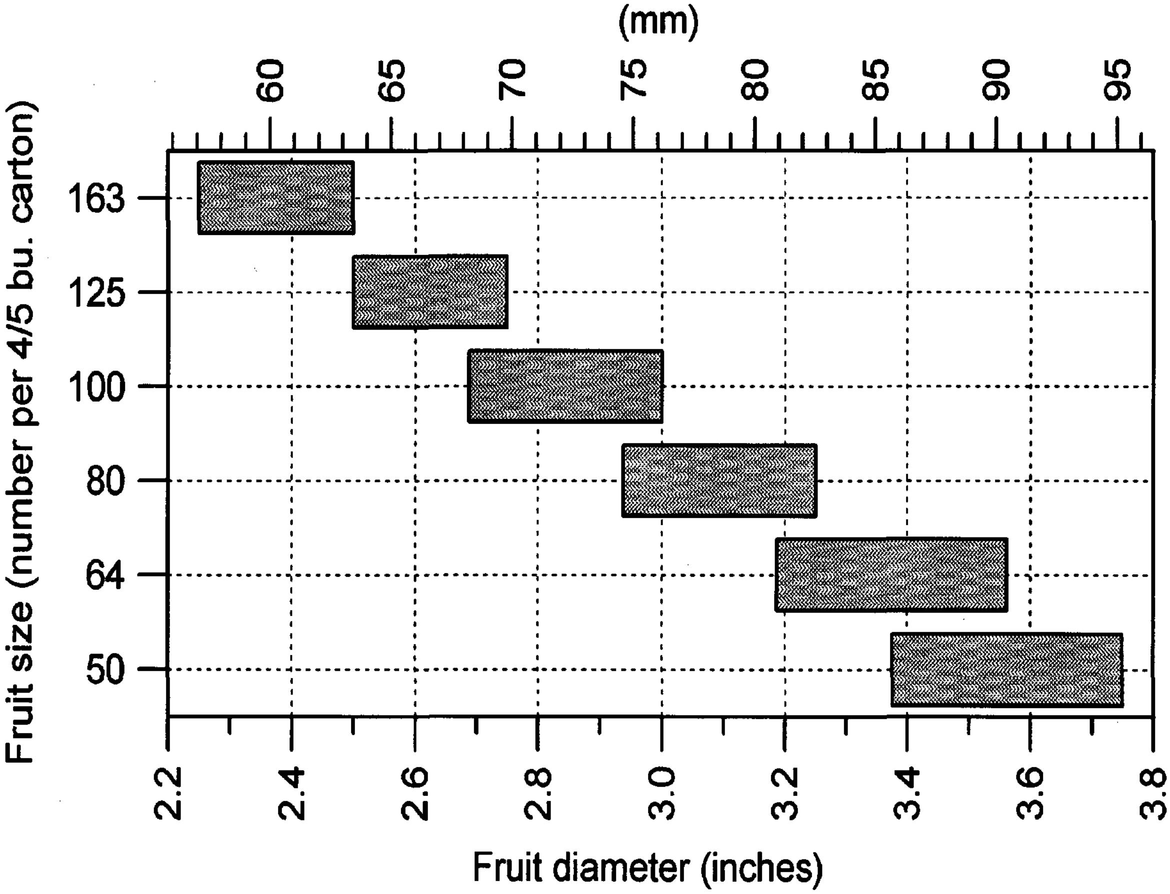

Figure 3. Allowable diameter ranges by pack size for Florida oranges

The total number of fruit harvested per tree was significantly higher for the non-salinized trees compared to the 2500 or 3500 ppm treatment in the each of the three seasons (1998/99 through 2000/01) where data was collected (Fig. 4). In addition, the fruit count of the lower salinity level treatments tended to be greater in the other seasons when fruit numbers were counted. The 3-season average number of fruit harvested was 788, 721, 603, and 557 fruit/tree for salinity treatments 500,1500,2500, and 3500 ppm TDS, respectively (Fig. 4).

In the 1996/97 season when fruit samples were hand calipered, average fruit diameter was largest for those trees receiving the non-salinized irrigation water (Table 13). Average fruit volume compared to the 500 ppm TDS treatment was 88%, 77%, and 85% for the 1500, 2500, and 3500 ppm treatments, respectively.

In the other seasons (when all fruit was optically sized) the number of smaller fruit (size 125 and smaller) was similar, regardless of salinity level (Tables 14-17). However, the high salinity level resulted in significantly fewer larger-sized fruit than the other treatments in 3 of the 5 seasons. There was a significant decrease in larger fruit as the irrigation salinity level increased (Fig. 5) when the data was averaged for the three seasons when size distribution was collected. There was about a 35% reduction in the number of fruit for sizes 64, 80, and 100 fruit when the irrigation salinity was increased from 500 ppm to 3500 ppm TDS (Fig. 6). This is a reduction that averaged 70 fruit per tree of size 100 and larger fruit for each 1000 ppm increase in salinity TDS.

Cumulative yields (boxes) followed the same trends as fruit size and number, with the higher salinity levels having reduced yields (Fig. 7). Over the 5 seasons (Fig. 8), the 3500 ppm treatment resulted in about 850 boxes per acre less production than the non-salinized treatment trees (or about 170 boxes/acre each year reduction in yield). This is a 24% reduction in yield, or about an 11% decrease for each 1000 ppm increase in salinity. This translates to about a 60 box/acre per year decrease in yield for each 1000 ppm increase above the base of 500 ppm TDS.

Table 13. Average fruit diameter (May 8, 1997, n=180), peel thickness (May 16, 1997, n=60), and yield (May 23, 1997, n=30) by salinity treatment for 'Valencia' oranges.

Salinity level (ppm)	Average diameter (mm)	Average volume (cm^3)	Peel thickness (mm)	Average Yield (box/tree)	Average TSS (lb/tree)
500	72.0 a	195 a	2.7 a	3.7 a	26.0 a
1500	69.3 b	172 b	2.6 ab	3.6 ab	25.8 a
2500	66.3 d	150 d	2.7 a	3.0 b	21.5 b
3500	68.3 c	165 c	2.5 b	2.3 c	16.3 c

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 14. Size distribution and yield for 'Valencia' orange harvested April 30, 1998.

Salt treatment (ppm)	Fruit size (No. per carton)			Total No. fruit	Yield	
	125 and less	100 & 80	64 & 50+		(boxes per tree)	TSS (lb/tree)
500	201	501	80	782	5.9 a	38.5 a
1500	192	416	61	669	5.5 a	41.2 a
2500	137	432	83	651	4.4 b	28.2 b
3500	266	332	60	658	4.0 b	29.4 b

Means followed by the same letter in the same column are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 15. Size distribution (number in each size class) and yield for 'Valencia' orange harvested April 13, 1999.

Salt treatment (ppm)	Fruit size (No. per carton)			Total No. fruit	Yield	
	125 and less	100 & 80	64 & 50+		(boxes per tree)	TSS (lb/tree)
500	32 a	324 a	249 a	593 a	5.3 a	37.2 a
1500	33 a	331 a	172 b	535 ab	4.1 b	29.9 b
2500	9 b	185 b	265 a	459 b	3.8 bc	25.3 bc
3500	13 ab	241 ab	168 b	422 b	3.1 c	21.9 c

Means followed by the same letter in the same column are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 16. Size distribution (number in each size class) and yield for 'Valencia' orange harvested in March 29, 2000.

Salt treatment (ppm)	Fruit size (No. per carton)			Total No. fruit	Yield	
	125 and less	100 & 80	64 & 50+		(boxes per tree)	TSS (lb/tree)
500	126 ab	522 a	141	788 a	5.3 a	34.4 a
1500	84 bc	489 ab	130	702 ab	4.8 ab	30.2 ab
2500	49 c	398 b	131	578 bc	4.3 bc	27.4 bc
3500	138 a	419 ab	96	528 c	4.0 c	25.5 c

Means followed by the same letter in the same column are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 17. Size distribution (number in each size class) and yield for 'Valencia' orange harvested in April 10, 2001.

Salt treatment (ppm)	Fruit size (No. per carton)			Total No. fruit	Yield	
	125 and less	100 & 80	64 & 50+		(boxes per tree)	TSS (lb/tree)
500	187 a	668 a	114 a	969 a	5.6 a	35.5 a
1500	175 a	531 b	124 a	830 ab	5.1 ab	33.3 ab
2500	144 a	473 bc	86 a	703 b	4.4 bc	28.1 bc
3500	215 a	371 c	92 a	677 b	3.8 c	24.9 c

Means followed by the same letter in the same column are not significantly different according to Duncan's Multiple Range Test (P=0.05).

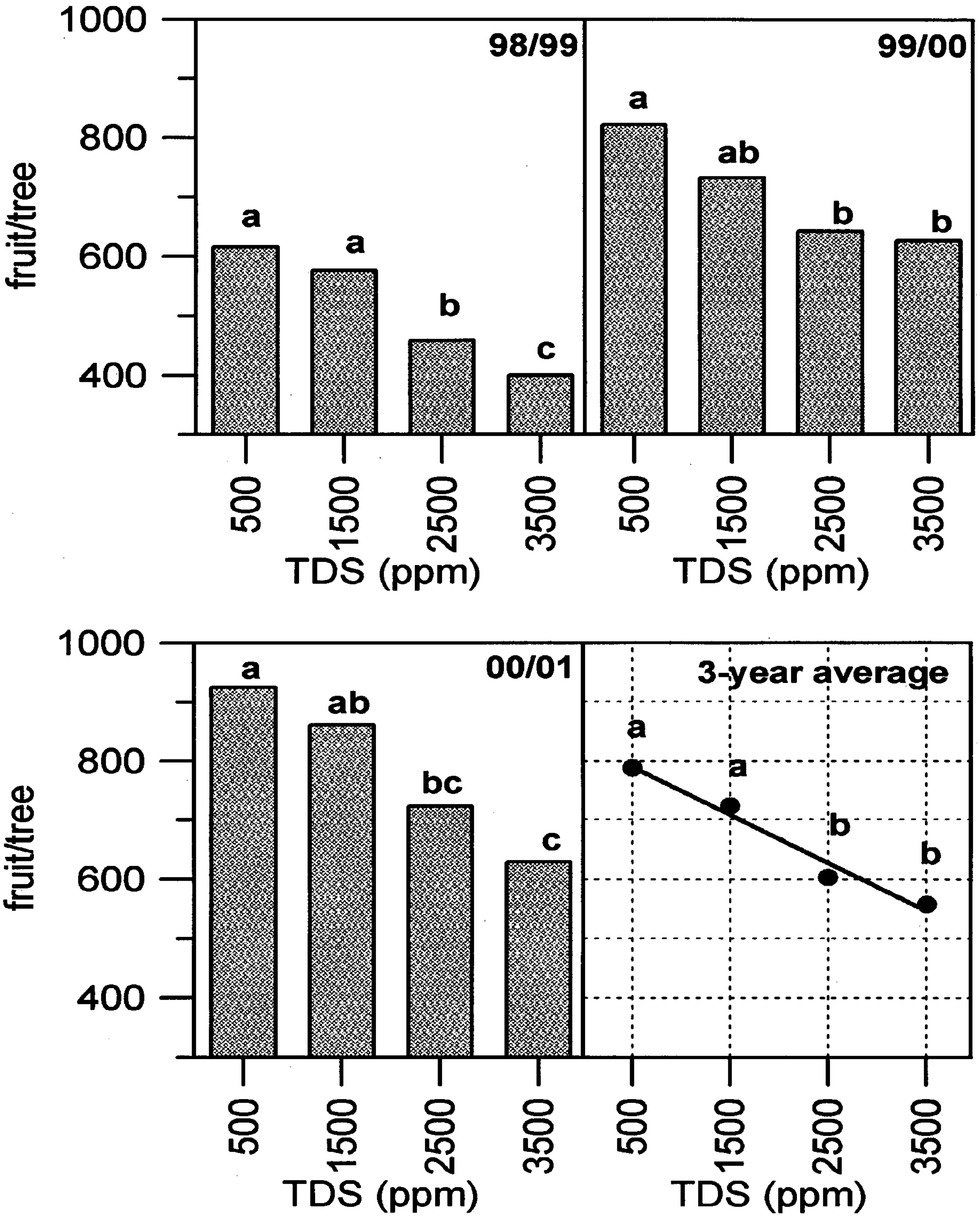

Figure 4. Cumulative fruit per tree for 1998/99 through 2000/01 seasons by irrigation salinity level. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

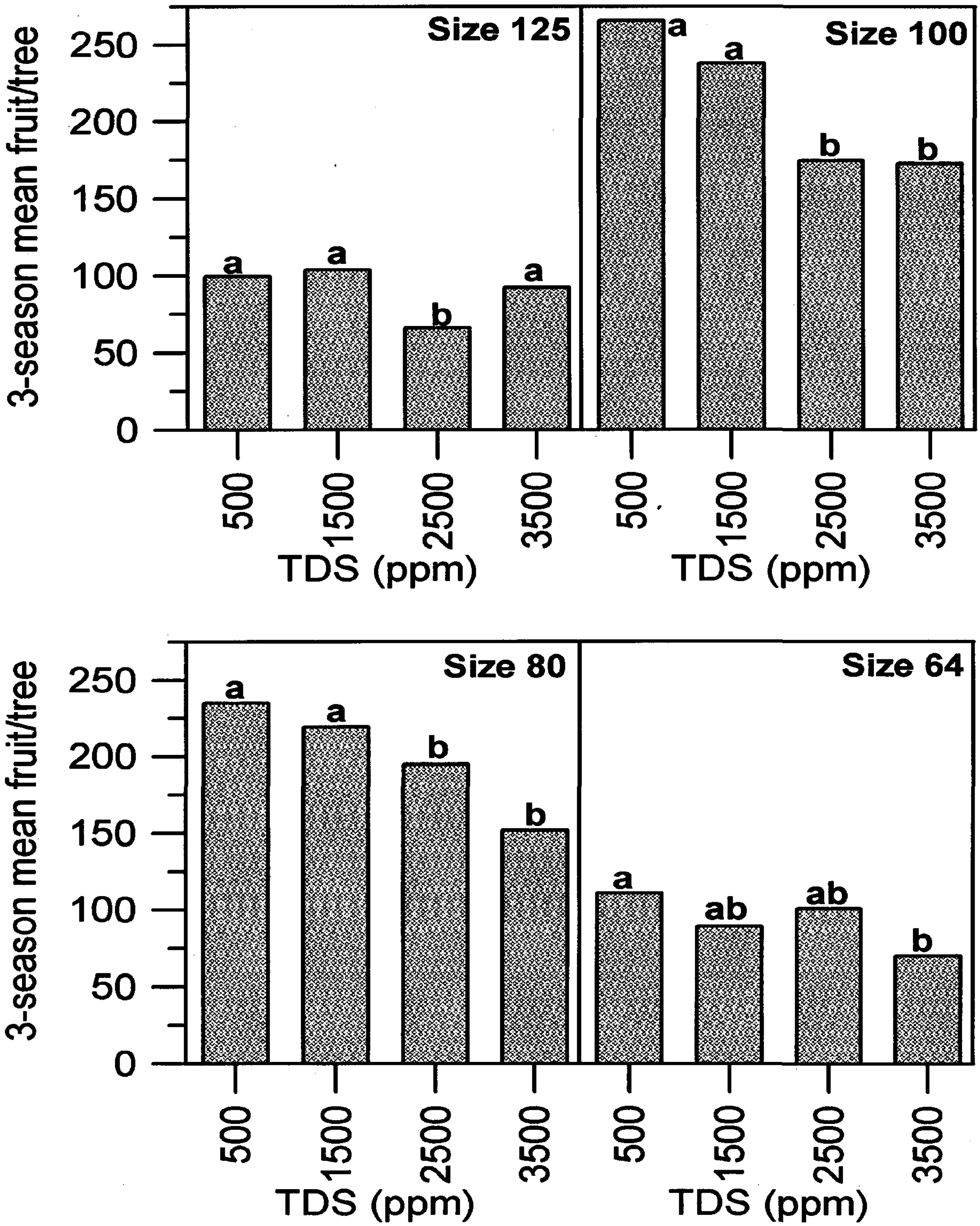

Figure 5. Average fruit size distribution for 1998/99 through 2000/01 seasons by irrigation salinity level. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

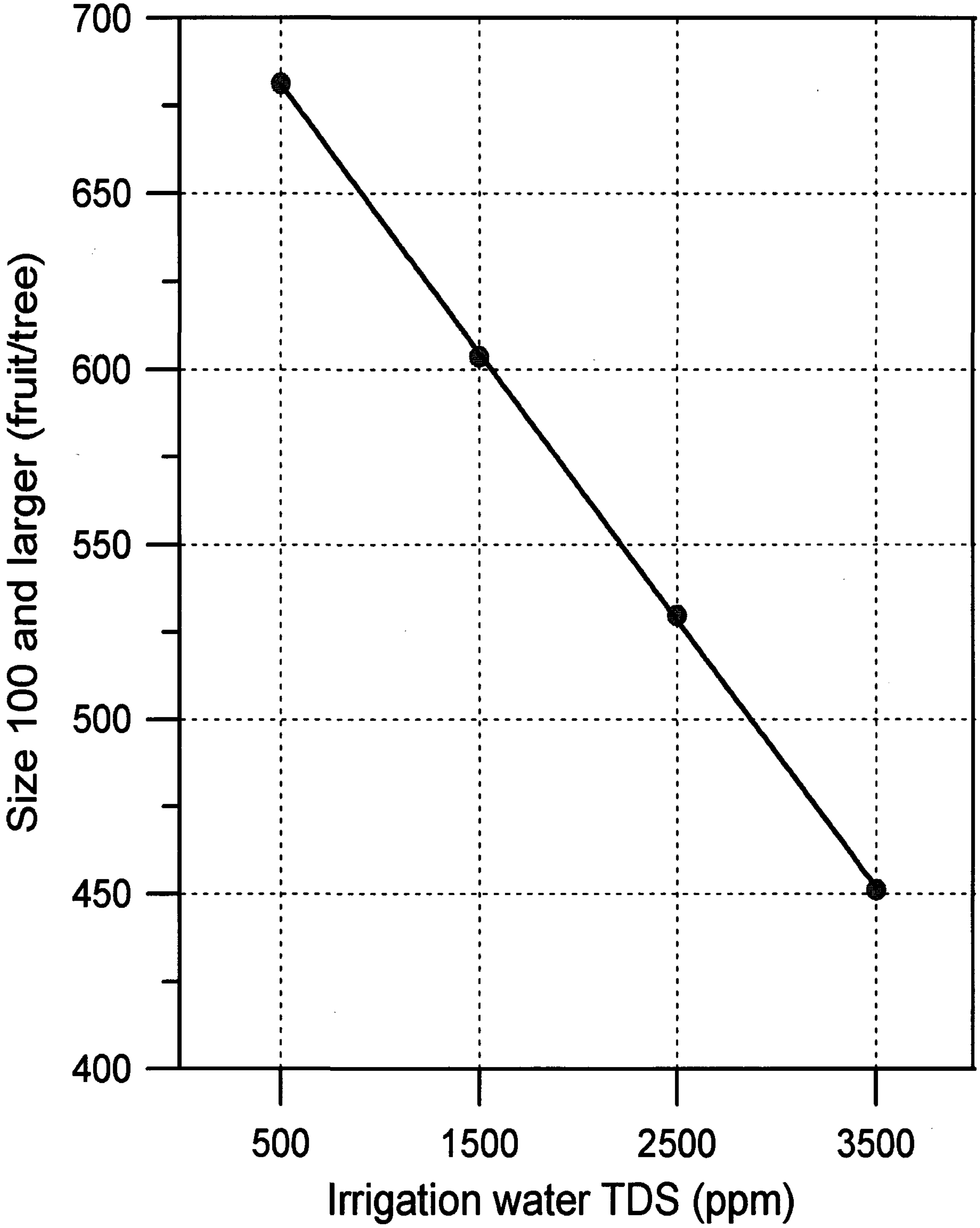

Figure 6. Average number of fruit size 100 and larger for 1998/99 through 2000/01 seasons by irrigation salinity level.

