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Managing Salinity in Florida Citrus¹

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Introduction

The usual focus of citrus irrigation is to maintain water in the root zone in a range suitable for optimum crop growth. However in some areas, salinity management may become the major objective of irrigation management. 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.

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 (Table 1). The processes of evaporation, and transpiration tend to concentrate any salts present in the soil. 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 solids (TDS) along the coast.

In Florida, salinity problems for citrus 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 on Indian River citrus since as early as 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 Fig. 1, which graphically illustrates the effect of groundwater removal on salt water intrusion. Salt water has a density of about 1.027 versus 1.0 for fresh water. Because of this difference in density, the depth to the fresh:saltwater interface is 38 times the distance between the static water table and mean sea level (Ghyben-Herzberg principle).

Example 1

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.

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Before: Interface = $15 \times 38 = 570$ ft

After: Interface = $5 \times 38 = 190$ ft

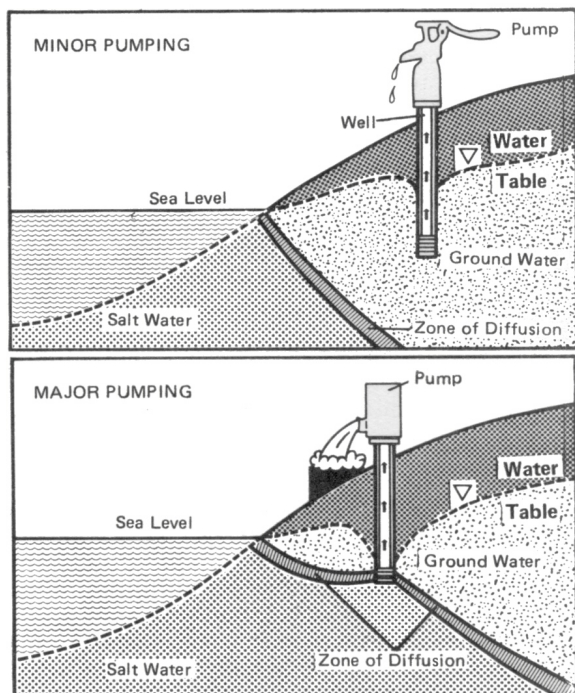


Figure 1. Effects of pumping rates in coastal areas on salt water intrusion into the freshwater shallow aquifer.

In the Indian River area, irrigation wells normally are 600-1,200 ft deep, and are in the upper Floridan Aquifer. Generally, deeper wells have higher salinity levels. The salts in these wells come 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. 2). The water quality in some wells deteriorates as the artesian pressure drops, while others remain relative unaffected. (Note the change of over 1,000 ppm in one well versus only 300-400 ppm in the other in Fig. 2).

Surface water supplies in the Indian River area are also subject to periodic high salinity (Fig. 3). As the dry season progresses, salinity levels in Indian River area ditches and canals increase through evaporation, re-use of irrigation water, and the addition of water from more saline Floridan Aquifer wells. Highest surface water salinity levels typically occur in April. When summer rains begin, canal salinity levels normally drop rapidly.

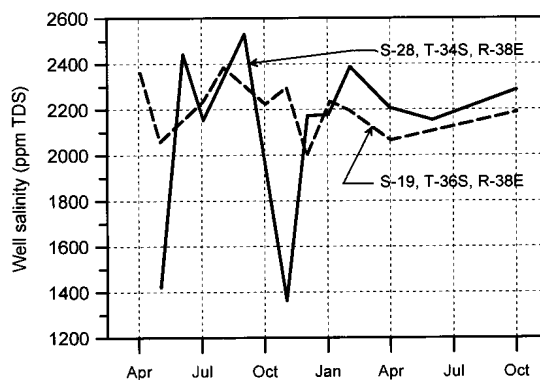


Figure 2. Salinity concentrations and changes by season for two Indian River area wells.

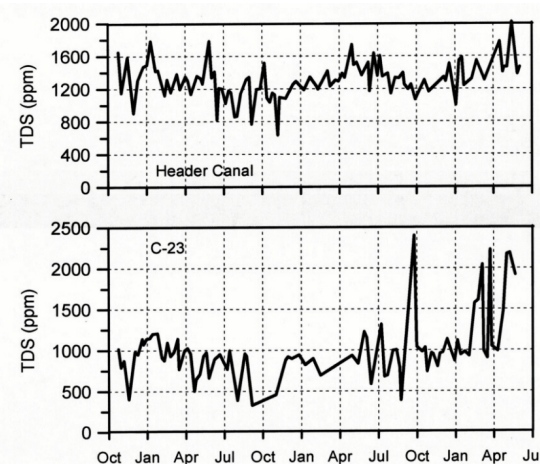


Figure 3. Salinity concentrations in Indian River area canals.

Measurement

Salinity 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. Since 1 liter of water typically weighs about 1 million milligrams, for practical purposes the units of ppm and mg/L are equal.

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. As a result, EC indicates the presence or absence of salts, but does not indicate which salts are present. A

high EC in soil water may result from irrigation with salty water or from dissolved fertilizer salts from a recent application. To determine the source of the salts in a sample, further chemical tests must be performed.

EC measurements are taken with conductivity meters and results are given in units of conductance. Hand-held conductivity sensors (Fig. 4) are convenient for measuring conductivity in the field. They come in a variety of designs and can range in cost from \$40 to several hundred dollars.



Figure 4. Typical handheld conductivity meter.

The SI (metric) unit of salinity measurement is deci-Siemens per meter (dS/m), which is the same as 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 100-5,000, the units are typically micro-Siemens per centimeter ($\mu\text{S}/\text{m}$) which is equivalent to micromho/cm ($\mu\text{mho}/\text{cm}$).

The conversion from electrical conductance to TDS depends on the particular salts present in the solution. The conversion factor of $700 \times \text{EC}$ (in dS/m) is applicable for converting EC values to TDS for Florida irrigation waters. 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 meters use conversion factors of 630 or 640 \times EC to get ppm. However, some meters may use a factor as low as 500 or as high as 800 to convert from dS/m to ppm. It is important to know what conversion factor your unit uses so you can properly interpret results for Florida conditions.

Conversions:

$$1 \text{ mg/L} = 1 \text{ ppm}$$

$$\text{dS/m} \times 700 = \text{ppm} \text{ (for salts typically found in Florida surface and ground water)}$$

$$\mu\text{S}/\text{cm} \times 0.7 = \text{ppm}$$

$$\mu\text{S}/\text{cm} = \mu\text{mho}/\text{cm}$$

Example 2

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

$$2.3 \text{ dS/m} \times 700 = 1,610 \text{ ppm}$$

Example 3

A meter that has a built-in conversion factor of $1 \text{ dS/m} = 630 \text{ ppm}$ has a reading of 2,300 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

$$2300 \text{ ppm} / 630 \text{ ppm/dS/m} = 3.65 \text{ dS/m}$$

Then convert back to ppm using a factor of 700

$$3.65 \text{ dS/m} \times 700 \text{ ppm/dS/m} = 2,555 \text{ ppm}$$

Salt Load

Large amounts of salts can be deposited in the soil during continued irrigations with high salinity water (Fig. 5). For example, in water with 2,000 ppm TDS, there is about 1.7 lb of salt in each 100 gallons applied (Fig. 6). 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 2,000 ppm TDS of irrigation water. In one week, each tree will have 4 3/4 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 with high salinity water can suffer the reduced growth, small fruit, and decreased yields which accompany salt stress.



Figure 5. Pounds of salt in 100 gallons of water at 2000 mg/L (1.7lb) and 2500 mg/L (2.1 lb) concentration in irrigation water (1qt jars).