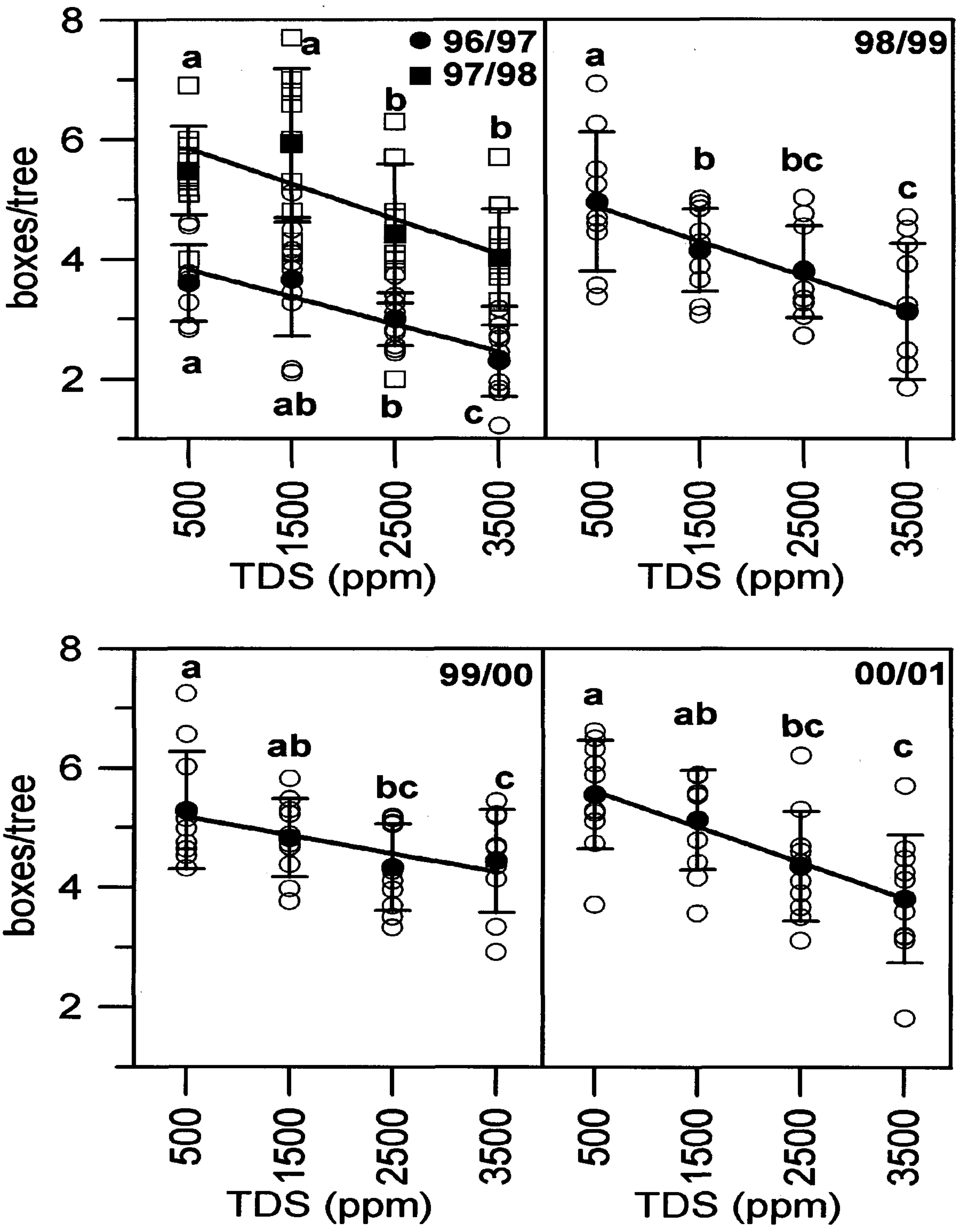

Figure 7. Yields (boxes/tree) for 1996/97 through 2000/01 seasons by irrigation salinity level. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05). Error bars represent 1 standard deviation from the mean.

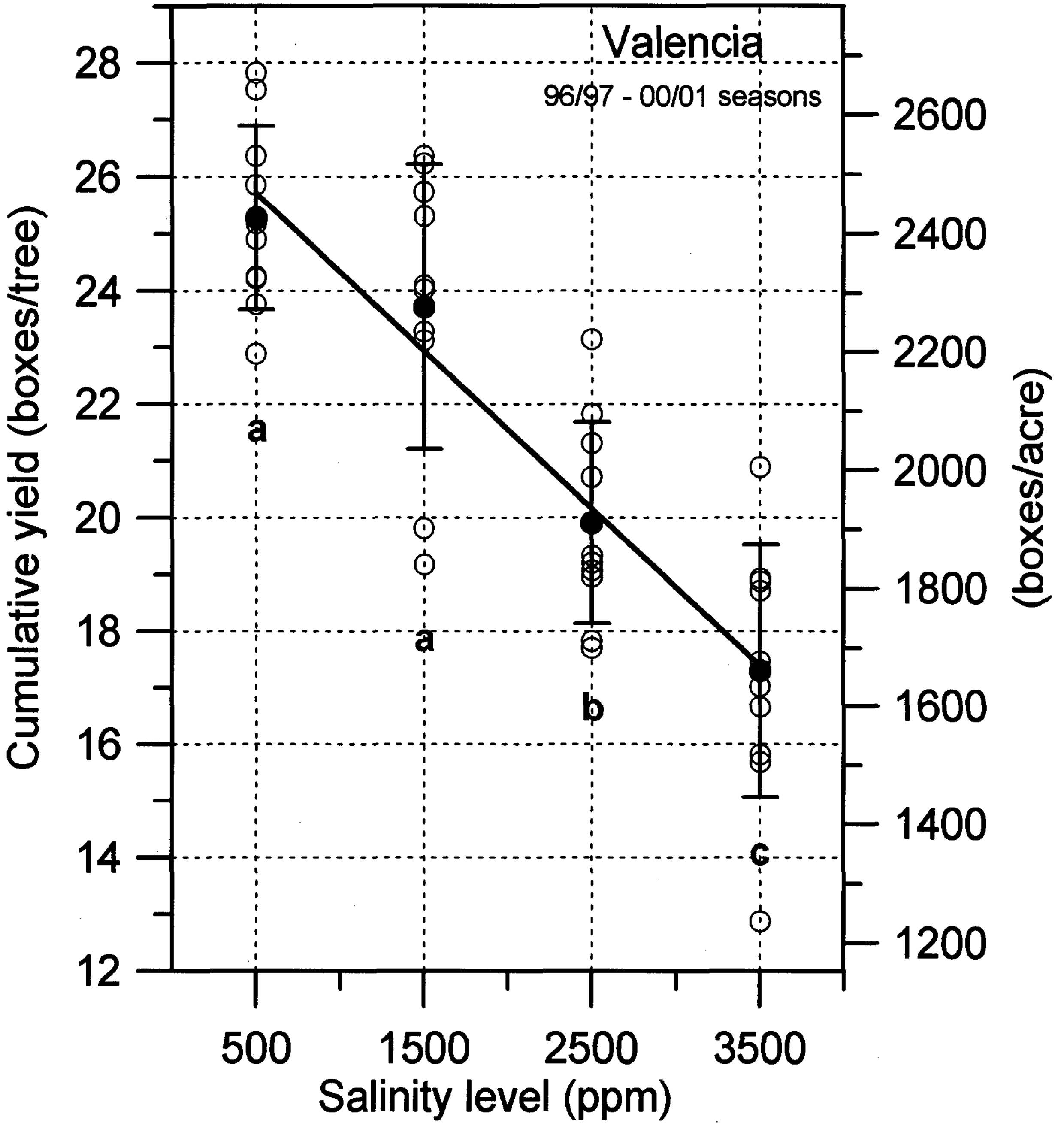

Figure 8. Cumulative yields (boxes/tree) for 1996/97 through 2000/01 seasons by irrigation salinity level. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05). Error bars represent 1 standard deviation from the mean.

Total Soluble Solids (TSS) Production

For fruit that is sent to processing plants, growers are paid for the total soluble solids (TSS) produced. Therefore, it the quantity of solids produced per unit of land is one of the most important factors in determining the profitability of a particular production unit. The TSS for non-salinized trees ranged from 26 lb/tree to 38.5 lb/tree during the study, averaging 34.3 lb/tree (Tables 13-17). For the highly salinized trees (3500 ppm), the TSS ranged from 16.36lb/tree to 29.4 lb/tree, averaging 23.6 lb/tree (31% less). In each of the seasons, the TSS per tree produced was significantly less for the 2500 and 3500 ppm TDS treatments as compared to the non-salinized trees (Fig. 8).

Over the five seasons, the trees irrigated with 3500 ppm TDS water averaged 116 lb/tree of TSS produced, compared to 173 lb/tree on the trees watered with 500 ppm TDS water (Fig. 9). This translates to a reduction of 3.8 lb TSS per tree per year for each 1000 ppm increase in the salinity. At the block planting density of 97 trees/ac, the TSS reduction would be about 370 lb/ac per year.

Conclusions

The five seasons over which the study was conducted encompassed a wide range of rainfall and irrigation conditions. In the 1997-98 season, rainfall was generally adequate and little irrigation was applied. As a result, effects of salinity were minimal. The 2000/01 season coincided with one of the driest periods in recent history in Florida, and nearly 550 hours of irrigation were required.

Over the course of the study, significant observations of the effects of salinity were evident. The effects of irrigation with high salinity water were expressed in elevated leaf Cl levels. In each of the seasons except 1997/98, leaf Cl concentrations from trees in the 3500 ppm TDS treatment were about double that from non-salinized trees. 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. As a result of premature leaf drop and the associated loss of nutrients, there are often abnormalities in the leaf concentrations of other nutrients (notably Ca and Mg) which can cause imbalances in the tree. For a given salinity level, leaf Cl accumulation is primarily dependent on the rootstock on which the trees are grown. For the "Valencia' on rough lemon trees in the study, the leaf Cl levels increased an average of about 0.10% for each 1000 ppm increase in irrigation water TDS.

Salinity level had little effect on internal juice quality parameters. In Florida's climate, any differences in these measurement are often masked by the large climatic swings that may occur (i.e. hot and dry to wet and cool weather patterns). There were no significant differences in any of the years on the solids per box produced or the Brix:acid ratio at time of harvest. The soluble solids average for the five seasons was 6.7 lb/box for the 500 and 3500 ppm treatments and 6.8 lb/box for the 1500 and 2500 ppm TDS treatments. At harvest, the Brix:acid ratio averaged 13.7, 13.9, 13.6, and 13.5 for the 500, 1500, 2500, and 3500 ppm TDS treatments, respectively.

With the exception of the 1997/98 season (when irrigation was limited), higher salinity levels in the irrigation water decreased both fruit number and fruit size. The fewer fruit and smaller fruit in the higher salinity level treatments resulted in significantly less yield. Typically, fruit count per tree decreased about 70 fruit/year for each 1000 ppm increase in TDS.

Average yields for the five years ranged from 490 boxes/ac for the non-salinized treatment trees to 335 boxes/tree for trees irrigated with 3500 ppm TDS water (Fig. 11). Total yields were not significantly different for the 500 and 1500 ppm treatment, although the 1500 ppm treatment had about 6% less yield. Overall, yields decreased about a 0.6 boxes/tree per year for each 1000 ppm increase above the base of 500 ppm TDS. At the planting density of 97 trees/ac, this amounts to about 60 boxes/acre per year reduction for each 1000 ppm increase in TDS (an 11% yield decrease for each 1000 ppm TDS increase).

Average TSS during the five years of the study ranged from 3340 lb/ac/yr for the 500 ppm treatment to 2270 lb/ac/yr for the 3500 ppm TDS treatment (Fig. 11). There was an average reduction of about 360 lb TSS per tree per year for each 1000 ppm increase in the salinity (about 11% yield decrease for each 1000 ppm TDS increase).

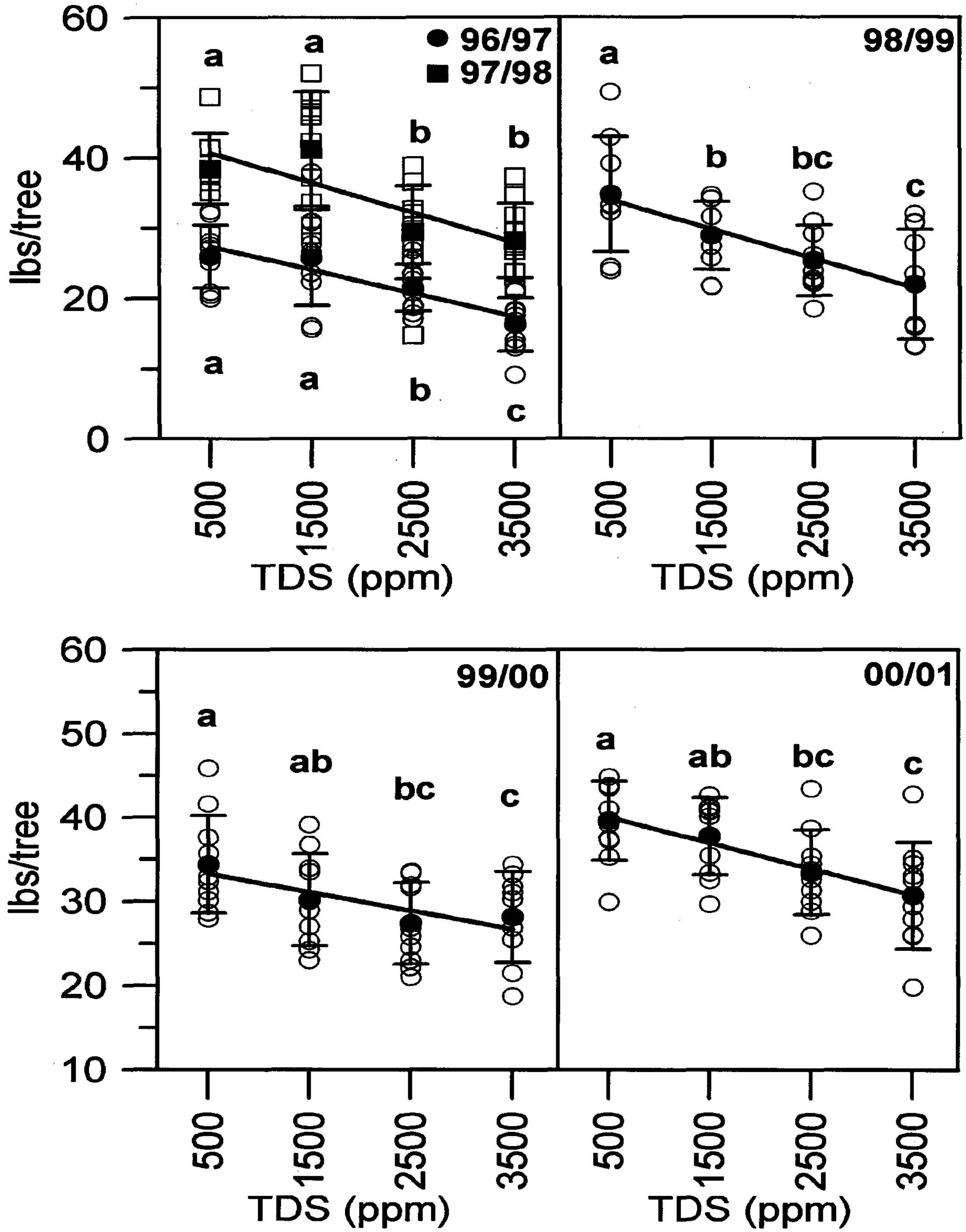

Figure 9. Total soluble solids (TSS) for 1996/97 through 2000/01 seasons by irrigation salinity level. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05). Error bars represent 1 standard deviation from the mean.

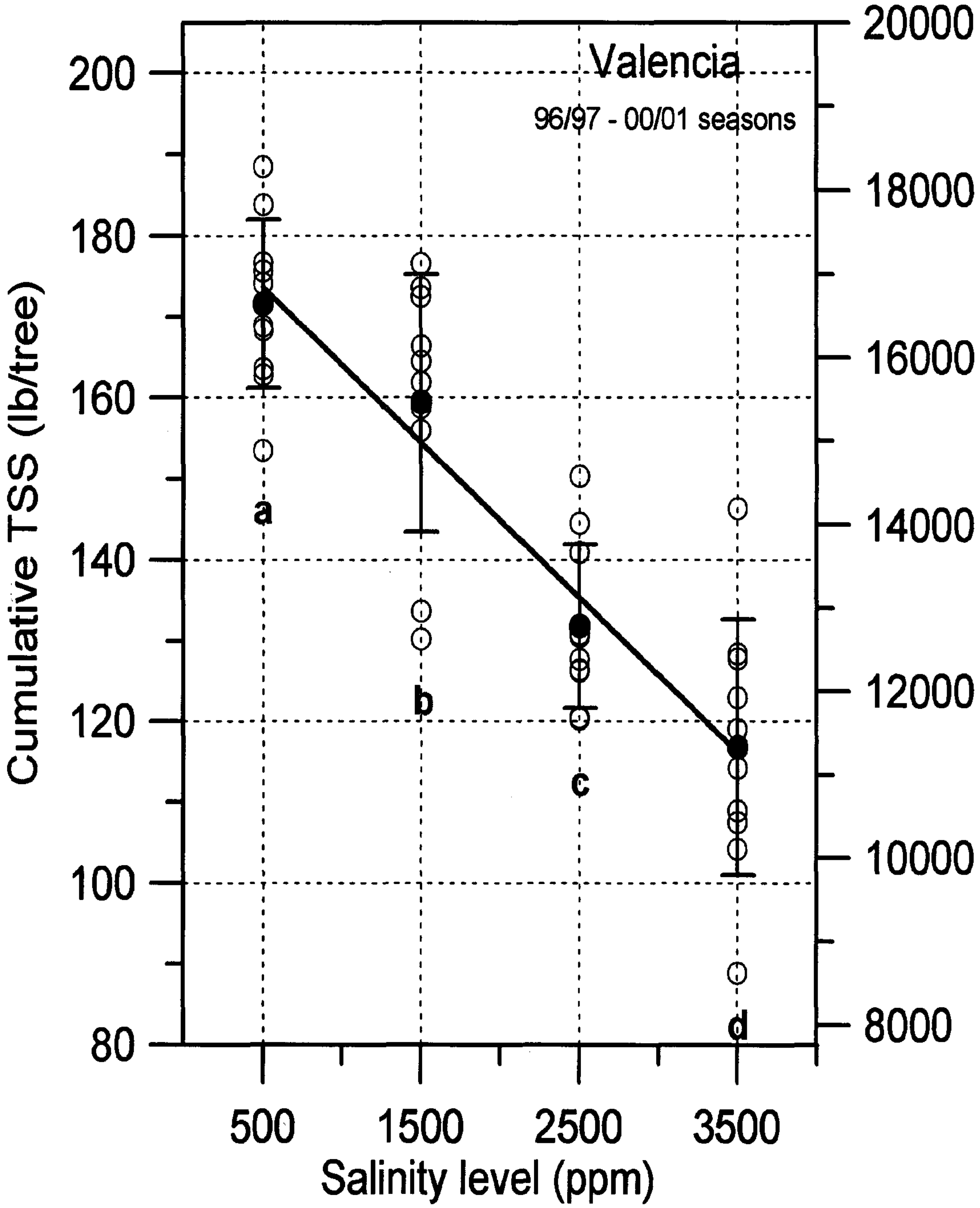

Figure 10. Cumulative total soluble solids (TSS) for 1996/97 through 2000/01 seasons by irrigation salinity level. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05). Error bars represent 1 standard deviation from the mean.

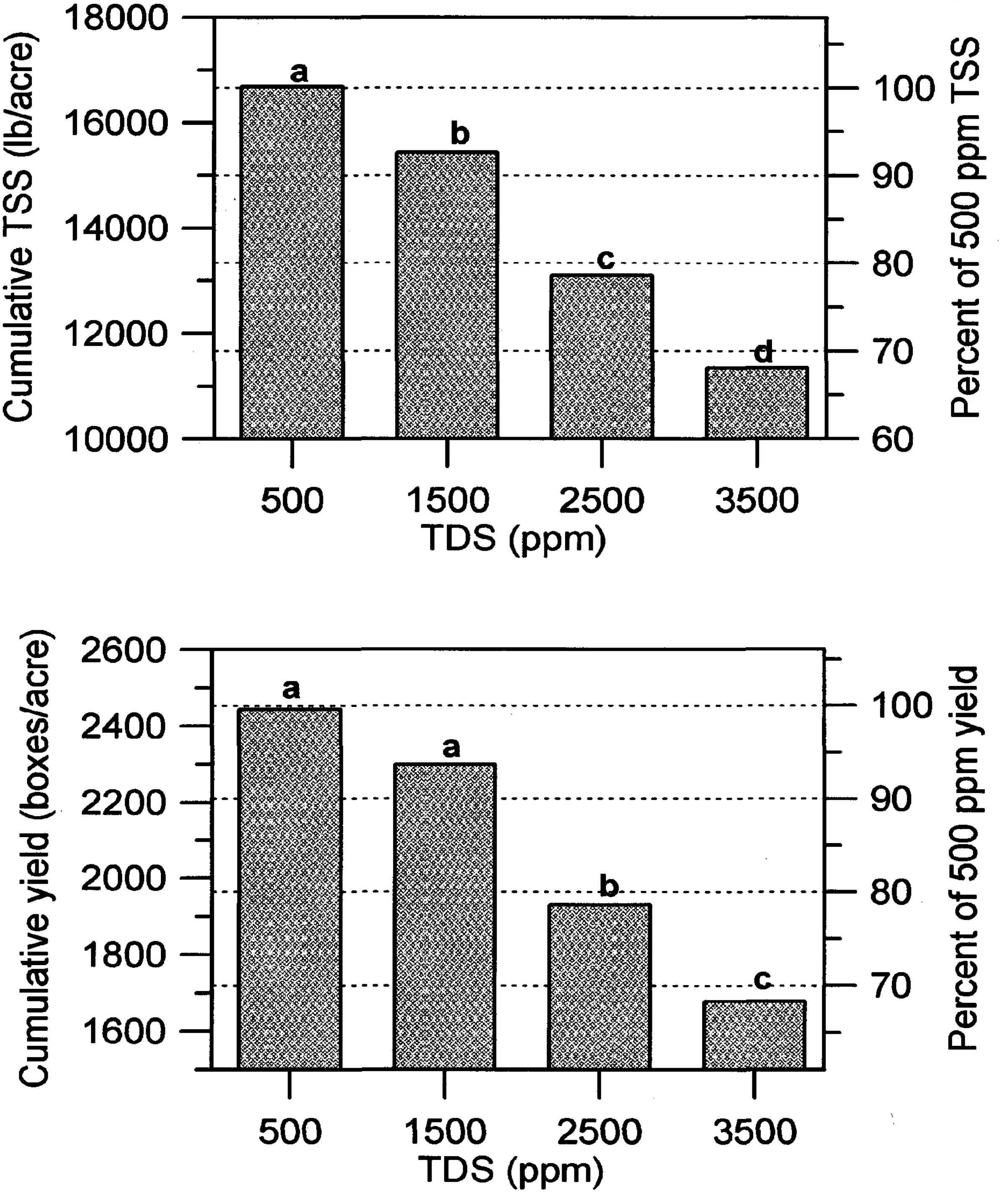

Figure 11. Five-season (1996/97 through 2000/01) cumulative yields and soluble solids by irrigation salinity level. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Effects of Saline Irrigation Water on 'Marsh' Grapefruit

Objective

The objective of the study was to measure and document the production and fruit quality changes that occur with the use of high salinity water for irrigation of mature 'Marsh' grapefruit trees under Florida flatwoods conditions.