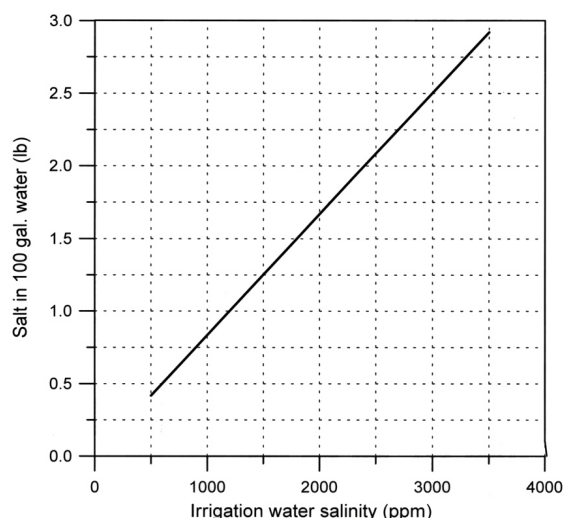


Figure 6. Pounds of salt in 100 gallons of water at various water salinity levels (TDS).

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 as from one low in salts. In effect, the trees have to work harder to move water into the roots. Fig. 7 shows typical effects of soil water salinity on the water stress within a plant. The stress level with 2000 ppm water at field capacity is about 3.5 atm. (Field capacity is the moisture content

that remains when the pore space water drains after the soil is thoroughly wetted; typically this occurs a day or so after a heavy rain in sandy soils.) Remarkably, this value is about the same as the stress encountered by the plant when good (100 ppm) water is used and half the water is depleted (going from 20% to 10% moisture). In other words, trees irrigated with water having 2,000 ppm salinity will be exposed to significant water stress even when the soil is at field capacity. Therefore, for citrus irrigated with saline water it is essential that irrigations be frequent (daily) to minimize salinity stress.

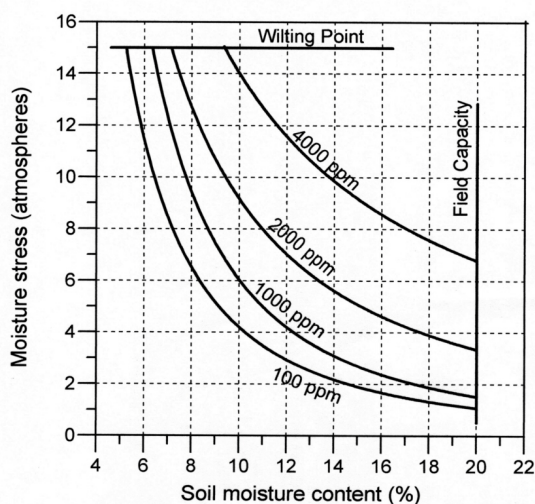


Figure 7. Typical effect of salinity on water stress levels within plants (adapted from Wadleigh and Ayers, 1945). Values are for the salinity of the soil solution, which is typically higher than for the applied irrigation water.

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 madarin -- rough lemon -- sour orange -- Swingle citrumelo -- Carrizo citrange. The range of some other rootstocks is given in Table 2. 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 EC of the soil solution (water in the root zone) 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.

The critical salinity level (where plants are adversely affected) 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 (Cl) toxicity, consisting of burned necrotic or dry appearing edges on leaves (Fig. 8) is the most common visible salt injury symptoms. Sodium (Na) toxicity symptoms seldom distinctly appear, but rather an overall leaf "bronzing" appears along with reductions in growth (Fig. 9). As with Cl, high leaf Na can cause nutrient imbalances at much lower concentrations than those required for visible symptoms.



Figure 8. Tip burn caused by excess salinity



Figure 9. Leaf bronzing caused by excess salinity.

As salinity increases, trees will begin to shed leaves and a thinning of the canopy becomes evident (Fig. 10). The symptoms are usually most visible at the top of the canopy (Fig. 11). There will also be an abundance of leaves on the ground. Progressive salinity will lead to defoliated branches and twig dieback (Fig. 12).



Figure 10. Canopy thinning resulting excess salinity.



Figure 11. Defoliation and twig death resulting excess salinity.



Figure 12. Severe leaf drop and twig die-back resulting from excess salinity in irrigation water.

In an Australian study, leaves were monitored on Washington navel trees irrigated with 300 and 1,200 ppm TDS water (Fig. 13). 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 1,200 ppm water, as compared to nearly 90% of those with the 300 ppm water.

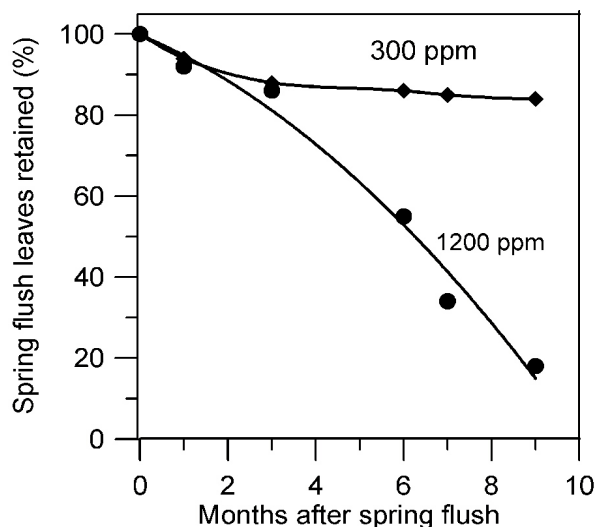


Figure 13. Retention of spring flush leaves for 'Washington' navel trees irrigated with 300 and 1200 ppm water (adapted from Howie and Lloyd, 1989).

Wetting Foliage

Saline 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 foliar concentration of either Na or Cl generally associated with leaf burn is about 0.25%. Controlled experiments have showed that citrus leaves easily accumulate Cl and Na from direct contact with water droplets. 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.

Unlike soil applied salinity, direct foliar contact injury affects trees about equally on all rootstocks. Young, tender shoots are especially vulnerable to salt burn. Young trees (1-2 years) on Swingle citrumelo rootstock seem to be especially susceptible to spray on their trunks, and often develop brown "blisters" of dead tissue on their trunks.

Fertilization

Fertilizers, either applied dry or as a solution, influence the TDS concentration of 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 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. As a result, the salinity problems quickly diminish as rain leaches accumulated salts and the fertilization method becomes less of a concern.

Selecting nutrient sources that have a relatively small osmotic effect in the soil solution can help reduce salt stress. The salt index of a material is a measure of the increase in soil solution osmotic effect when it is added to the soil. The salt index is specified relative to sodium nitrate, which has an index of 100 (Table 3). 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.

The salt index of natural organic fertilizers and slow-release products are low compared to the commonly used soluble fertilizers. However, 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. Many growers fertilize with pre-mixed materials, and they should request information on the overall salt index from their suppliers. When calculating your own salt index for fertilizers, the data in Table 3 can be used as illustrated in Example 4.

Example 4

Compare the salt index per unit plant nutrient of 100 lb of 8-0-8 solution made from ammonium nitrate and muriate of potash to a

blend made with ammonium nitrate and potassium nitrate.

From Table 3, the salt indices for the materials are:

- Ammonium nitrate (34% N) = 105
- Muriate of potash (60% K₂O) = 116
- Potassium nitrate (13% N and 46% K₂O) = 74

Calculate the amount of each material required to make 100 lb of the mixture (8 lb N and 8 lb K₂O)

- ammonium nitrate and muriate of potash mix

$$\text{NH}_4\text{NO}_3 \text{ (34\% N): } 8 \text{ lb} / 0.34 = 23.5 \text{ lb}$$

$$\text{KCl (60\% K}_2\text{O): } 8 \text{ lb} / 0.60 = 13.3 \text{ lb}$$

- ammonium nitrate and potassium nitrate mix

KNO₃ (13% N, 46% K₂O): 8 lb / 0.46 = 17.4 lb (17.4 lb required to supply 8.0 lb K₂O. in addition, 17.4 x 0.13 = 2.3 lb N is supplied from KNO₃)