Methods

The trees in the Marsh grapefruit experiment were on sour orange rootstock planted in 1969 on single-row beds in a commercial grove near Indiantown. Plot size was 5 trees, with 5 replications of each treatment in a randomized block experimental design. The irrigation water supply for the block was the St. Lucie Canal and was generally of excellent quality (about 500 ppm TDS).

Trees were irrigated with microsprinkler systems. The control treatment was irrigated with "good" quality water (in the range of 500 TDS) and with 3 higher levels of irrigation water salinity. Each salinity treatment added an increment of about 1000 ppm above the base rate of the control treatment (1500, 2500, and 3500 ppm). The higher salinity levels were achieved by injecting a brine mixture composed of NaCl, CaCl, and KCl (55%, 34%, and 11%, respectively, by weight) to the supply water. The brine mixture was applied during all irrigation events through the use of proportional injectors. Totalizing meters in the irrigation supply lines were used to measure irrigation applications.

Salinized irrigation began in February 1996. Irrigation management decisions were controlled by the managing company. Whenever irrigations were made, the brine solution was injected at a rate proportional to the flow rate through the lateral line.

Unfortunately, due to the negative returns for grapefruit in the last several years, the grove received minimal care. The economic situation was so poor that the fruit was not harvested in the 1998/99 season, and was left on the tree to drop off. Trees did not receive melanose and greasy spot sprays and fruit was not suitable for the fresh market in the 1997/98 through 1999/00 seasons. Since cultural practices were minimal (including irrigation) the corresponding yields were well below potential for the trees. Therefore good inferences were difficult to make from the data.

Rain and Irrigation

Rainfall in the 1996/97 citrus season was less than the long-term average for April through December (Table 18). Rainfall was scarce in April and the first part of May. Late July and early August had much less than normal rainfall, and several irrigations were at both sites in late July and throughout most of August when summer thunderstorms consistently failed to produce adequate rainfall (Fig. 12). Rainfall was lower than normal in December, when only 1.7 inches fell. Most of the irrigation occurred from late January through early April, a period which was generally rainless with above normal temperatures, and in October (Table 19).

Rainfall in the 1997/98 citrus season was adequate throughout most of the year (Table 18). Rainfall was above normal in March and April, but less than 3 inches fell in May. Nearly 32 inches of rain fell June through September. There was not a prolonged dry period with significant irrigation during the 1997/98 season.

The 1998/99 season was characterized by very high rainfall in January through March (nearly 19 inches) and low rainfall in April and May. August rainfall was lower than normal, but over 12 inches of rain fell in September. Little irrigation was required during the August 1998 through March of 1999.

Dry weather in the spring of 1999 made considerable irrigation necessary in March and April (68 hours). Rains began in May, and nearly 11 inches of rain was recorded in June. July was again a dry month, and irrigations were required.

Table 18. Rainfall (inches) for 'Marsh' grapefruit block and long-term average rain at the Indian River Research and Education Center, Ft. Pierce.

Year	Year				IRREC 1952-1999 Avg
	1996	1997	1998	1999	
Jan	-	2.40	4.80	2.00	2.25
Feb	-	1.20	9.10	0.90	2.87
Mar	8.60	3.60	4.80	0.70	3.44
Apr	1.70	3.80	2.20	0.80	2.49
May	3.50	2.90	2.70	3.00	4.81
Jun	5.00	6.60	5.10	11.00	6.92
Jul	5.60	11.40	5.10	1.50	6.93
Aug	4.10	7.50	3.80	9.39	7.09
Sep	7.10	6.20	12.30	5.66	7.93
Oct	6.50	0.90	4.10	9.61	6.51
Nov	2.55	2.40	8.40	0.80	2.91
Dec	1.65	5.30	1.00	2.13	1.97
Total	46.3	54.2	63.4	47.49	56.14

Table 19. Irrigation (hours with 15 gph emitters) for 'Marsh' grapefruit block from January 1996 through May 2000.

Year	Year				Avg
	1996	1997	1998	1999	
Jan	-	14	0	0	5
Feb	-	7	0	0	2
Mar	0	10	0	38	12
Apr	18	12	49	30	26
May	24	0	40	0	16
Jun	0	0	27	15	11
Jul	38	0	8	15	15
Aug	45	0	0	0	11
Sep	15	2	0	0	4
Oct	16	22	10	0	12
Nov	20	0	0	0	5
Dec	21	0	10	0	8
Total	197	67	144	98	127

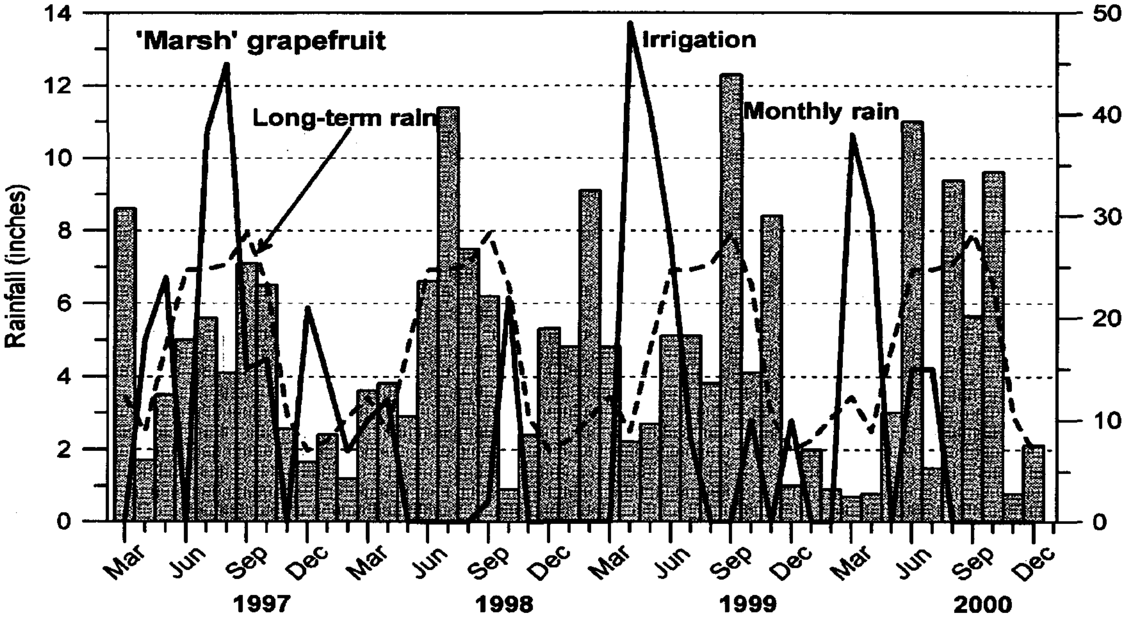

Figure 12. Monthly rainfall, irrigation, and long-term rain for 'Marsh' grapefruit block.

Fertilization

In 1996, fertilizer applications were made on January 25, June 19, and September 23. In the January and June applications, 330 lb/ac of a 15-3-156 material was applied. In the September application, 200 lb/ac of a 15-3-15 analysis material was applied. The total annual N applied was 129 lb N per acre.

The 1997 fertilizations block took place in January, June, and September. The January and September applications were made with 200 lb/ac of 15-3-15 broadcast. The June application was a "double" application with 400 lb/ac of 15-3-15 broadcast. The total annual N applied was 120 lb N per acre.

In 1998, fertilizer applications were made on April 15 and July 29 and October 20. In the April application, 225 lb/acre of 14-2-14 (1.5 Mg, 0.01B) was applied and the July application was made at a rate of 225 lb/ac with a 13-0-16 blend. The October application was 336 lb/ac of a 16-0-16. The total annual N applied was 116 lb N per acre.

In 1999, fertilizer applications were made in February and June, with applications consisting of 336 lb per acre of a 16-0-16 material. The total annual N applied was 108 lb N per acre.

Leaf Mineral Concentrations

Spring flush leaves were sampled from the grapefruit plots during July or August 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 other minerals. Solutions were prepared from the samples and they were analyzed (N, P, K, Ca, Mg, and Na) by the IFAS Analytical Research Laboratory in Gainesville. Leaf Cl concentrations were determined locally at the IRREC with a chloridometer.

There were no trends with respect to salinity level and leaf concentrations of the major elements (N, P, and K) during the 4 seasons. However, trees receiving the elevated salinity level had higher leaf Cl levels in 3 of the 4 years (Tables 20-23). In addition, leaf Na levels were elevated in the high salinity treatment leaves during the 1997/98 and 1999/00 seasons.

When leaf Cl concentrations were averaged over the four seasons, there was a definite trend of increased Cl concentration with increasing salinity level (Fig. 13). There was a major increase in accumulation of Cl in the leaves when irrigation water salinity increased over 2500 ppm TDS. On average, leaf Cl concentration increased an average of 0.04% for each 1000 ppm increase in irrigation water TDS.

Table 20. Mean leaf mineral concentrations for 'Marsh' grapefruit trees sampled August 12, 1996 (n=5).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	1.95	0.14	1.37	4.43 b	0.45 b	0.04	0.11 b
1500	1.82	0.13	1.28	5.07 a	0.50 a	0.04	0.09 b
2500	1.81	0.14	1.42	4.46 b	0.46 ab	0.05	0.11 b
3500	1.81	0.13	1.26	4.52 b	0.49 ab	0.13	0.55 a

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 21. Mean leaf mineral concentrations for 'Marsh' grapefruit trees sampled July 17, 1997 (n=5).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	1.97	0.12	1.00	5.20	0.40	0.06 b	0.13 b
1500	1.93	0.12	1.02	5.28	0.39	0.07 ab	0.14 b
2500	1.12	0.12	1.02	5.40	0.40	0.07 ab	0.12 b
3500	2.01	0.11	0.93	5.24	0.37	0.09 a	0.24 a

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 22. Mean leaf mineral concentrations for 'Marsh' grapefruit trees sampled Aug.17, 1998.

Salt Level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	1.58	0.11	1.28	4.77	0.42 a	0.07	0.116
1500	1.58	0.11	1.36	4.37	0.39 b	0.07	0.136
2500	1.63	0.11	1.25	4.71	0.41 ab	0.08	0.214
3500	1.63	0.11	1.30	4.41	0.40 ab	0.07	0.186

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05)

Table 23. Mean leaf mineral concentrations for 'Marsh' grapefruit trees picked July 25, 1999.

Salt Level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
500	1.89	0.12	1.06	4.33 b	0.33	0.06 b	0.13 b
1500	1.91	0.12	0.99	4.47 ab	0.32	0.09 a	0.18 ab
2500	1.86	0.11	0.89	4.74 a	0.31	0.08 a	0.20 a
3500	1.82	0.11	0.86	4.58 ab	0.31	0.08 a	0.21 a

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05)

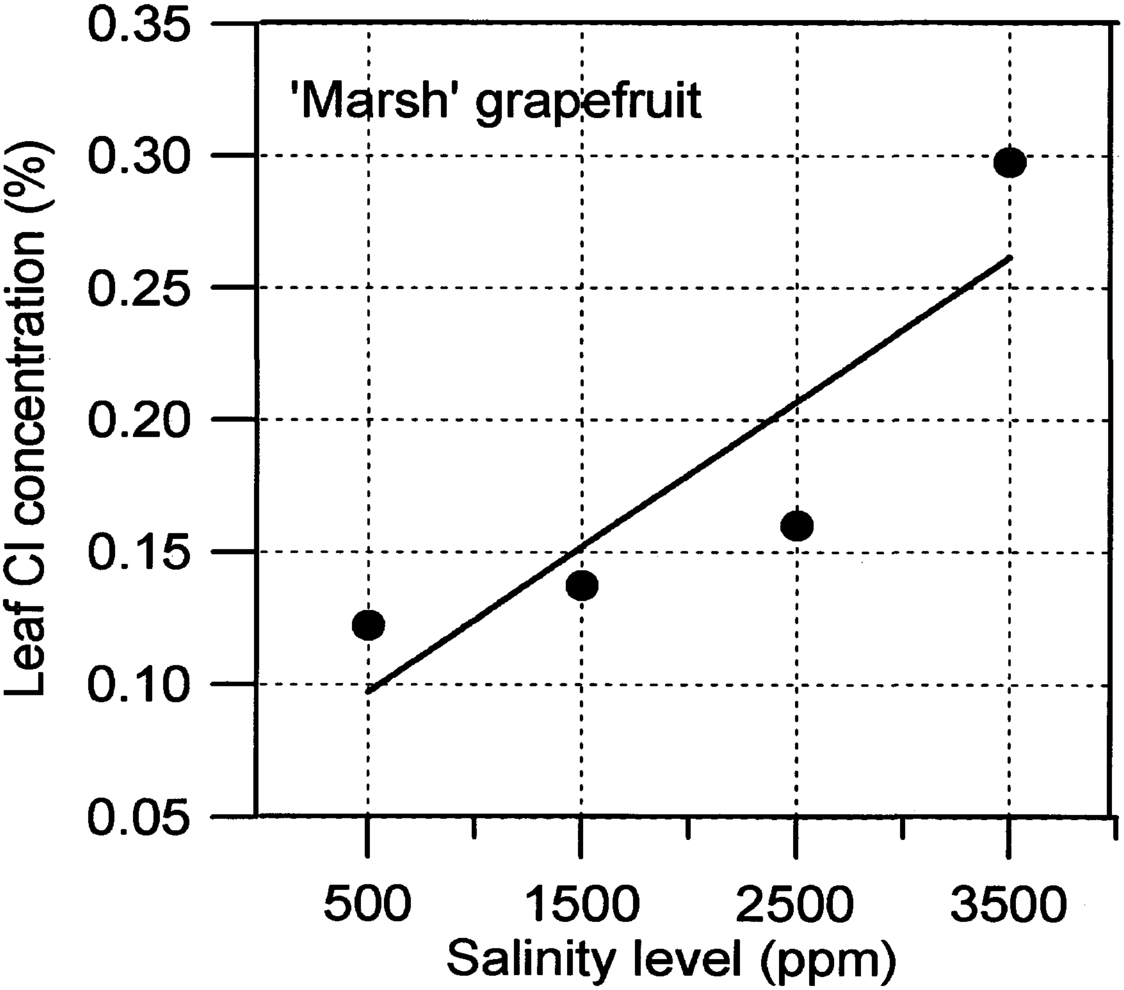

Figure 13. Mean leaf Cl concentrations in 'Marsh" grapefruit for 1996/97 through 1999/00 seasons by irrigation salinity level.

Juice Quality

The grapefruit plots were sampled in September or October of each year. In the 1996/97 season, fruit were also sampled in December. At each sampling, fruit were randomly picked from all around the trees, with a total of 40-50 fruit per plot. The fruit were analyzed at the Florida Department of Citrus Lab in Lake Alfred with standard methods for juice content, Brix, acid content and solids (lbs) per box.

There were little differences in juice quality with respect to the irrigation water salinity treatments in the 'Marsh' block (Tables 24-28). Although not statistically significant, the high salinity level tended to have smaller fruit and fruit that had a slightly higher juice content and Brix:acid ratio.

Table 24. Average juice quality parameters for 10 size-40 fruit (3 $^{12}/_{16}$ - 4 $^{5}/_{16}$ inch diameter) sampled from each plot on September 24, 1996.

Salinity level (ppm)	Juice volume (ml)	Brix (%)	Acid (%)	Brix:acid ratio
500	1270	10.1 ab	1.81	5.6
1500	1332	10.3 a	1.83	5.6
2500	1270	10.1 ab	1.78	5.6
3500	1298	9.9 b	1.77	5.6

Means with the same letter for the same parameter are not significantly different according to Duncan's Multiple Range Test at P=0.05 (n=5).

Table 25. Average juice quality parameters and peel thickness for fruit sampled from each plot on Dec. 3-4, 1996. Juice parameters are from 40 fruit randomly sampled per plot and peel thickness are from 10 size-40 fruit (3 $^{12}/_{16}$ - 4 $^{5}/_{16}$ inch diameter) per plot.

Salinity level (ppm)	Percent juice (%)	Brix (%)	Acid (%)	Brix:acid ratio	Solids per box (lb)	Peel thickness (mm)
500	56.2	10.4	1.48	7.1 a	5.00	6.2
1500	55.9	10.7	1.48	7.3 ab	5.10	6.4
2500	55.4	10.5	1.45	7.2 ab	4.96	6.5
3500	56.0	10.5	1.43	7.4 b	5.02	6.2

Means with the same letter for the same parameter are not significantly different according to Duncan's Multiple Range Test at P=0.05 (n=5).

Table 26. Mean juice quality parameters for 25 'Marsh' grapefruit picked at random on September 18, 1997.

Salt level (ppm)	Avg. weight (%)	Juice content (%)	Acid (%)	Brix	Solids per box (lb)	Brix:acid ratio
500	402	44.4 b	1.50	9.52	3.59	6.34
1500	386	45.4 ab	1.45	9.55	3.59	6.53
2500	395	46.0 a	1.46	9.43	3.69	6.45
3500	401	45.4 ab	1.47	9.43	3.54	6.43

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 27. Mean juice quality for 40 'Marsh' grapefruit picked at random September 18, 1998.

Salt level (ppm)	Average weight (g)	Juice content (% weight)	Acid (%)	Brix	Brix:acid ratio	Solids per box (lb)
500	406	41.5	1.52 a	10.00	6.60	3.53
1500	403	42.9	1.46 a	9.91	6.77	3.56
2500	389	45.7	1.44 ab	11.63	8.20	4.51
3500	386	46.3	1.37 b	9.89	7.22	3.89

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05)

Table 28. Mean juice quality for 40 'Marsh' grapefruit picked at random October 15, 1999.

Salt level (ppm)	Average weight (g)	Juice content (% weight)	Acid (%)	Brix	Brix: acid ratio	Solids per box (lb.)
500	467	50.3	1.41	9.79	6.9	4.2
1500	427	51.5	1.37	9.80	7.2	4.3
2500	441	51.9	1.40	9.74	6.9	4.4
3500	414	52.2	1.38	9.74	7.0	4.3

Means are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Yield and Size Distribution

The major-axis diameters of 50-60 fruit selected at random within each plot were measured with calipers during December or January of each year. The fruit were divided into 5-mm groups which corresponded to the traditional grapefruit sizes (fruit are sized in the packing house according to how many fit in a 4/5 bushel carton, Table 29). The number of fruit in each size category was counted and divided by the total number of fruit to get the percent of each size. The number of fruit on each tree within each plot was counted in December or January of each year to get total fruit numbers per tree. The number of boxes of fruit per tree was calculated by the sum of the number of fruit multiplied by the percent of each size divided by the number of fruit per box for that size.

Table 29. Grapefruit size categories.

Size (No. of fruit in 4/5 Bu. carton)	Diameter (inches)	Diameter (mm)
18	$5\,{}^{0}/_{16} - 5\,{}^{9}/_{16}$	125.0 - 129.9
23	$4\,{}^{11}/_{16} - 5\,{}^{4}/_{16}$	120.0 - 124.9
27	$4\,{}^{6}/_{16} - 4\,{}^{15}/_{16}$	115.0 - 119.9
32	$4\,{}^{3}/_{16} - 4\,{}^{12}/_{16}$	110.0 - 114.9
36	$3\,{}^{15}/_{16} - 4\,{}^{8}/_{16}$	105.0 - 109.9
40	$3\,{}^{12}/_{16} - 4\,{}^{5}/_{16}$	100.0 - 104.9
48	$3\,{}^{9}/_{16} - 4\,{}^{2}/_{16}$	95.0 - 99.9
56	$3\,{}^{7}/_{16} - 4\,{}^{0}/_{16}$	90.0 - 94.9
64	$3\,{}^{5}/_{16} - 3\,{}^{14}/_{16}$	85.0 - 89.9

Yields in the 1996/97 through 1998/99 seasons averaged about 3 to 3.8 boxes per tree (Tables 30-32). Due to the dry spring and inadequate irrigation and cultural practices, yields dropped to only about 1.5 boxes/tree in the 1999/2000 season (Table 33). Even with these less-than-optimum conditions, some trends emerged from the data. Trees irrigated with the 500 and 1500 ppm TDS water had similar yields, while the 2500 and 3500 ppm treatments had 11% and 14% reduction in yields compared to the 500 ppm treatment, respectively (Fig. 14).

Cumulative yields for the 4 seasons were about 12.3 box/tree for the 500 and 1500 ppm treatments compared to around 11.0 for the 2500 ppm and 10.8 for the 3500 ppm treatments. These represent 12-13% decreases in production for the higher salinity levels compared to the non-salinized trees.

Table 30. 'Marsh' size distribution and yield estimate for 1996/97 season from measurements taken January 10, 1997.

Salinity level (ppm)	Fruit size (mm)						Yield (boxes per tree)
	<95	95-100	100-105	105-110	110-115	>115	
	Percent of total fruit						
500	39	20	12	14 a	7	8	3.75
1500	32	28	16	14 a	5	5	3.78
2500	53	31	13	2 b	1	0	3.39
3500	46	22	20	8 ab	2	1	3.47

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 31. 'Marsh' size distribution and yield estimate for 1997/98 season from measurements taken January 26, 1998.

Salinity level (ppm)	Fruit size (mm)						Yield (boxes per tree)
	<95	95-100	100-105	105-110	110-115	>115	
	Percent of total fruit						
500	15	17	20	20	7 b	21	3.6
1500	13	16	25	20	11 ab	16	3.7
2500	16	14	22	17	15 a	15	3.3
3500	16	19	25	18	11 ab	11	3.0

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 32. 'Marsh' size distribution and yield estimate for 1998/99 season from measurements taken December 18, 1998.

Salinity level (ppm)	Fruit size (mm)						Yield (boxes per tree)
	<95	95-100	100-105	105-110	110-115	>115	
	Percent of total fruit						
500	28	21	7	19 b	14	10	3.5
1500	38	19	11	15 b	10	8	3.4
2500	18	17	12	30 a	15	8	2.9
3500	31	15	9	22 ab	12	10	2.9

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 33. 'Marsh' size distribution and yield estimate for 1999/00 season from measurements taken December, 1999.

Salinity level (ppm)	Fruit size (mm)						Yield (boxes per tree)
	<95	95-100	100-105	105-110	110-115	>115	
	Percent of total fruit						
500	14	8	20	14	15	11	1.5
1500	18	13	15	17	10	7	1.4
2500	18	13	18	15	7	10	1.4
3500	17	14	20	15	12	8	1.4

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05)..

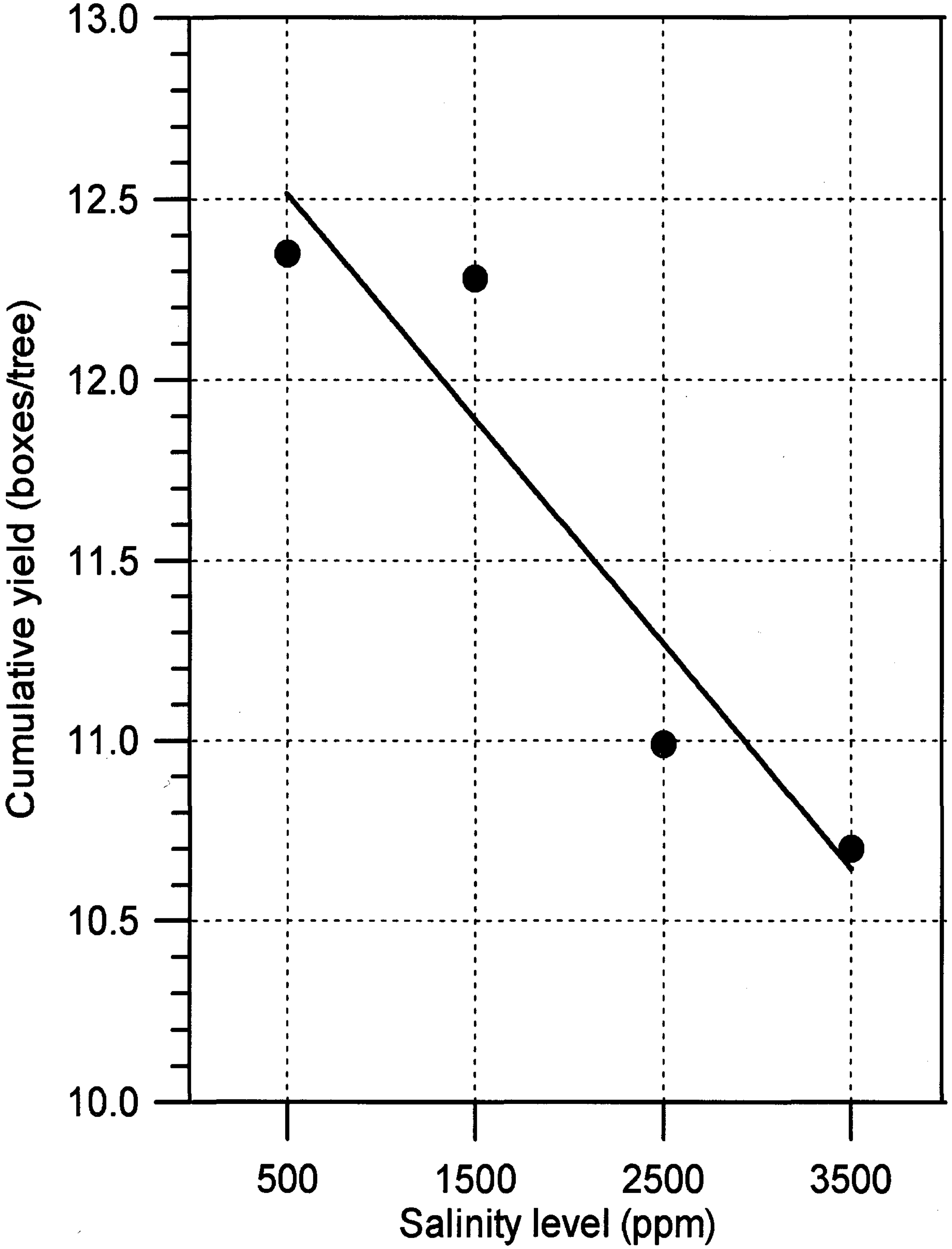

Figure 14. Cumulative 4-year (96/97-99/00) yields (boxes/tree) by irrigation salinity level for 'Marsh' grapefruit.

Conclusions

The data collected in this study was from a grapefruit block that was producing well below its potential due to minimal cultural inputs during all except the first year of the study. The trees in the study had the capacity to bear 5-8 boxes per tree. However, the average production during the study period was 3 boxes per tree or less. Even though cultural practices were poor and little irrigation was applied (even in the critical periods in the 1999/00 season during the critical bloom, fruit set, and early development stages), significant observations of the effects of salinity were evident. High salinity levels were expressed in elevated leaf Cl levels. Typically, leaf Cl levels increased about 0.04% for each 1000 ppm increase in irrigation water TDS. With more intense management, this rate would be expected to increase.

Salinity level had little effect on internal juice quality parameters. However, higher salinity levels tended to have smaller fruit, but increased juice content and soilds/box. Yield response was similar for the 500 and 1500 ppm rates, and the 2500 ppm treatment was only about 3% more than the 3500 ppm treatment.

Cumulative yields for the 4 seasons were 12.4 box/tree for the 500 ppm treatment and 12.3 for the1500 ppm treatment, compared to 11.0 for the 2500 ppm and 10.7 for the 3500 ppm treatments. These represent 11% (2500 ppm) and 14% (3500 ppm) decreases in production for the higher salinity levels compared to the non-salinized trees. If threshold of 1500 ppm is assumed, the yield decreases represent about a 7% decrease in yield for each 1000 ppm above the base of 1500 ppm. These values represent data from non-optimum cultural operations. The effects of salinity on yield reductions would be expected to be greater on groves operated to achieve optimum production.

Effects of Saline Irrigation Water on 'Ray Ruby' Grapefruit

OBJECTIVE

The objective of the study is to measure and document the production and fruit quality changes that occur with the use of high salinity water for irrigation of red grapefruit trees under Florida flatwoods conditions.

METHODS

A field experiment with 'Ray Ruby' grapefruit block located at the Indian River Research Education Center was initiated for the study. The trees were planted in 1990 on 50 foot wide double-row beds. Tree spacing was 15 ft in-row by 24 ft across-row, with a tree density of 116 trees/acre. Trees used in the study were on Swingle citrumelo and Carrizo citrange rootstocks. Each plot contained 4 trees on each rootstock, with 4 replications of each water salinity and rootstock combination arranged in a randomized block experimental design.

All trees were irrigated with microsprinkler systems. The control treatment was irrigated with water from a surficial aquifer well with a salinity concentration of about 500 ppm TDS. Three 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 1200 ppm above the base rate of the control treatment (1600, 2700, and 3800 ppm). The brine mixture was applied during all irrigation events at a rate proportional to the flow rate through the lateral line.

Rain and Irrigation

Although rainfall in 1997 was less than the long term average of about 56 inches, the rain was well distributed (Table 34). As a result, only 57 hours of irrigation were applied to the trees (Table 35). Most of the irrigations were made during April and early May (Fig. 15).

The 1998 season was characterized by above normal rainfall in February and March and about half the normal rainfall in June and July. This was followed by very high rains, with nearly 30 inches of rain falling from mid-August to November. The annual rainfall of 53 inches was slightly below the long-term average.

Dry weather in the spring of 1999 made considerable irrigation necessary in March though May during the critical flowering and fruit set period. Over 200 hours of irrigation was required in the March through mid-May period. Rains began in May, and nearly 11 inches of rain was recorded in June. July was again a dry month, and 32 hours of irrigation was required. Hurricanes Floyd and Irene in September and October resulted in excessive rainfall. Hurricane Irene, which crossed the state from southwest to northeast passed over the area in mid-October. The winds were high enough to blow 10-15% of the fruit off the trees.

Rainfall was well below normal during the winter of 1999/00 and the drought continued throughout all of 2000. Annual rainfall for 2000 was nearly 20 inches below normal, and irrigations were required throughout the year. Over 700 hours of irrigation was required, with applications of 4 hours per day often running continuously for several weeks.

The study period encompassed years with above average rainfall requiring little irrigation (1997 and 1998), near average rainfall conditions (1999), and extended drought requiring very high irrigation applications (2000). Over the four years of the study, irrigation averaged 288 hours per year. During 1997 and 1998, only 20% and 27% of the average irrigation hours were required, respectively. In 1999, the 304 hours of irrigation were 6% above average. During the extended drought in 2000, irrigation hours were about 2.5 times average.

Table 34. Rainfall (inches) for 'Ray Ruby' grapefruit block.

Month	Year				1952-2000 Avg
	1997	1998	1999	2000	
Jan	2.98	1.67	3.12	2.00	2.25
Feb	1.36	4.49	1.45	1.29	2.87
Mar	1.22	4.87	0.57	2.68	3.44
Apr	7.40	2.47	3.52	2.46	2.49
May	2.12	2.42	5.20	0.75	4.81
Jun	6.69	3.14	10.63	6.61	6.92
Jul	6.68	3.43	1.06	6.79	6.93
Aug	11.29	11.77	9.96	2.32	7.09
Sep	3.75	7.00	9.92	3.73	7.93
Oct	2.13	1.79	11.52	6.29	6.51
Nov	3.37	8.67	1.60	0.24	2.91
Dec	0.64	0.91	1.14	2.85	1.97
Total	49.63	52.63	59.69	38.01	55.76

Table 35. Irrigation (hours with 10 gph emitters) for 'Ray Ruby' grapefruit block.

Month	Year				Avg
	1997	1998	1999	2000	
Jan	2	0	0	36	10
Feb	5	0	16	25	12
Mar	10	0	60	68	35
Apr	17	20	112	80	57
May	18	18	40	88	41
Jun	9	30	0	32	18
Jul	0	6	32	48	22
Aug	0	0	0	64	16
Sep	0	0	0	68	17
Oct	5	0	0	64	17
Nov	0	0	20	80	25
Dec	0	4	24	60	22
Total	57	78	304	713	288

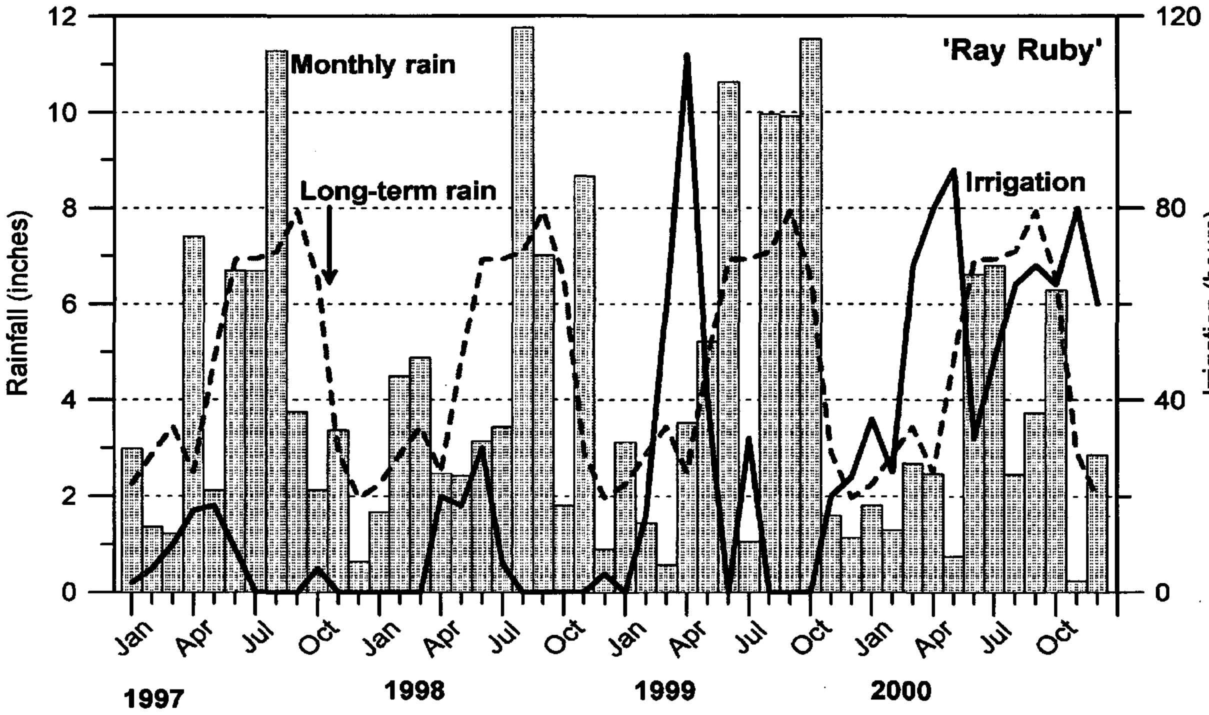

Figure 15. Monthly rainfall, irrigation, and long-term rain for 'Ray Ruby' grapefruit block.

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. Applications were made according to the following:

1997

Three applications (Feb 20 June 16, Oct 15) with 5.0 lb/tree of 8-4-8 material applied. A total of 140 lb N per acre was applied for the year.

1998

Applications in 1998 included 5.0 lb/tree of 8-4-8 applied on April 9, July 23, and November 24. Total for the year was 140 lb N per acre.

1999

In 1999, 5.0 lb/tree of 8-4-8 was applied on February 24 and June 4, and 5.2 lb/tree of 8-4-8 was applied on October 4. The total annual N applied was 142 lb/acre.

2000

Fertilizer applications in 2000 were made on Feb. 3 with 5.75 lb/tree, June 20 with 5.25 lb/tree, and Nov. 17 at 5.5 lb/tree of 8-4-8 material. The total annual N applied was 153 lb/acre.

Leaf Mineral Concentrations

Spring flush leaves were sampled from 'Ray Ruby' grapefruit plots during the 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 other minerals. Solutions were prepared from the samples and they were analyzed (N, P, K, Ca, Mg, and Na) by the IFAS Analytical Research Laboratory in Gainesville (1997 - 1999) or Pioneer Labs, Ft. Pierce (2000). Leaf Cl concentrations were determined at the IRREC with a chloridometer.

With the exception of leaf Cl levels, little differences were noted in leaf mineral concentrations among rootstocks or salinity levels (Tables 36 through 39). During 1997 and 1998, when few irrigations were required, there were only small differences in leaf Cl among salinity levels. However, in 1999 and 2000 when significant irrigations were required, leaf Cl concentrations increased. Of all the commonly used rootstocks in Florida, Carrizo has the highest tendency to accumulate Cl. Normally leaf Cl concentrations of 0.5% or more indicate salt accumulation. Due to the high irrigation levels in 1999 and 2000, even the lowest salinity levels produced leaves on Carrizo that were nearly double 0.5% critical level. In addition, leaves from trees on Carrizo accumulated nearly twice as much Cl as those on Swingle, even at lower salinity levels.

Table 36. Mean leaf mineral concentrations for 'Ray Ruby' grapefruit samples taken July 1997 (n=4).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
Carrizo							
500	2.32	0.18	1.45	4.74	0.68	0.18	0.08 b
1600	2.45	0.16	0.99	4.23	0.67	0.16	0.11 ab
2700	2.72	0.15	1.03	4.17	0.72	0.15	0.11 ab
3800	2.48	0.15	1.15	4.14	0.71	0.15	0.14 a
Swingle							
500	2.37	0.16 b	1.18	4.49 a	0.67	0.15 b	0.34
1600	2.50	0.15 b	1.21	3.97 ab	0.59	0.15 b	0.21
2700	2.61	0.15 b	1.44	3.93 b	0.53	0.15 b	0.23
3800	2.55	0.17 a	1.42	4.09 ab	0.54	0.17 a	0.39

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 37. Mean leaf mineral concentrations for 'Ray Ruby' grapefruit trees sampled July 1998 (n=4).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
Carrizo							
500	1.86	0.14	0.94	3.39	0.53 b	0.11	0.69
1600	1.65	0.14	0.76	3.31	0.54 b	0.07	0.71
2700	1.73	0.13	0.89	3.49	0.59 ab	0.08	0.75
3800	1.64	0.13	0.87	3.61	0.66 a	0.08	0.80
Swingle							
500	1.67	0.14 ab	0.85	4.08 a	0.44	0.10 a	0.35
1600	1.82	0.12 b	1.01	3.49 b	0.39	0.07 b	0.22
2700	1.79	0.13 b	0.98	3.71 b	0.43	0.07 b	0.24
3800	1.82	0.16 a	1.02	3.66 b	0.41	0.08 ab	0.29

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 38. Mean leaf mineral concentrations for 'Ray Ruby' grapefruit trees sampled July 1999 (n=4).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
Carrizo							
500	1.91	0.14	0.91	3.66	0.49	0.08 ab	1.02 b
1600	1.94	0.14	1.08	3.41	0.46	0.07 b	1.87 a
2700	2.10	0.13	1.02	3.45	0.46	0.09 ab	1.57 ab
3800	2.05	0.13	1.01	3.36	0.45	0.12 a	1.95 a
Swingle							
500	1.82 b	0.15	1.21	3.66	0.37	0.07	0.51
1600	2.01 a	0.14	1.16	3.50	0.40	0.06	0.55
2700	2.08 a	014	1.29	3.32	0.40	0.09	0.42
3800	2.09 a	0.15	1.35	3.11	0.39	0.10	0.71

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 39. Mean leaf mineral concentrations for 'Ray Ruby' grapefruit trees sampled July 2000 (n=4).

Salt level (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)
Carrizo							
500	2.13	0.17 a	1.24	3.11	0.50 ab	0.03 a	0.90 b
1600	2.47	0.15 b	1.06	3.70	0.45 b	0.04 ab	1.14 ab
2700	2.40	0.15 b	0.84	3.28	0.56 ab	0.05 a	1.77 a
3800	2.27	0.13 c	0.97	3.08	0.62 a	0.05 a	1.61 ab
Swingle							
500	2.24 ab	0.15	1.20	3.44	0.44	0.03	0.26 b
1600	2.62 a	0.14	1.18	3.32	0.39	0.04	0.35 b
2700	2.44 ab	0.16	1.14	3.41	0.43	0.04	0.47 ab
3800	2.17 b	0.16	1.15	3.10	0.49	0.04	0.71 a

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

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 in the 3800 ppm treatment trees were almost double that of the non-salinized trees (Tables 38 and 39). In addition, leaf Na levels were elevated in the high salinity treatment leaves during the 1999 and 2000 season.

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 the 3800 ppm treatment, nearly three times that of the 500 ppm 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 (Figs. 16 and 17). Leaf Cl concentration in Carrizo increased an average of 0.2% for each 1000 ppm increase in irrigation water TDS. For Swingle, the increase in leaf Cl concentration was considerable less, averaging of 0.03% for each 1000 ppm increase in irrigation water TDS.

Fruit Size

The quantity of fruit harvested along with fruit size and packout percentage are major factors determining returns to fresh fruit producers. Larger fruit generally bring higher fruit prices, especially early in the season. Fruit are sized at the packing house based on how many fit in a 4/5 bushel 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 (Fig. 18). Therefore, the diameter versus pack size data for oranges were used to develop a regression curve which was used to estimate boxes from fruit number and fruit size.

In the 1998 and 2000 seasons, the maximum diameter of all fruit from harvested trees was measured using a portable sizing machine that uses optical imaging (infrared). The number of fruit in each of the normal pack size categories was totaled for each tree and statistically analyzed. (Tables 40 and 41).

In the 1998 season when adequate rainfall negated the need for irrigations through much of the year, there was not much difference in the size distribution of fruit among salinity treatments (Fig. 19). However, in the 2000 season, fruit on both rootstocks tended to decrease in size as the salinity level increased. Trees on Carrizo irrigated with 500 ppm water had about 50% more size 36 and larger fruit during the 2000 season than trees watered with 2700 or 3800 ppm water. The results were even more dramatic for Swingle rootstock, as the trees irrigated with 500 ppm water had 1.5 - 2 times as many size 36 and larger fruit than trees watered with 1600 ppm TDS or higher salinity. For both rootstocks, both the number of fruit and the size of the fruit tended to decrease with increasing salinity in the irrigation water.