Therefore the ammonium nitrate must supply 8.0 - 2.3 lb = 5.7 lb of N

$$\text{NH}_4\text{NO}_3 \text{ (34\% N): } 5.7 \text{ lb} / 0.34 = 16.9 \text{ lb}$$

- Calculate total salt index for mix

$$\text{Ammonium nitrate + muriate of potash} = 23.5 \text{ lb} \times 105 + 13.3 \text{ lb} \times 116 = 4,010$$

$$\text{Ammonium nitrate + potassium nitrate} = 16.9 \times 105 + 17.4 \times 74 = 3,062$$

- Ratio of the two programs

$$4,010 / 3,062 = 1.31$$

- Although both solutions have the same analysis, the salt index of the ammonium nitrate + muriate of potash blend is 31% greater than that for the ammonium nitrate + potassium nitrate blend.

The Cl in KCl or Na in NaNO₃ materials add more toxic salts to the soil solution. In addition to

direct stress from salinity, high rates of salt application can alter soil pH, and thus cause soil nutrient imbalances. High rates of some salts can further contribute to tree nutrient imbalances by displacing limiting ions 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 evapotranspiration (ET) by the citrus trees result 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. 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.

Consider a flatwoods sandy soil that holds 15% moisture at field capacity (Fig. 14). If the soil solution salt concentration is 2,000 ppm at field capacity, the roots will be exposed to concentrations of 4,000 ppm when half of the water is depleted. Again, the solution to this problem is to keep the soil wet!

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 of Florida's sandy soils are flushed out fairly quickly following rainfall of 1+ inches. Figure 15 shows soil salinity during a 3-month period when drought conditions made

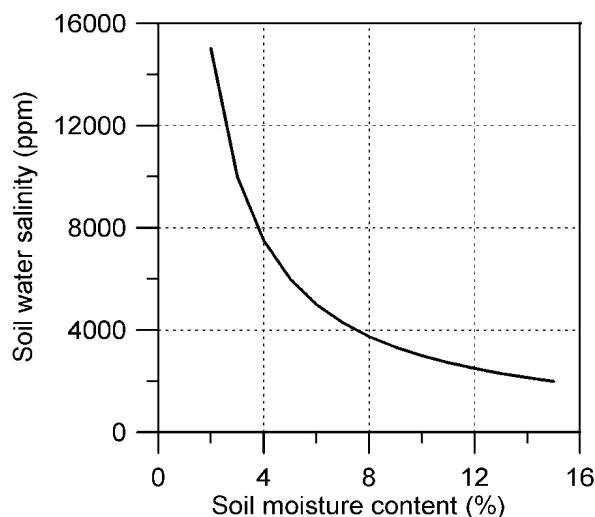


Figure 14. Increase in soil water salinity as the soil dries and the same amount of salts remain in solution.

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 to 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 maintain daily irrigations until adequate rainfall leaches accumulated salts below the root zone (usually 1 inch of rain is sufficient on sandy soils).

Water moving up from the water table can influence salinity 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.

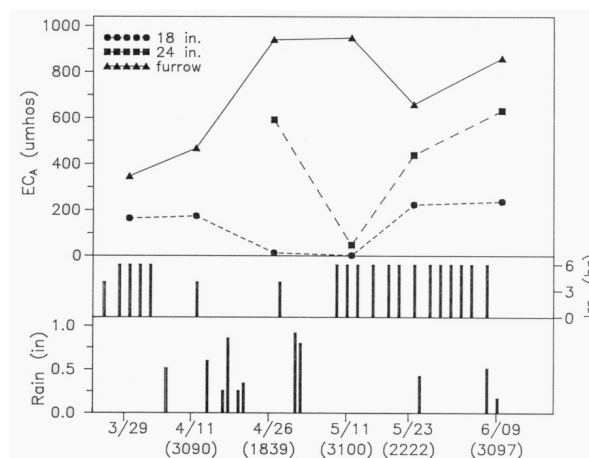


Figure 15. Salinity profiles in bedded citrus (values in parenthesis (i.e. 3090) represent the irrigation water salinity in $\mu\text{S/cm}$).

Accumulation of salts over the years is rarely a problem in Florida since abundant summer rainfall leaches salts from the root zone. 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.

Summary

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 not least every other week during the peak irrigation season.

Irrigation rates should be monitored to make sure that excess salts are leached below roots (Fig. 16). An indication of adequate irrigation rates is the presence of water moving into water furrows and/or drain lines following irrigations. Rain will put salts that have accumulated near the surface back into solution. If there is insufficient rain for adequate flushing into the soil (less than 1 inch), the salts may end up back in the root zone. Therefore, it is a good practice to continue regular irrigations until the salts are flushed from the root zone.

Keep poor quality water off of leaves, especially under conditions of high evaporative demand.

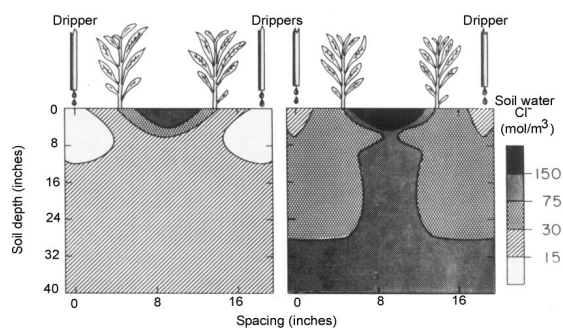


Figure 16. Chloride profiles for 17% (left) and 2% leaching (right) in a field plot study with drip irrigation (adapted from Hoffman et al., 1979).

Irrigate at night whenever possible to minimize evaporative concentration of salts.

Be aware of the effect of fertilizer salts on increasing osmotic stress. Consider selecting fertilizer sources that have the lowest salt index per unit of plant nutrients. Increase the frequency of fertilizations with lower rates per application, which will reduce concentration of fertilizer salts in the soil at any one time. 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 0.25% and Cl levels over 0.5% indicate imminent problems.

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Table 1. 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

Table 2. Citrus rootstocks ranked in order of decreasing ability to restrict chloride and sodium accumulation in scion (adapted from Maas, 1992).

Rank	Chloride	Sodium
1	Sunki mandarin	Sour orange
2	Grapefruit	Cleopatra mandarin
3	Cleopatra mandarin	Rusk citrange
4	Rangpur lime	Rough lemon
5	Rough lemon	Rangpur lime
6	Sour orange	Sweet orange
7	Trifoliolate orange	Cuban shaddock
8	Sweet lemon	Savage citrange
9	Calamondin	Citrumelo 4475
10	Sweet orange	Troyer citrange
11	Sweet lime	Sunki mandarin
12	Savage citrange	Grapefruit
13	Rusk citrange	Sampson tangelo
14	Troyer citrange	Ponkan mandarin
15	Carrizo citrange	Calamondin

Table 3. Salt index of various fertilizer sources (sodium nitrate =100).

Material and Analysis	Salt Index (Sodium Nitrate=100)	
	Per equal weights of material	Per unit (lb) of plant nutrients
Nitrogen		
Ammonium nitrate, 34% N	105	3
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 ₂ O	92	3.2
Natural organic, 5% N	4	0.7

Table 3. Salt index of various fertilizer sources (sodium nitrate =100).

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% N, 62% 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 nitrate 13% N, 46% K_2O	74	1.2
Potassium sulfate, 46% K_2O	46	0.9
Monopotassium Phosphate, 52% P_2O_5 , 34% K_2O	8	0.1
Sulfate of potash-magnesia, 22% K_2O	43	2