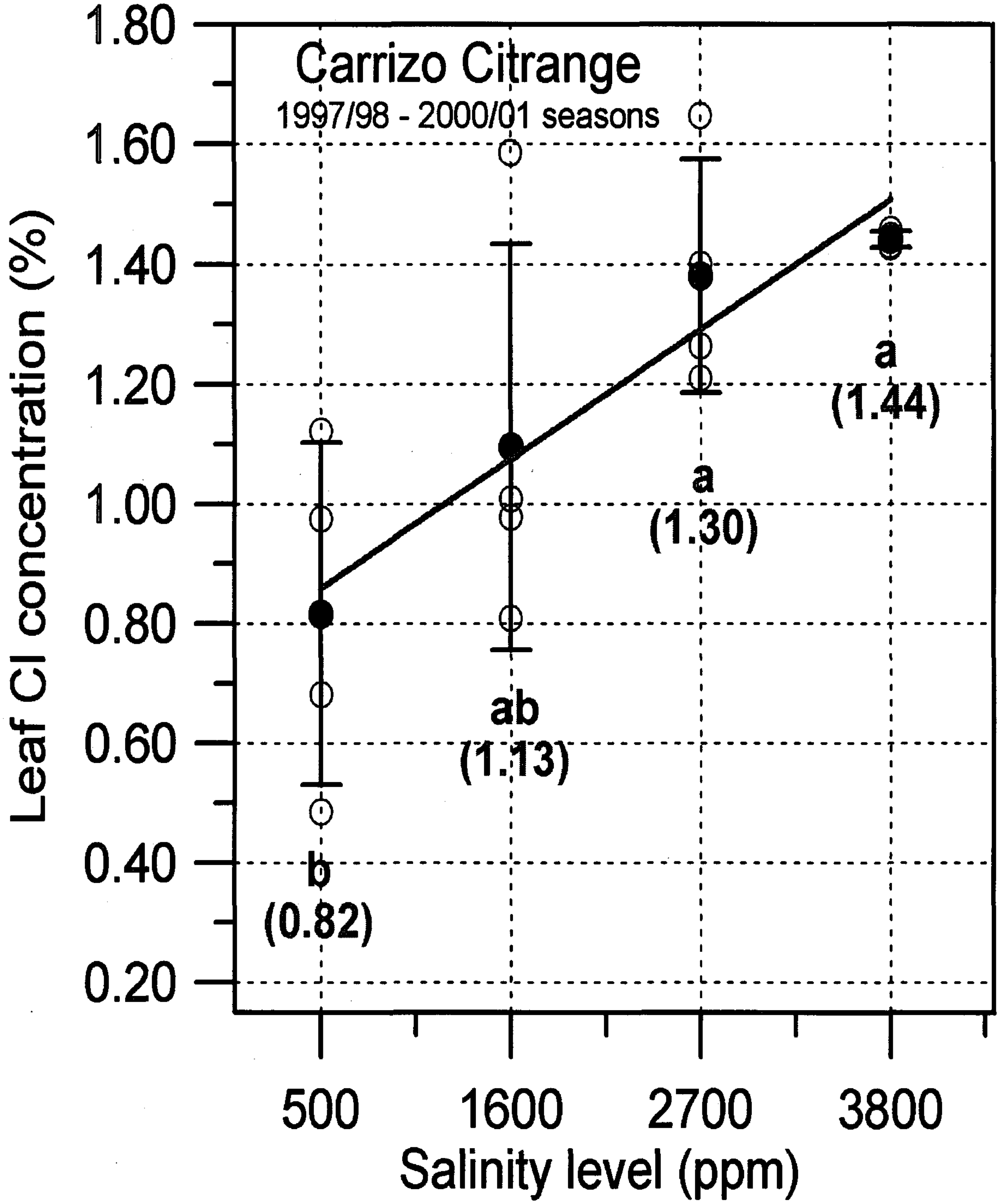

Figure 16. Mean leaf Cl concentrations for 1997/98 through 2000/01 seasons for 'Ray Ruby' grapefruit on Carrizo citrange rootstock trees. Means followed by the same letter are not significantly different according to Duncan's multiple range (n=16, P=0.05).

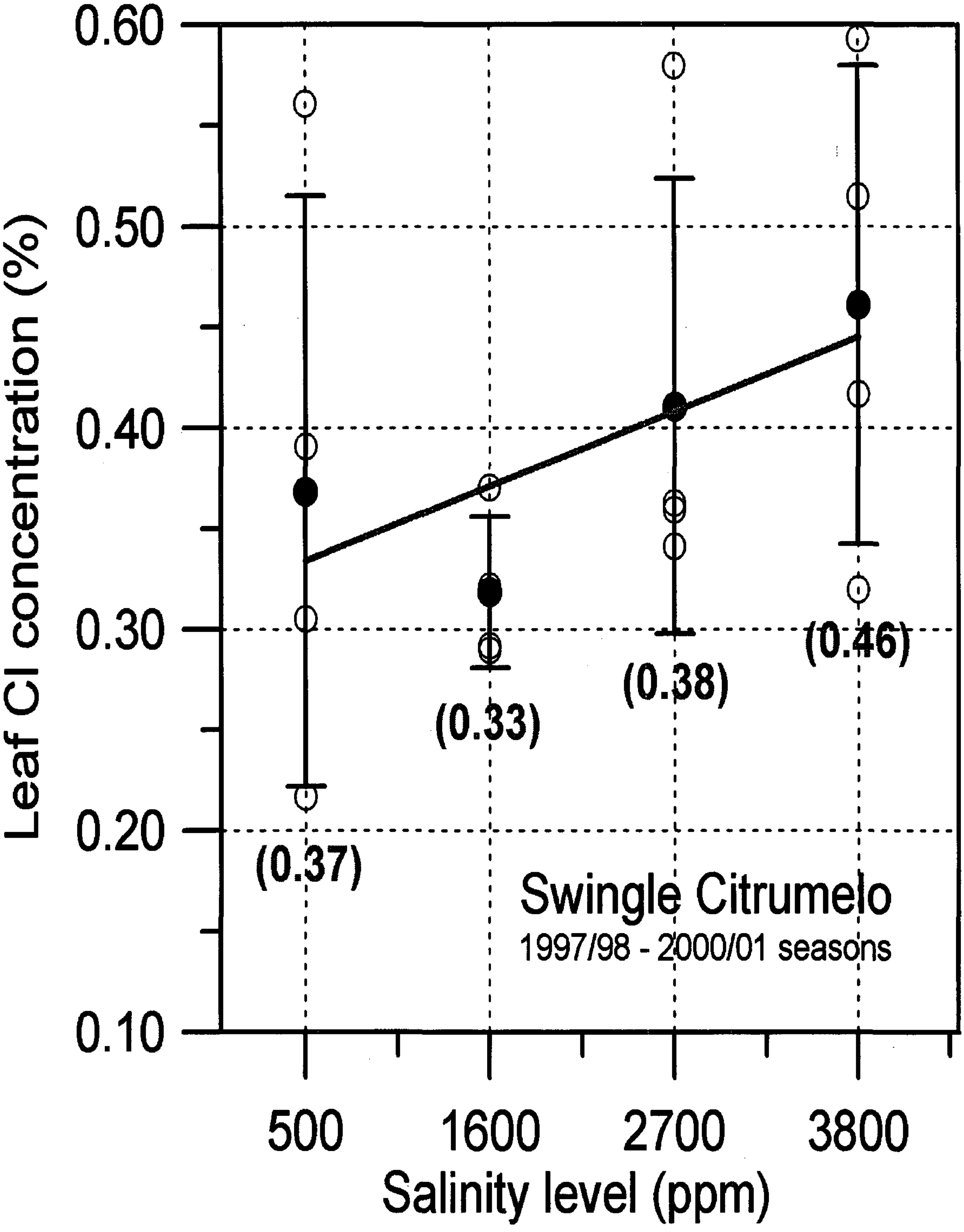

Figure 17. Mean leaf Cl concentrations for 1997/98 through 2000/01 seasons for 'Ray Ruby' grapefruit on Swingle citrumelo rootstock trees. Means are not significantly different according to Duncan's multiple range (n=16, P=0.05).

Table 40. Size distribution (percent of fruit in each size class) and yield for 'Ray Ruby' grapefruit harvested December 1998.

Salt level (ppm)	Fruit size (No. per carton)				Total No. fruit	Mean fruit dia. (mm)
	Less than 48	48 & 40	36 & 32	Larger than 32		
Carrizo Citrange						
500	157	103	17 ab	-	278	91
1600	138	89	11 b	-	239	92
2700	143	101	18 a	-	264	91
3800	128	109	19 a	-	258	92
Swingle Citrumelo						
500	224 a	126	13 b	-	363 a	90 b
1600	150 b	112	16 ab	-	278 b	91 a
2700	168 b	124	17 ab	-	310 b	91 a
3800	144 b	120	21 a	-	287 b	92 a

Means followed by the same letter in the same column are not significantly different according to Duncan's multiple range test (P=0.05).

Table 41. Size distribution (percent of fruit in each size class) and yield for 'Ray Ruby' grapefruit harvested December 2000.

Salt level (ppm)	Fruit size (No. per carton)				Total No. fruit	Mean fruit dia. (mm)
	Less than 48	48 & 40	36 & 32	Larger than 32		
Carrizo Citrange						
500	52	85	92 a	39	270 a	101
1600	84	67	70 b	45	252 ab	101
2700	83	84	54 ab	32	270 b	99
3800	60	60	51	35	206 b	102
Swingle Citrumelo						
500	45 b	88	112 a	62 a	309	104 a
1600	94 a	100	81 ab	28 b	302	98 b
2700	66 ab	82	78 ab	40 b	266	101 ab
3800	84 ab	90	63 b	25 b	262	99 b

Means followed by the same letter in the same column are not significantly different according to Duncan's multiple range test (P=0.05).

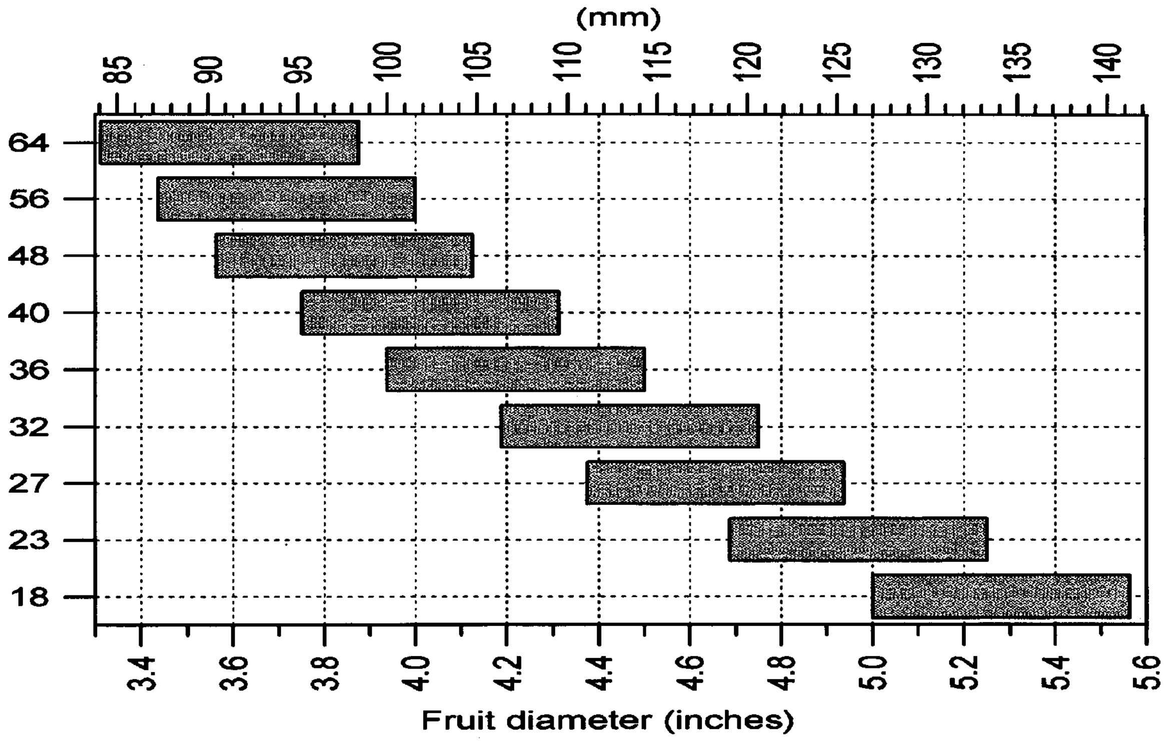

Figure 18. Fruit diameter ranges by pack size for Florida grapefruit.

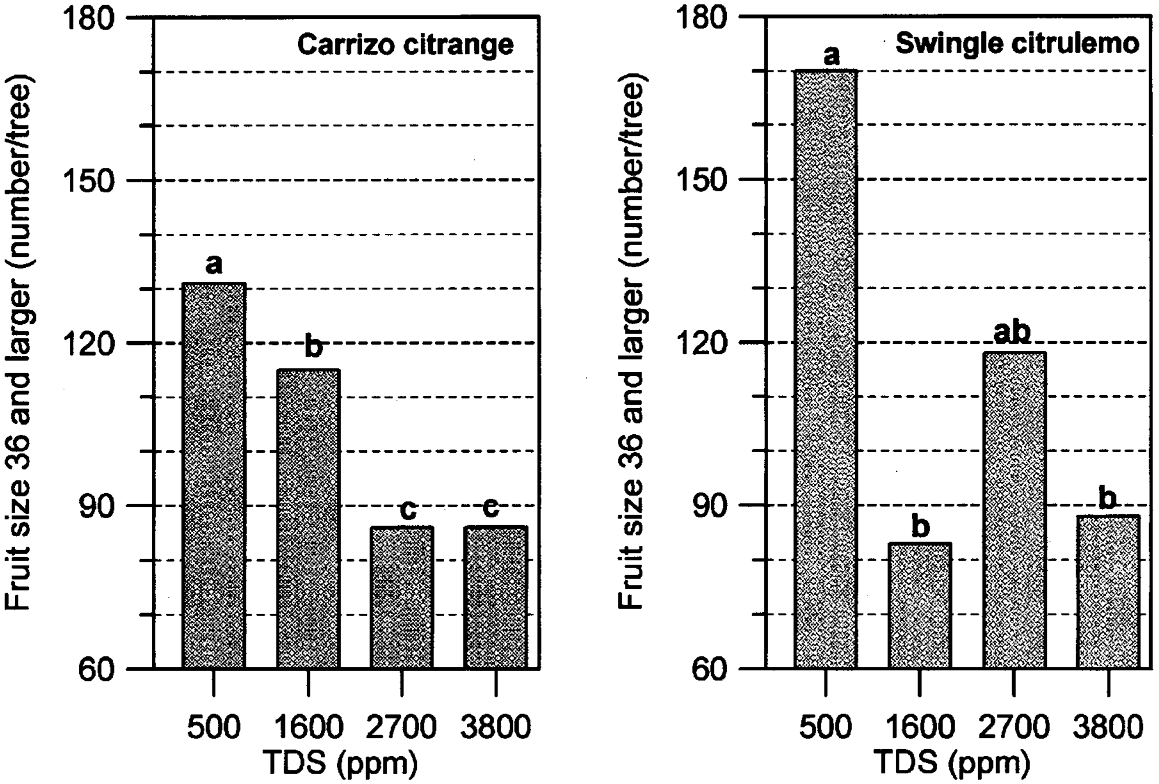

Figure 19. Number of size 36 and larger grapefruit harvested per tree in December 2000 by irrigation salinity level. Means followed by the same letter are not significantly different according to Duncan's multiple range (n=16, P=0.05).

Fruit Yield

In each of the seasons, trees were harvested individually during the commercial harvest. In each season, the harvest occurred in mid- to late-December. At harvest, all of the fruit from each tree was picked and then volumetrically measured or run through the portable sizing unit that weighed, sized, and counted.

Over the four years of the study, the yield on trees irrigated with the 500 ppm water increased significantly from about 3.5 boxes/tree to over 5.0 boxes/tree as the trees matured (Table 42). Even the trees watered with 3800 ppm water saw a 20%+ increase in production over the 4-year period.

Even in 1997 and 1998, when irrigations were minimal, there were yield reductions with increased salinity in the irrigation water for the trees on Carrizo (Fig. 20). The yield reductions for trees on Carrizo between the 500 ppm and 3800 ppm water salinity levels were 40% in 1997, 30 % in 1998, 54% in 1999, and 71% in 2000.

There were no significant yield reductions with increased salinity for trees on Swingle during the 1997 season (Fig. 21). However, the yield reductions for trees on Swingle between the 500 ppm and 3800 ppm water salinity levels were 37% in 1998, 18% in 1999, and 72% in 2000.

Table 42. 'Ray Ruby' fruit yield (boxes/tree) by season (n=16).

Salt level (ppm)	1997/98	1998/99	1999/00	2000/01	Total	% of 500 ppm yield
Carrizo Citrange						
500	3.5 a	3.5 a	3.7 a	5.3 a	16.0	100
1600	3.2 ab	3.0 ab	3.4 ab	4.4 ab	13.0	81
2700	2.5 b	2.9 ab	2.3 b	3.5 bc	11.2	70
3800	2.5 b	2.7 b	2.4 b	3.1 c	10.7	67
Swingle Citrumelo						
500	3.2	4.1 a	3.3 ab	5.5 a	16.1	100
1600	3.2	3.5 b	3.6 a	3.6 b	13.9	86
2700	3.0	3.2 b	2.9 bc	3.2 b	12.3	76
3800	2.6	3.0 b	2.8 c	3.2 b	11.6	72

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range test (P=0.05).

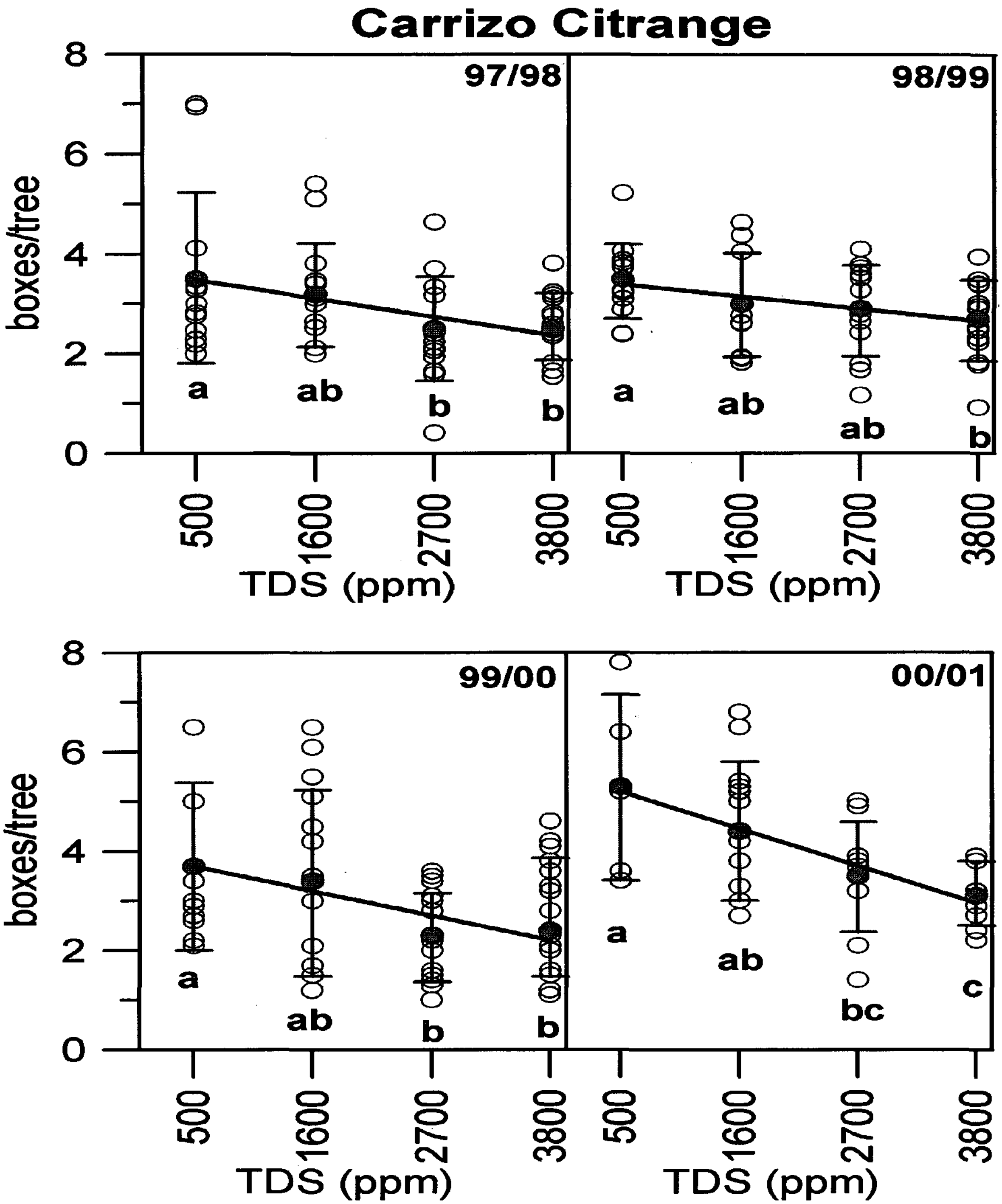

Figure 20. Seasonal yield (boxes/tree) for 1998/99 through 2000/01 seasons for 'Ray Ruby' grapefruit on Carrizo citrange rootstock by irrigation salinity level. Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range test (P=0.05). Error bars represent 1 standard deviation from the mean.

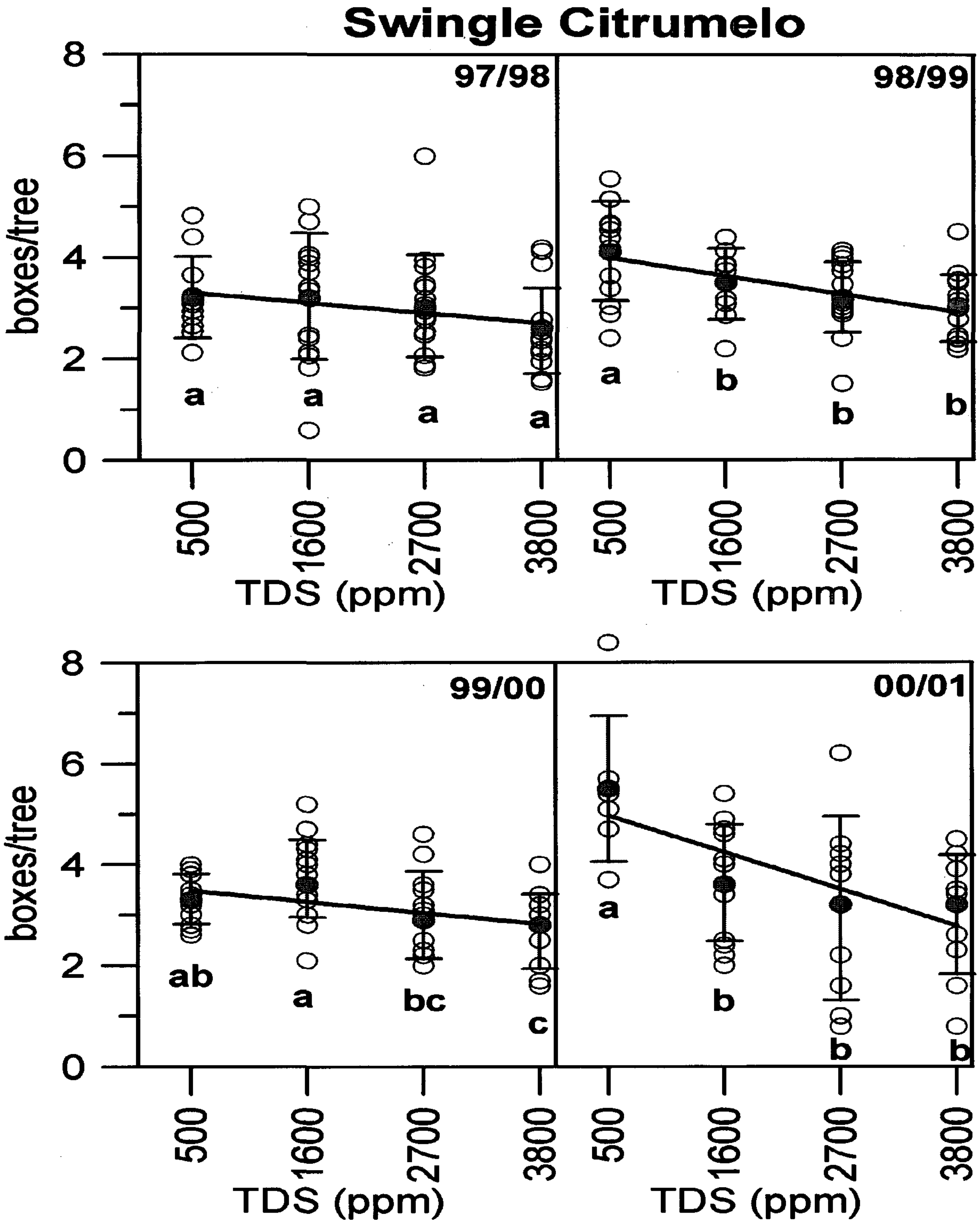

Figure 21. Seasonal yield (boxes/tree) for 1998/99 through 2000/01 seasons for 'Ray Ruby' grapefruit on Swingle citrumelo rootstock by irrigation salinity level. Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range test (P=0.05). Error bars represent 1 standard deviation from the mean.

Over the 4 seasons, the cumulative yields versus salinity curves for both rootstocks were quite similar (Fig. 22), Average total yields for the 500 ppm TDS water were 16.0 boxes per tree for the Carrizo trees compared to 16.1 boxes/tree for the Swingle trees. The 3500 ppm treatment resulted in about 30% less yield than the non-salinized treatment trees for both rootstocks (Table 42). This translates to a 35-45 box per acre per year decrease in yield for each 1000 ppm increase above the base of 500 ppm TDS.

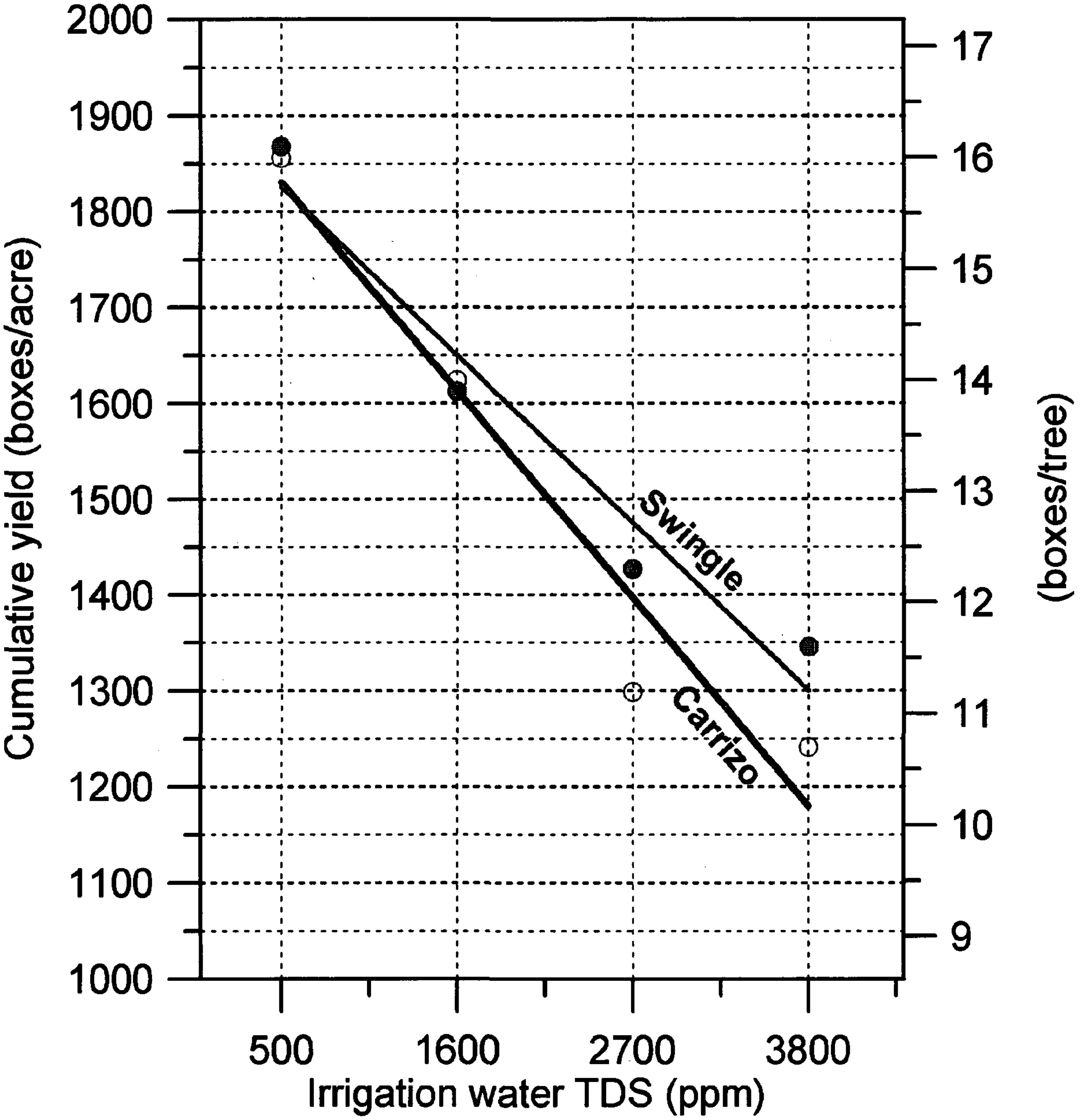

Figure 22. Cumulative yields for 1998/99 through 2000/01 seasons for 'Ray Ruby' grapefruit on Carrizo citrange and Swingle citrumelo rootstocks.

Juice Quality

The 'Ray Ruby' grapefruit plots were only sampled for juice analysis in December of 1999 and December 2000. Fruit were randomly picked from all around the trees, with a total of 50-60 fruit per plot. The fruit were analyzed at the Florida Department of Citrus Lab in Lake Alfred with standard methods for juice content, Brix, acid content and solids (lbs) per box. Total solids produced per tree was calculated by multiplying yield (boxes/tree) by the solids per box determined from the juice sample for each plot.

The non-salinized trees had significantly larger fruit compared to the rest of the treatments. In 1999, the highest salinity rate produced higher solids per box for fruit from Carrizo trees (Table 43). This tendency was not repeated in 2000 nor was it evident in the fruit sampled from trees on Swingle (Table 44). In both years, the Brix:acid ratio was slightly higher for fruit from Carrizo trees as compared to Swingle.

In the 2000/01 season, both rootstocks showed decreased solids as the salinity rate increased (Table 45). The 3500 ppm treatment produced 30-35% less solids than the non-salinized treatment trees for both rootstocks (Fig. 23). This translates to a decrease of 240 lb/ac per year (Swingle) to 300 lb/ac per year (Carrizo) decrease in solids for each 1000 ppm increase above the base of 500 ppm TDS (at a density of 116 trees/acre).

Table 43. Mean juice quality parameters for 50 'Ray Ruby' grapefruit picked at random in December 1999 (n=4).

Salt level (ppm)	Avg. weight (%)	Juice content (%)	Acid (%)	Brix	Brix:acid ratio	Solids per box (lb)
Carrizo Citrange						
500	435 a	58.2	1.02 b	9.2 b	9.1 a	4.6 b
1600	390 ab	57.1	1.14 a	9.4 b	8.3 b	4.6 b
2700	375 ab	56.0	1.06 ab	9.4 b	8.9 ab	4.5 b
3800	359 b	58.4	1.09 ab	9.8 a	9.0 a	4.9 a
Swingle Citrumelo						
500	383	59.0	1.32	9.6	7.7	4.8
1600	367	58.9	1.17	9.7	8.4	4.9
2700	354	60.4	1.17	10.0	8.6	5.1
3800	351	57.1	1.15	9.9	8.5	4.8

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range test (P=0.05).

Table 44. Mean juice quality parameters for 50 'Ray Ruby' grapefruit picked at random in December 2000 (n=4).

Salt level (ppm)	Avg. weight (%)	Juice content (%)	Acid (%)	Brix	Brix:acid ratio	Solids per box (lb)
Carrizo Citrange						
500	313	58.6	9.4	1.04	9.1	4.7
1600	305	58.2	9.5	1.02	9.3	4.7
2700	307	58.9	9.5	1.04	9.2	4.7
3800	312	58.5	9.4	1.09	8.7	4.7
Swingle Citrumelo						
500	321	60.2	9.4	1.10	8.6	4.8
1600	314	59.5	9.6	1.12	8.6	4.8
2700	321	60.2	9.6	1.14	8.5	4.9
3800	307	59.6	9.6	1.15	8.4	4.9

Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range test (P=0.05).

Table 45. Total solids (lb/tree) for 'Ray Ruby' grapefruit by season (n=4).

Salt level (ppm)	1999/00	2000/01	Total	% of 200 ppm
Carrizo Citrange				
500	17.0 ab	24.9 a	41.9	100
1600	15.6 a	20.7 ab	36.3	87
2700	10.4 b	16.5 ab	26.8	64
3800	11.8 ab	14.6 b	26.3	63
Swingle Citrumelo				
500	15.8	26.4 a	42.2	100
1600	17.6	17.3ab	34.9	83
2700	14.8	15.7 b	30.5	72
3800	13.4	15.7 b	29.1	69

Means followed by the same letter are not significantly different according to Duncan's Multiple Range test (P=0.05).

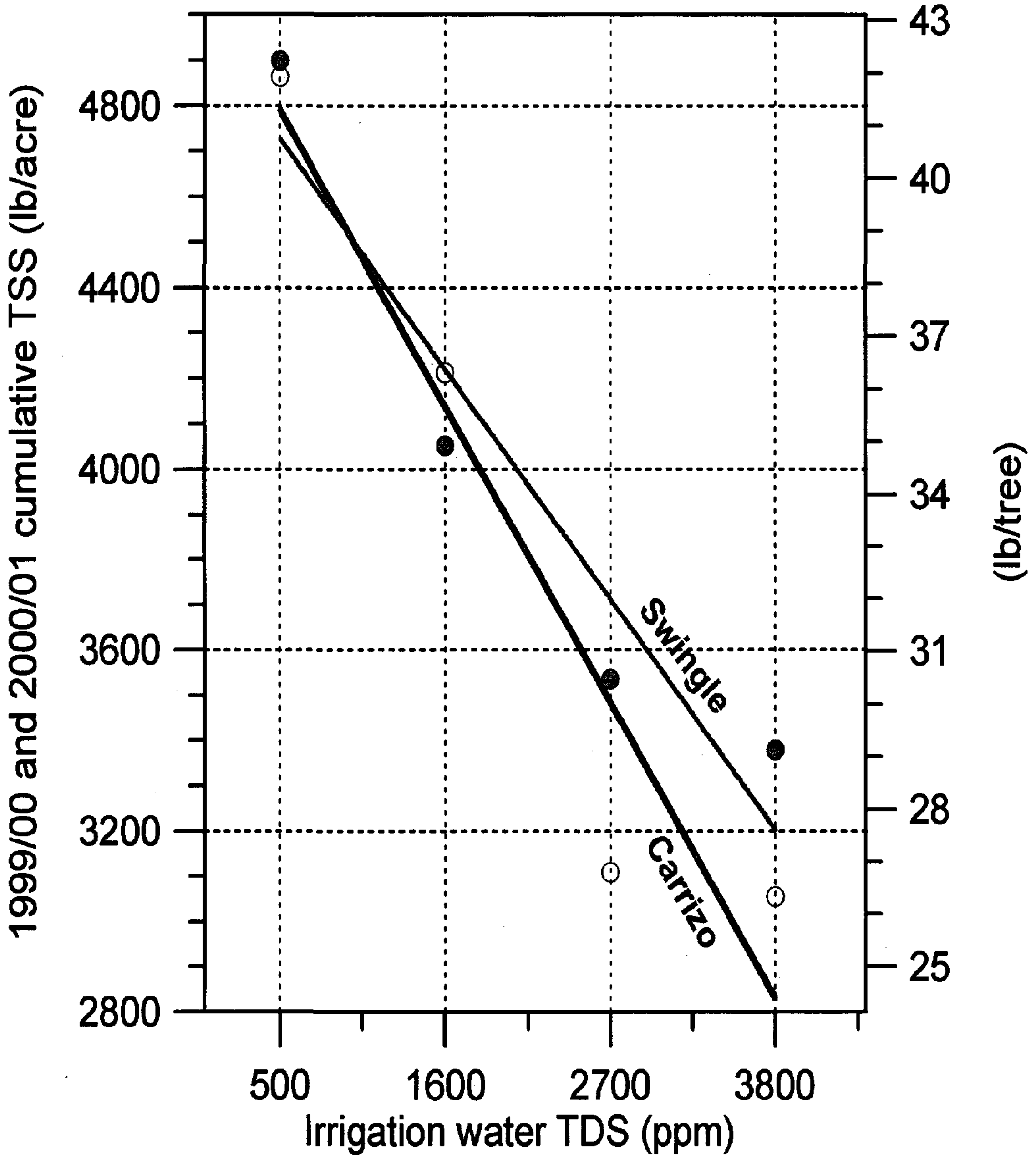

Figure 23. Cumulative total soluble solids for 1998/99 through 2000/01 seasons for 'Ray Ruby' grapefruit on Carrizo citrange and Swingle citrumelo rootstocks.

Conclusions

Even though little irrigation was required during 2 of the 4 years of the study, significant observations of the effects of salinity were evident. High salinity levels were expressed in elevated leaf Cl levels. Leaves from trees on Carrizo accumulated much higher Cl concentrations than leaves from Swingle trees. Typically, leaf Cl levels increased about 0.20% for each 1000 ppm increase in irrigation water TDS for Carrizo and 0.04% for Swingle. 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. As a result of premature leaf drop and the associated loss of nutrients, there are often abnormalities in the leaf concentrations of other nutrients (notably Ca and Mg) which can cause imbalances in the tree.

During years with extended dry periods requiring significant irrigation, higher salinity levels can be expected to reduce fruit size (and grower returns). For both rootstocks, both the number of fruit and the size of the fruit tended to decrease with increasing salinity in the irrigation water. The non-salinized trees had significantly larger fruit compared to the rest of the treatments. In the 2000/01 season when drought necessitated numerous irrigations, trees on Carrizo irrigated with 500 ppm water had about 50% more size 36 and larger fruit than trees watered with 2700 or 3800 ppm water. For trees on Swingle rootstock, trees irrigated with 500 ppm water had 1.5 - 2 times as many size 36 and larger fruit than trees watered with 1600 ppm TDS or higher salinity.

Yields were significantly less for the higher salinity levels during each season. Over the 4 seasons, average yields for Carrizo were reduced about 50 boxes/ac per year for each 1000 ppm increase in TDS of the irrigation water. For Swingle rootstock, the reduction was about 40 boxes/acre per year for each 1000 ppm increase in TDS in the irrigation water. These reductions averaged 9% (Swingle) and 11% (Carrizo) for each 1000 ppm increase of TDS in the irrigation water.

In the 1999/00 juice analysis, the non-salinized trees had slightly lower Brix at the time of measurement, but not a significantly lower Brix:acid ratio. The Brix:acid ratio averages at time of harvest in December for the 1999/00 and 2000/01 seasons were 9.1, 8.8, 9.0, and 8.9 (Carrizo) and 8.2, 8.5, 8.6, and 8.5 (Swingle) for the 500, 1600, 2700, and 3800 ppm TDS treatments, respectively. All treatments had similar solids per box for the two seasons as well, averaging 4.7, 4.7, 4.6, and 4.8 (Carrizo) and 4.8, 4.9, 5.0, and 4.9 (Swingle) lb/box for the 500, 1600, 2700, and 3800 ppm TDS treatments, respectively. The two-season reduction in total soluble solids due to salinity averaged 240 lb/ac for Swingle and 300 lb/ac for Carrizo per year for each 1000 ppm increase in TDS (at a density of 116 trees/acre).

Summary and Conclusions

The five seasons over which the studies were conducted encompassed a wide range of rainfall and irrigation conditions. Average rainfall for the area is about 56 inches per year. Rainfall recorded at the IRREC for the study period was 51.8, 49.3, 52.6, 59.7, and 37.8 inches for 1996, 1997, 1998, 1999, and 2000, respectively. As a result, the results from the studies include data from above, below, and near average rainfall years. The results, therefore are probably a good assessment of long-term effects of salinity.

One of the most visible effects of irrigation with high salinity water was the damage to leaves, which was expressed in elevated leaf Cl levels. With the exception of the 1997/98 season (when irrigation was limited), leaf Cl concentrations from trees receiving salinized irrigation water were considerably elevated above that in non-salinized trees. Elevated leaf Cl results in premature leaf drop, which diverts tree resources from growth and fruit production to replacement of lost leaves. As a result of premature leaf drop and the associated loss of nutrients, there are often abnormalities in the leaf concentrations of other nutrients (notably Ca and Mg) which can cause imbalances in the tree.

None of the experiments had consistent differences in the juice quality parameters with respect to irrigation salinity level. The average Brix:acid ratio and solids per box were similar in each experiment, regardless of salinity level. However, as a result of more fruit and larger fruit, the cumulative yield and cumulative solids produced were significantly higher in the non-salinized treatments.

'Valencia' orange

The "Valencia' orange study was conducted on trees with rough lemon, one of the more tolerant rootstocks to both sodium and chloride. Over the five seasons of the study, the leaf Cl levels increased averaged about 0.10% for each 1000 ppm increase in irrigation water TDS. With the exception on the 1997/98 season (when irrigation was limited), higher salinity levels in the irrigation water decreased both fruit number and fruit size. Typically, fruit count decreased about 70 fruit/year per tree for each 1000 ppm increase in TDS.

Average yields for the five years ranged from 490 box/ac for the non-salinized treatment trees to 335 box/tree for trees irrigated with 3500 ppm TDS water. Overall, yields decreased about a 0.6 box/tree per year for each 1000 ppm increase in irrigation water salinity. At the planting density of 97 trees/ac, this amounts to about 60 boxes/acre per year reduction (about 11%) for each 1000 ppm increase in TDS.

Average TSS during the five years of the study ranged from 3340 lb/ac for the 500 ppm treatment to 2270 lb/ac for the 3500 ppm TDS treatment. There was an 11% average reduction in TSS per tree per year for each 1000 ppm increase in the salinity (about 370 lb/ac/yr per 1000 ppm).

'Marsh Grapefruit

The data collected in the 'Marsh' grapefruit block was from a grove that was producing well below its potential due to minimal cultural inputs during all except the first year of the study. The trees in the study had the capacity to bear 5-8 boxes per tree, with the average production during the study being only 3 boxes per tree or less. Even though cultural practices were poor and little irrigation was applied, significant observations of the effects of salinity were evident. High salinity levels were expressed in elevated leaf Cl levels, with leaf Cl levels increasing about 0.04% for each 1000 ppm increase in irrigation water TDS.

Yield response was similar for the 500 and 1500 ppm rates, and the 2500 ppm treatment was only about 3% more than the 3500 ppm treatment. Cumulative yields for the 4 seasons were 12.4 boxes/tree for the 500 ppm treatment and 12.3 for the1500 ppm treatment, compared to 11.0 for the 2500 ppm and 10.7 for the 3500 ppm treatments. These represent 11% (2500 ppm) and 14% (3500 ppm) decreases in production for the higher salinity levels compared to the non-salinized trees. If threshold of 1500 ppm is assumed, the yield decreases represent about a 7% decrease in yield for each 1000 ppm above the base of 1500 ppm. These values represent data from non-optimum cultural operations. The effects of salinity on yield reductions would be expected to be greater on groves operated to achieve optimum production.

'Ray Ruby' Grapefruit
Leaves from trees on Carrizo accumulated much higher Cl concentrations than leaves than leaves from Swingle trees. Typically, leaf Cl levels increased about 0.20% for each 1000 ppm increase in irrigation water TDS for Carrizo and 0.04% for Swingle.

The number of fruit per tree and the size of the fruit tended to decrease with increasing salinity for both rootstocks. The non-salinized trees had significantly larger fruit compared to the rest of the treatments. In the 2000/01 season when drought necessitated numerous irrigation, trees on Carrizo irrigated with 500 ppm water had about 50% more size 36 and larger fruit season than trees watered with 2700 or 3800 ppm water. For trees on Swingle rootstock, trees irrigated with 500 ppm water had 1.5 - 2 times as many size 36 and larger fruit than trees watered with 1600 ppm TDS or more water.

Yields were significantly less for the higher salinity levels during each season. Over the 4 seasons, average yields for Carrizo were reduced about 50 boxes/ac per year for each 1000 ppm increase in TDS of the irrigation water. For Swingle rootstock, the reduction was about 40boxes/acre per year for each 1000 ppm increase in TDS of the irrigation water. These reductions averaged 9% (Swingle) and 11% (Carrizo) for each 1000 ppm increase in TDS of the irrigation water.

All treatments had similar solids per box, averaging 4.7, 4.7, 4.6, and 4.8 (Carrizo) and 4.8, 4.9, 5.0, and 4.9 (Swingle) lb/box for the 500, 1600, 2700, and 3800 ppm TDS treatments, respectively. The two-season reduction in total soluble solids due to salinity averaged 240 lb/ac for Swingle and 300 lb/ac for Carrizo per year for each 1000 ppm increase in TDS (at a density of 116 trees/acre).

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Appendix 1. List of Abbreviations

Ca	Calcium
Cl	Chloride
K	Potassium
P	Phosphorus
ppm	parts per million
Mg	Magnesium
N	Nitrogen
Na	Sodium
TSS	Total soluble solids
TDS	Total dissolved solids

Appendix 2. Salinity and Florida Citrus

Introduction

Flatwoods citrus growers often have only poor quality (high salinity) water available for irrigation. As early as 1900, damage to citrus trees on Florida's east coast was attributed 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 ppm total dissolved solids (TDS) per well. High salinity irrigation water is also found in southwest Florida and in the Tampa Bay area (Table 46). Many Flatwoods growers have no alternative other than to use this poor quality water for citrus irrigation. Therefore, knowing how to minimize the effects of saline irrigation water on citrus is an important production consideration.

All natural waters and soil solutions contain soluble salts. However, the amount and type of salts that are in water vary greatly. In some areas of the state, the groundwater can contain very high levels of salinity. These salts are concentrated in the soil with the process of irrigation, evaporation, and transpiration. In addition, strong winds off the ocean can deposit salt spray many miles inland. Salt concentrations in rainfall can be as high as 40 ppm of total dissolved salts (TDS) along the coast.

When dealing with salinity problems, it is important to realize that all water is not equal. In fact, salinity management might be a major objective of irrigation management, even though the primary objective of irrigation is normally to maintain the soil matric potential in a range suitable for optimum crop growth. Irrigation with high salinity water requires irrigations to be more frequent and of greater amounts than when good quality water is used. During extended droughts, salinity levels will dictate irrigation scheduling.

Table 46. Groundwater salinity by location (adapted from Wander and Reitz, 1951).

County	No. of samples	Average TDS (ppm)
Brevard	10	2580
St. Lucie	38	1100
Indian River	55	1530
Manatee	26	1045
Sarasota	14	1315
Charlotte	11	2485
Polk wells	2	195
Polk lakes	9	70

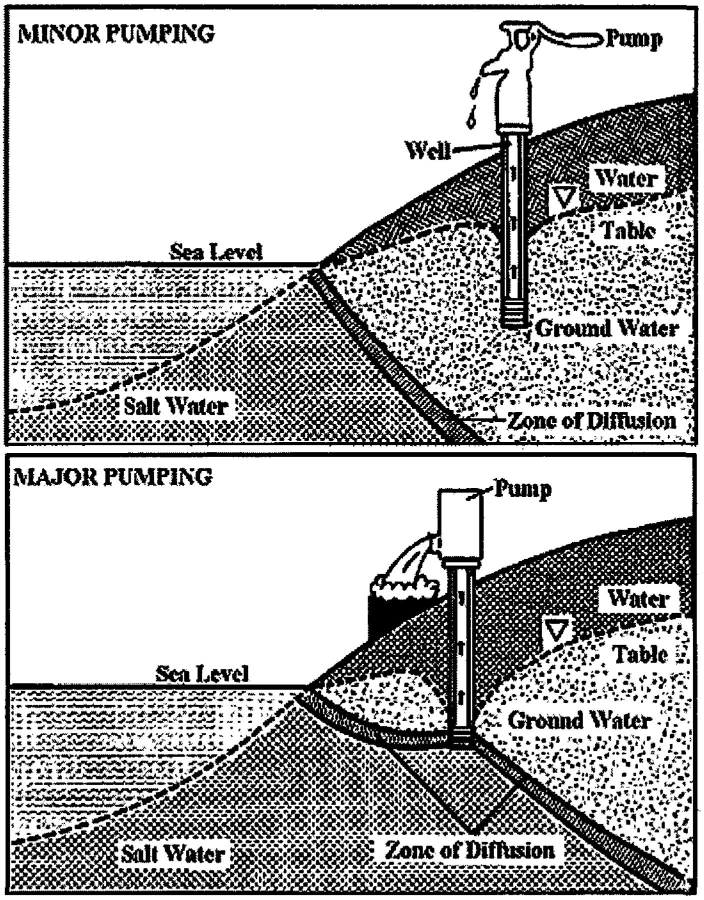

Figure 24. Effects of pumping rates in coastal areas on salt water intrusion into the freshwater shallow aquifer.

In Florida, salinity problems are generally of concern only in flatwoods areas as the irrigation supply in Ridge areas is typically of excellent quality. Salinity problems have been documented in the Indian River citrus area since as early as 1900 (Robinson, 1900). More recently, problems with salinity have occurred in citrus groves in the Tampa Bay and Southwest Florida production areas. In some coastal areas, high salinity levels in wells can be attributed to salt water intrusion into the fresh water zone from the ocean. The effects of pumping rate in coastal areas on salt water intrusion is illustrated in Figure 24. Salt water has a density of about 1.027 as compared to 1.0 for fresh water. The Ghyben-Herzberg principle states that depth to the fresh:saltwater interface is 38 times the distance between the static water table and mean sea level.

Example: For a static water level of 15 ft msl, estimate the depth to the fresh:saltwater interface. If pumping resulted in a drawdown of 10 feet in the well (to 5 ft msl) determine the change in depth to the interface.

Before pumping: Interface = 15 x 38 = 570 ft
After pumping: Interface = 5 x 38 = 190 ft

In the Indian River area, irrigation wells normally are 600-1200 ft deep and are in the upper Floridan Aquifer. Generally, deeper wells have higher salinity levels. The salts in these wells comes from the highly mineralized limestone that is in the water bearing strata. The salinity of these wells can vary from month to month and from year to year (Fig. 25). The quality in some wells deteriorates as the artesian pressure drops, while others remain relative unaffected. (Note the change of over 1000 ppm in one well versus only 300-400 ppm in the other in Fig. 25).

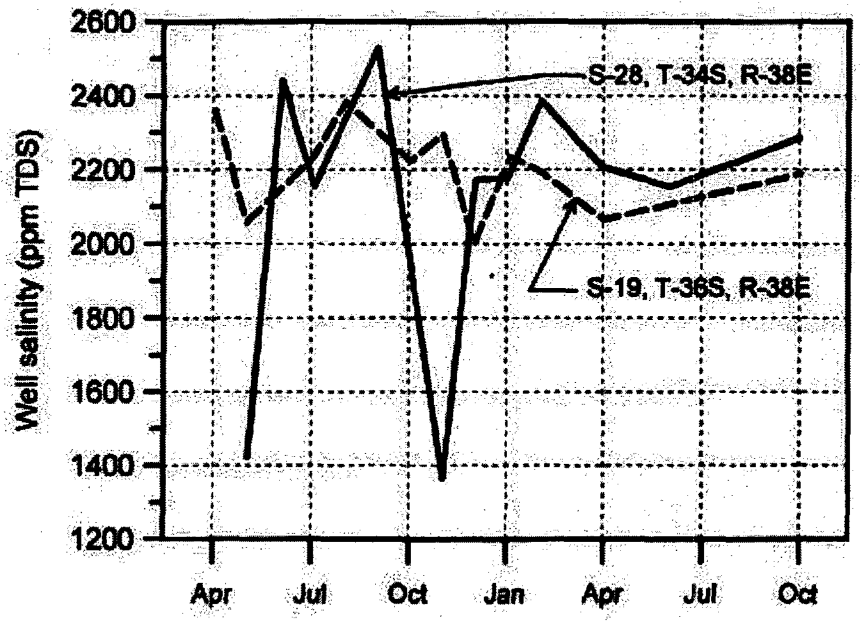

Figure 25. Salinity concentrations and changes by season for two Indian River area wells.

Surface water supplies in the Indian River area are also subject to periodic high salinity loadings (Fig. 26). As the dry season progresses, salinity levels of surface water in Indian River area ditches and canals increase as a combination of re-use of irrigation water and the augmentation of the surface water supply from the more saline Floridan Aquifer wells. Highest surface water salinity levels typically occur in April. When summer rains begin, canal salinity levels normally drop rapidly.

Groundwater can influence the salinity profile in the root zone if the net flow of water is upward for significant periods of time. High concentrations of salt may accumulate near the surface in the absence of sufficient irrigation or rainfall to maintain downward water flow. Typically, the salt concentration is usually higher in the soil than in the applied water. The increase in salinity results from plant transpiration and soil surface evaporation which selectively removes relatively pure water and concentrates the salts. The average salt concentration of the soil solution in the root zone is often assumed to be about three times the salinity of the applied water.

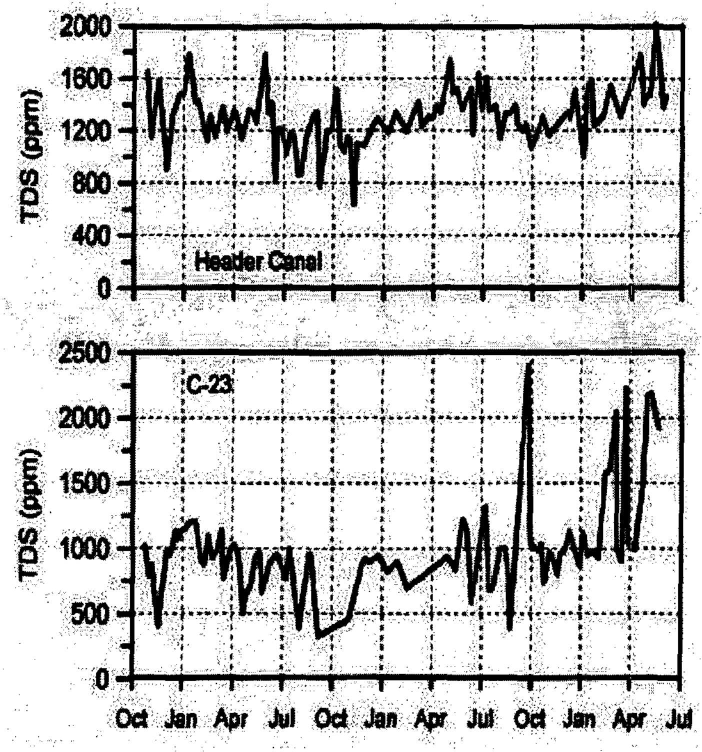

Figure 26. Salinity concentrations in Indian River area canals.

Salt accumulations in the soil are generally only removed by leaching below the crop root zone. Therefore, the key to salinity control is to provide a net downward flow in the root zone. Even in well-managed groves, the soil water will be several times more saline than the irrigation water. With insufficient leaching and drying out of the soil, this ratio can easily increase ten-fold or more, resulting in injury to the trees.

Accumulation of salts over the years is not a problem in most cases due to the abundant rainfall at sufficient rates to leach the salts from the root zones. Salts in typical sandy soils are generally leached out with the first inch of rainfall. However, in some poorly drained heavier soils, salt accumulation can be a problem. These soils require more careful monitoring of salinity-related problems.

Measurement

The quantity of salts in water is commonly reported in units of total dissolved solids (TDS) or electrical conductivity (EC). TDS are measured by evaporating a sample of water and weighing the residue. The results are reported in parts per million (ppm) or mg/L, depending on whether the calculation is on a weight or volume basis. For most practical purposes, ppm is equal to mg/L.

The EC of a solution is a measure of the ability of the solution to conduct electricity. When ions (salts) are present, the EC of the solution increases. If no salts are present, then the EC is low indicating that the solution does not conduct electricity well. The EC indicates the presence or absence of salts, but does not indicate which salts might be present. If the EC of a sample is relatively high, no indication from the EC test is available to determine if this condition was from irrigation with salty water or if the field had been recently fertilized and the elevated EC is from the soluble fertilizer salts. To determine the source of the salts in a sample, further chemical tests must be performed.

Figure 27. Typical hand-held conductivity meter.

EC measurements are taken with platinum electrodes and presented in units of conductance. Hand-held conductivity sensors (Fig. 27) are convenient for measuring conductivity in the field. They come in a variety of designs and can range in cost from $40-50 to several hundred dollars.

The SI (metric) unit of measurement is deci-Siemens per meter (dS/m) which is equal in magnitude to the commonly used conductance term of millimho/cm (mmho/cm). Both of these terms are generally in the range of 0-5. If the numbers reported are higher, in the range of 100-5000, the units are typically micro-Siemens per centimeter (µS/m) which micromho/cm (µmho/cm) The conversion from electrical conductance to TDS depends on the particular salts present in the solution. The conversion factor of 700 x EC (in dS/m) is applicable for converting EC values to TDS for Florida irrigation waters. Often times commercially available meters will read directly in ppm. Care must be taken when using these meters so that results are reported consistently. Most of these type of meters will use conversion factors of 630 or 640 x EC to get ppm. These are common conversion factors that are used in many places throughout the world. However, some meters may use a factor as low as 500 or as high as 800 to convert from dS/m to ppm.

Conversions:

1 mg/L = 1 ppm
dS/m x 700 = ppm
µS/cm x 0.7 = ppm
µS/cm = µmho/cm

Example

Determine the salinity in ppm for a water sample with EC of 2.3 dS/m.

2.3 dS/m x 700 = 1610 ppm

Example

A meter that has a built in conversion factor of 1 dS/m = 630 ppm has a reading of 2300 ppm. What would be the TDS if the factor of 700 suitable for most Florida water was used instead.

Convert to dS/m using the meter factor of 630
2300 ppm / 630 ppm/dS/m = 3.65 dS/m
Then convert back to ppm using a factor of 700
3.65 dS/m x 700 ppm/dS/m = 2555 ppm

Soil Salinity Measurements in The Field

The EC of the soil has little direct detrimental effect on sandy mineral soils, but EC directly affects plants growing in the soil. As EC increases, more attention to water management is needed to prevent salinity from adversely affecting citrus. In Florida, the Extension Soil Testing Laboratory uses a 2:1 solution:soil ratio with which to determine EC. In most states and most literature, the saturated paste extract (EC_e) method is used. The saturated paste method is more time consuming than the 2:1 extraction, and results in inadequate amounts of solution in Florida's sandy soils. The conversion from the 2:1 extraction result to the saturated paste is a factor of 8 ($EC_e = EC_{2:1} \times 8$). In general, when the soil $EC_{2.1}$ exceeds 0.25 dS/m ($EC_e = 0.25 \times 8 = 2.0$ dS/m), citrus will begin to experience stress due to salts.

Example:

What is the equivalent EC_e for a soil with a measured $EC_{2:1}$ of 0.4 dS/m?

$EC_e = 0.4 \times 8 = 3.2$ dS/m

Soil salinity probes are an effective means of tracking salinity levels in Florida sandy soils (Fig. 28). Since most soil minerals are insulators, electrical conduction in saline soil is primarily through the pore water, which contains dissolved salts. The contribution of exchangeable cations to electrical conduction is relatively small in saline soils because these cations are less abundant and mobile than the soluble electrolytes. EC in soils is also affected by the number, size, and continuity of soil pores, as well as salt and water contents.

For given soil types where water content is at a standard level, apparent conductivity (EC_a) is related to soil salinity. The water content at field capacity is sufficiently reproducible to serve as the reference water content required to establish calibrations between EC_a and soil salinity (EC_e). In irrigated groves, the soil water in the wetted area comes to field capacity shortly after an irrigation.

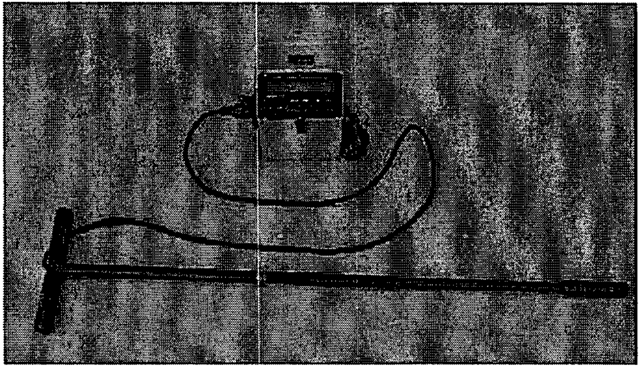

Figure 28. Soil salinity probe.

Salinity probes can be used to measure soil electrical conductivity profiles within the soil. A succession of measurements (typically at 6-inch increments) are taken with the vertical sensor inserted into the soil via an access hole. Average soil salinity (EC_e) may be determined from EC_a. measurements once calibrations are established between EC_e and EC_a for a particular soil provided the EC_a determinations are made at approximately the same water content as that for which the calibrations were made. Separate calibrations for each soil are not usually necessary since calibrations are similar enough for soils of similar water holding capacities and textures.

Salt Load

Large amounts of salts can be deposited on the soil during continued irrigations with high salinity water (Fig. 29). For example, in water with 2000 ppm TDS, there is about 1.7 lb of salt in each 100 gallons applied (Fig. 30). The salts that are applied will remain in the soil unless they are leached out through excess irrigation or rain water applied to the soil. Consider a block of citrus that receives the equivalent of 40 gal/tree/day of 2000 ppm TDS of irrigation water. In one week, each tree will have 4¾ lb of salt applied around it. As the drought continues, more and more salt will accumulate if adequate irrigation strategies are not employed. Without proper water and nutrient management, citrus irrigated

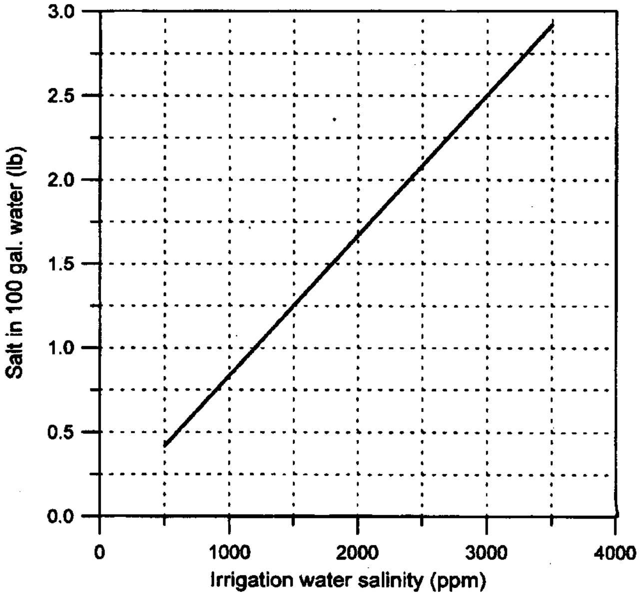

Figure 29. Pounds of salt in 100 gallons of water at various water salinity levels (TDS).

with high salinity water can suffer the reduced growth, small fruit, and decreased yields which accompanies salt stress.

Osmotic Stress

Salts in solution exert an osmotic effect that reduces the availability of free (unbound) water through both chemical and physical processes. Roots are therefore not able to extract as much water from a solution that is high in salts than from one low in salts. In effect, the trees have to work harder to move water into the roots. Fig. 31 shows typical effects of salinity on the water stress within a plant. In the example, the stress level with 100 ppm water when half the water is depleted (going from 20% to 10% moisture) is about 3 atm. Remarkably, this stress level is less than 4 atm stress level that occurs at field capacity when the soil solution has 2000 ppm TDS. (Field capacity is the moisture content that occurs in sandy soils a day or so after excess rains completely wet the soil). In other words, even at field capacity the 2000 ppm salinity has significant water stress. Therefore, for citrus irrigated with saline water it is essential that irrigations be frequent (daily) to minimize salinity stress.

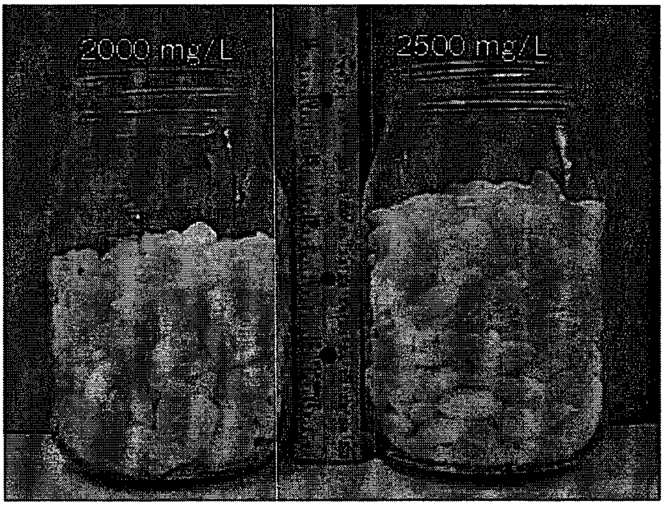

Figure 30. Salt load in 100 gallons of water at 2000 mg/L (1.7 lb) and 2500 mg/L (2.1 lb) concentration in irrigation water (1 qt jars).

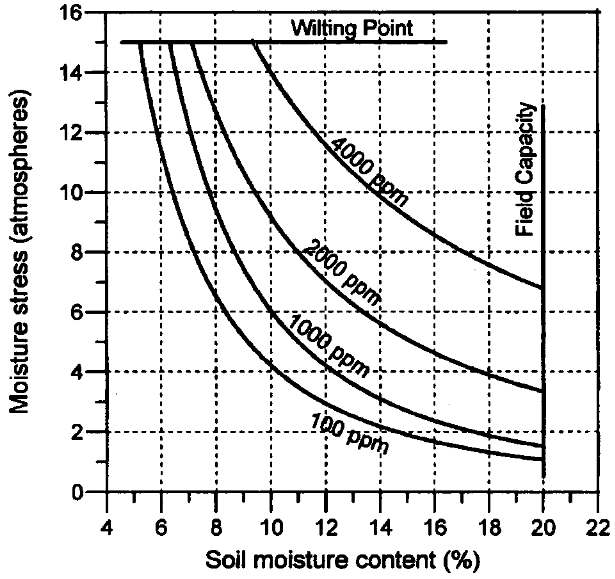

Figure 31. Typical effect of salinity on water stress levels within plants (adapted from Wadleigh and Ayers, 1945).

There are distinct differences in the rate of chloride and sodium uptake among citrus rootstocks. The general decreasing order of salinity tolerance to chlorides for common rootstocks is (best to worst) Cleopatra mandarin ⇨ rough lemon ⇨ sour orange ⇨ Swingle citrumelo ⇨ Carrizo citrange. The range of some other rootstocks is given in Table 47. It is important to remember that growth and yield of trees on all rootstocks can be reduced by excessive salts.

Symptoms of Salt Injury

The critical salinity level varies with the buffering capacity of the soil (soil type, organic matter), climatic conditions, and the soil moisture status. Many salinity-induced symptoms such as reduced root growth, decreased flowering, smaller leaf size, and impaired shoot growth are often difficult to assess, but occur prior to ion toxicity symptoms in leaves. Chloride toxicity, consisting of burned necrotic or dry-appearing edges on leaves (Fig. 32) of the most common visible salt injury symptoms. Often, Na toxicity symptoms seldom distinctly appear but rather an overall leaf "bronzing" appears along with reductions in growth (Fig. 33). As with Cl, high leaf Na can cause nutrient imbalances at much lower concentrations than those required for visible symptoms.

Table 47. Citrus rootstocks ranked in order of decreasing ability to restrict chloride and sodium accumulation in scion (adapted from Maas, 1992).

Rank	Chloride	Sodium
1	Grapefruit	Sour orange
2	Cleopatra mandarin	Cleopatra mandarin
3	Rangpur lime	Rusk citrange
4	Rough lemon	Rough lemon
5	Sour orange	Rangpur lime
6	Trifoliate orange	Sweet orange
7	Sweet orange	Savage citrange
8	Rusk citrange	Citrumelo 4475
9	Troyer citrange	Troyer citrange
10	Carrizo citrange	Grapefruit

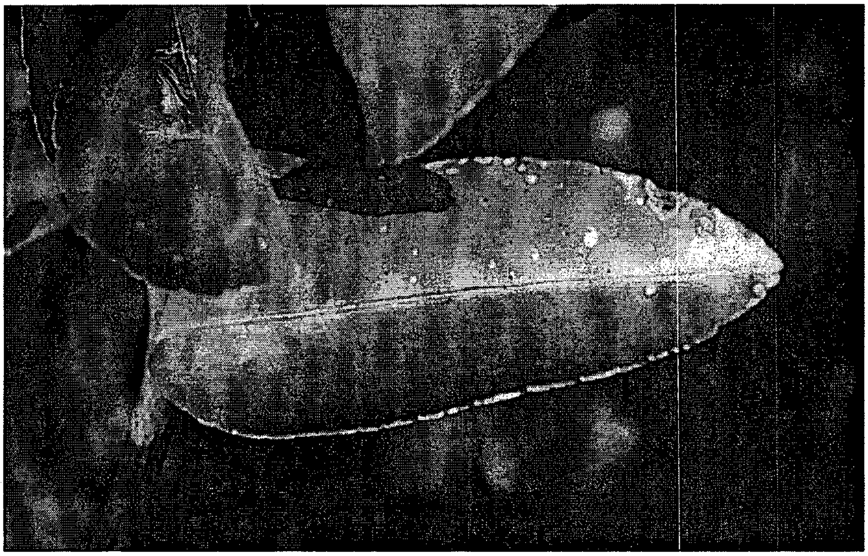

Figure 32. Tip burn caused by excess salinity

Figure 33. Leaf bronzing caused by excess salinity.

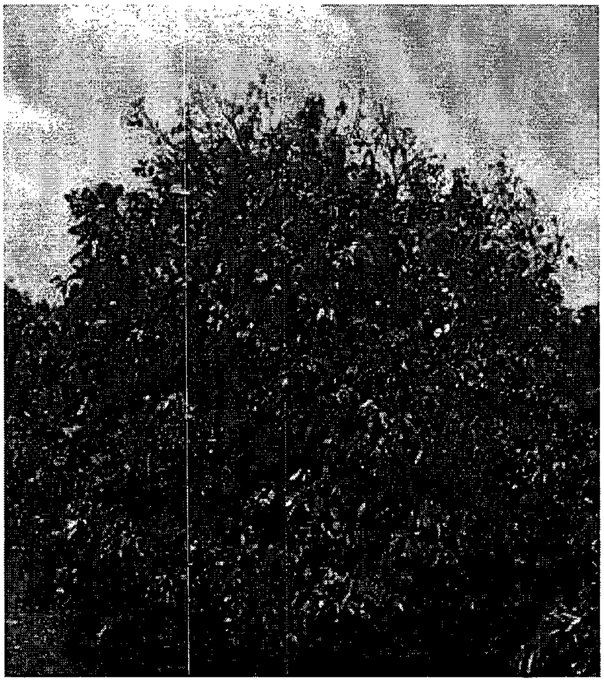

Figure 34. Canopy thinning resulting excess salinity.

Figure 35. Defoliation and twig death resulting excess salinity.

As salinity loads increase, trees will begin to shed leaves and a thinning of the canopy is evident (Fig. 34). The symptoms are usually most evident looking up into the top of the canopy. There will also be an abundance of leaves on the ground. Progressive salinity will lead to defoliated branches and twig dieback (Fig. 35).

In an Australian study, leaves were monitored on 'Washington' navel trees irrigated with 300 and 1200 ppm TDS water (Fig. 36). Leaves on trees irrigated with the higher salinity level had significantly shorter lives. After 9 months, only about 15% of the spring flush leaves were still on the trees irrigated with the 1200 ppm water as compared to nearly 90% of those with the 300 ppm water.

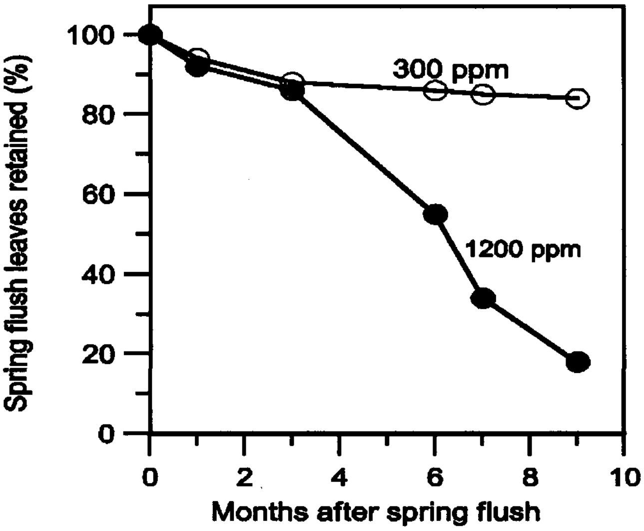

Figure 36. Retention of spring flush leaves for 'Washington' navel trees irrigated with 300 and 1200 ppm water (adapted from Howie and Lloyd, 1989).

Wetting Foliage

Irrigation water that wets the foliage (partially or fully) can result in severe damage to the leaves in the skirt of the trees. There are reports where chloride and sodium concentrations of the lower leaves were about four times greater than those of the upper leaves (grapefruit, Valencia and Washington navel).

The lowest concentration of either sodium or chloride generally associated with leaf burn is about 0.25%. Controlled experiments showed that citrus leaves easily accumulate chloride and sodium from direct contact with water drops. The accumulation is greater from intermittent than continuous wetting and from daytime than nighttime irrigation. Accumulation is a function of the rate of evaporation, which results in increased salt concentration of the water film on the leaves.

The sensitivity of a citrus to injury through direct foliar contact bears no relationship to its general soil salinity tolerance. Unlike soil-applied salinity, trees on all rootstocks are about equally sensitive to injury through direct foliar contact. Young, tender shoots are especially vulnerable to salt burn. Young trees (1-2 years) on Swingle citrumelo rootstock seem to be more susceptible to spray on their trunks, and often develop brown "blisters" of dead tissue on their trunks.

Fertilization

The frequency of injecting nutrients or of applying granular fertilizer has a direct effect on the concentration of TDS in the soil solution. A fertilization program that uses frequent applications with relatively low concentrations of salts will normally result in less salinity stress than programs using only two or three applications per year. Controlled-release fertilizers and frequent fertigations are ways to economically minimize salt stress when using high salinity irrigation water. Growers using surface water in high salinity areas generally see a marked improvement in water quality when the summer rains begin. Under these conditions, fertigations during the wet season should pose no problems.

Selecting nutrient sources that have a relatively small osmotic effect in the soil solution can help reduce salt stress. The osmotic effect that a material adds to a soil solution is defined as its salt index relative to sodium nitrate, taken to be equal to 100 (Table 48). Since sources of phosphorus (P) generally have a low salt index, they usually present little problem. However, the salt index per unit (lb) of N and potassium (K) should be considered.

Table 48. Salt index of fertilizer sources.

	Salt Index (Sodium Nitrate=100)	
Material and Analysis	Per equal weights of materials basis	Per unit (lb) of plant nutrients
Nitrogen		
Ammonium nitrate, 35% N	105	3.0
Ammonium nitrate, 20.5% N	61	3.0
Ammonium sulfate, 21.2% N	69	3.3
Calcium nitrate, comm. grade, 15.5% N	65	4.2
Sodium nitrate, 16.5% N	100	6.1
Urea, 46.6% N	75	1.6
Nitrate of Soda Potash, 15% N, 14% K	92	3.2
Natural organic, 5% N	4	0.7
Phosphate		
Normal Superphosphate, 20% P_2O_5	8	0.4
Concentrated Superphosphate, 45% P_2O_5	10	0.2
Concentrated Superphosphate, 48% P_2O_5	10	0.2
Monoammonium phosphate, 12.2% N, 61.7% P_2O_5	30	0.4
Diammonium phosphate, 18% N, 46% P_2O_5	34	0.5
Potash		
Potassium chloride, 60% K_2O	116	1.9
Potassium chloride, 63.2% K_2O	114	1.8
Potassium nitrate 13.8% N, 46.6% K_2O	74	1.2
Potassium sulfate, 46% K_2O	46	0.9
Monopotassium Phosphate, 52.2% P_2O_5, 34.6% K_2O	8	0.1
Sulfate of potash-magnesia, 21.9% K_2O	43	2.0

The salt index of natural organic fertilizers and slow-release products are low compared to the commonly used soluble fertilizers. High-analysis fertilizers may have a lower salt index per unit of plant nutrient than lower-analysis fertilizers since they may be made with a lower salt index material. Hence at a given fertilization rate, the high-analysis formulation may have less of a tendency to produce salt injury.

Example

Compare the salt index per unit plant nutrient of 100 lb of 8-0-8 solution made from ammonium nitrate (38 lb) and muriate of potash (13.3 lb) to a blend made with ammonium nitrate (17.1 lb) and potassium nitrate (26.6 lb).

From Table 48, the salt indices for the materials are:
Ammonium nitrate (35% N) = 105
Muriate of potash (63% P_2O_5) = 114
Potassium nitrate (14% N and 46% K_2O) = 74
Ammonium nitrate + muriate of potash = 38 lb x 105 + 13.3 lb x 114 = 5506
Ammonium nitrate + potassium nitrate = 17.1 x 105 + 26.6 x 74 = 3764
5506/3764 = 1.46

Although both solutions have the same analysis, the salt index of the ammonium nitrate + muriate of potash blend is 46% greater than that for the ammonium nitrate + potassium nitrate blend.

The Cl in KCl or Na in $NaNO_3$ materials add more toxic salts to the soil solution. High rates of salt application can alter soil pH and thus cause soil nutrient imbalances. Some ions can also add to potential nutrient imbalances in trees. For example, Na displaces K, and to a lesser extent Ca, in soil solutions. This can lead to K deficiencies and, in some cases, even to Ca deficiencies. Such nutrient imbalances can compound the effects of salinity stress. Problems can be minimized if adequate nutritional levels are maintained, especially those of K and Ca.

Salt Buildup

As the dry season progresses, salts accumulate in the soil. Evaporation removes relatively pure water from the soil surface, leaving the salts behind. Trees also attempt to exclude salts from being taken up into the water stream. Evaporation from the soil surface and and evapotranspiration (ET) results in a reduced volume of water in the soil. Since there is less water and only a slight drop in the amount of salts in the soil, the concentration (ppm) of salts in solution increases.

For example, consider flatwoods sandy soil that holds 15% moisture at field capacity (Fig. 37). If the soil solution salt concentration is 2000 ppm at field capacity, the roots will be seeing concentrations of 4000 ppm when half of the water is depleted. Again, the solution to manage the problem effectively is to keep the soil wet!

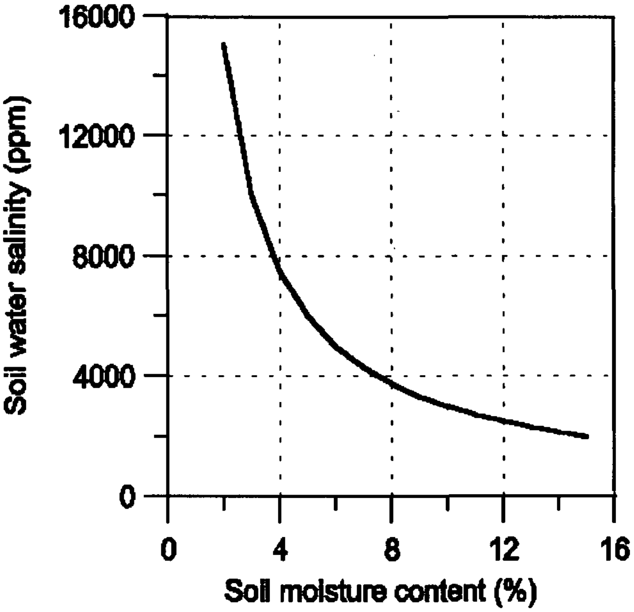

Figure 37. Increase in soil water salinity as the soil dries and the same amount of salts remain in solution.

Once salts accumulate in the soil, the only way to remove them is to leach them below the root zone with excess irrigation or rainfall. This means that with each irrigation, enough water should be applied so that there is a net downward flow in the root zone. In areas with shallow water tables, salts that are flushed through the root zone can move back into the root zone if the surface and top of the root zone dry out

Salt accumulations in most Florida sandy soils are flushed out fairly quickly following rainfall of 1 or more inches. Figure 38 shows soil salinity during a 3-month period when drought conditions made irrigation (microsprinkler) necessary. Salinity levels at a depth of 18 inches dropped to near zero following rains beginning April 13. The rains on April 30 flushed out the salts from the 24 inch depth. Salts were flushed from the profile and were found to build in the water furrow. Irrigations every 2-3 days beginning on May 9 resulted in increases in soil salinity at both the 18 and 24 inch depths.

Young trees affected by salinity present a great challenge. In their first year, trees typically require less than 1 gal/day per tree. However, frequent irrigations are even more critical on young trees when using high salinity water. With high salinity, young trees should be watered on a daily basis to minimize damage. During extended dry periods, salts will accumulate on the fringes of the wetted zone and move upwards as evaporation occurs. These salts will be put back in the soil solution with rainfall. If the rainfall amount is low, these salts will move back into the root zone and cause very high salinity levels. Therefore, it is a good practice to continue to irrigate until adequate rainfall is received to leach accumulated slats below the root zone (usually 1 inch of rain is sufficient on sandy soils).

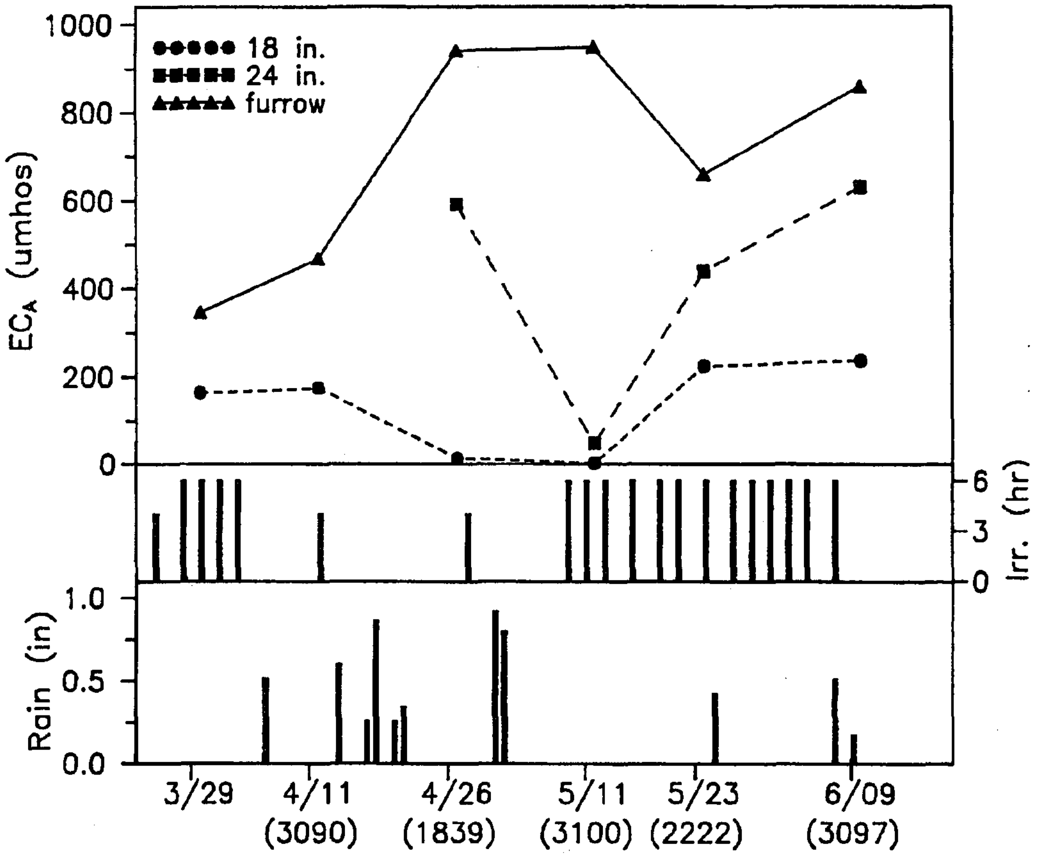

Figure 38. Salinity profiles in bedded citrus (values in parenthesis (i.e. 3090) represent the irrigation water salinity in µS/cm).

Managing High Salinity

Managing irrigation and fertilization with high salinity irrigation waters requires routine evaluations of the water with an EC meter. Irrigate frequently to prevent concentration of salts. Excess irrigations to leach accumulated salt may become necessary and should be made no less frequently than every other week during the peak irrigation season. Irrigation rates should be monitored to make sure that excess salts are leached below roots. It may be necessary to initiate irrigations when small rainfall events occur. Rain will put salts that have accumulated near the surface back into solution. If there is insufficient rain (less than 1 inch), the salts may end up back in the root zone. Therefore, it is a good practice to continue irrigations until the salts are flushed from the root zone.

Keep poor quality water off of leaves, especially under conditions of high evaporative demand. Irrigate at night whenever possible to minimize evaporative concentration of salts. Choose fertilizer formulations that have the lowest salt index per unit of plant nutrients. Increase the frequency of fertilizations, thereby making it possible to reduce the salt content of each application and aid in preventing excess salt accumulation in the root zone. Maintain optimum but not excessive nutrient levels in soil and leaves with rates based on the long-term production from the grove. Fertilizer rates can usually be lower for trees with high salinity since production levels will probably be lower. Leaf tissue analysis should be used to detect excessive Na or Cl levels or deficient levels of other elements caused by nutrient imbalances from the salt stress. Na levels greater than 0.2% and Cl levels over 0.5% indicate imminent problems.