

SALINITY IN FLORIDA CITRUS PRODUCTION

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Additional index words. TDS, growth reduction, ion toxicity, rootstocks, scions, irrigation, fertilization.

Abstract. Potential problems associated with saline irrigation water and soils can be compounded by fertilization and irrigation practices. Methods of application and frequency of both fertilizer and water become of prime importance. Appropriate management decisions must be based on relative concentrations of salts in water, fertilizer solutions and soils. This article summarizes effects of excess salinity in citrus production and points out important considerations when dealing with saline irrigation water. These include: osmotic vs. toxic ion effects, rootstock and scion tolerance to salinity, granular vs. liquid fertilizer, fertilizer sources and formulations and potential problems associated with foliar applied sprays.

Citrus trees are more sensitive to salinity than many other crops. Excess salinity in some of Florida's irrigation waters is not new. As early as 1900 (17), damage to citrus trees on Florida's east coast was attributed to the high mineral content of artesian well water. Citrus-growing areas in Florida, however, annually receive adequate amounts of rainfall to leach out accumulated salts if the soil is sufficiently permeable. Therefore, soil-induced salt damage to trees historically has been a relatively short-term or localized problem usually associated with poor drainage. Recently, widespread interest in salinity has increased along with the rapid adoption of microirrigation systems. These systems allow nutrient salts to be routinely added to the irrigation water (fertigation) and to be applied over a limited ground surface area or even into a nursery container. In such situations, grower concerns about salinity, unlike those about drought, no longer disappear with the onset of rains. The purpose of this article is to summarize some effects of excess salinity on citrus and to offer practical suggestions on the management of saline irrigation water.

Tree response to saline water. The primary response to excess salts in irrigation water and soil solutions is a reduction of growth. Salts in solution exert an osmotic effect, measured by osmotic potential, 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. This can result in an immediate reduction in root growth followed by reductions in shoot growth and yield. The critical salinity level will vary with the buffering capacity of the soil (soil type, organic matter) and climatic conditions which affect daily tree water requirements and relative amounts of soil water depletion (18).

Toxicity symptoms. 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. Any ion present in excess—even excess mineral nutrient salts—can reduce growth and cause “fertilizer” burn. Chloride (Cl) toxicity, consisting of burned necrotic or dry-appearing edges on leaves, is one of the most common visible salt injury symptoms. Toxicity symptoms usually appear when leaf Cl levels reach about 1% of leaf dry weight (5) but, based on reductions in yield, a leaf Cl concentration as little as 0.2% should be considered excessive (12). The critical Cl concentration varies with climate and tree water use.

Visible sodium (Na) toxicity symptoms appear when leaf Na levels reach 0.10-0.25% of leaf dry weight (5). Again, such symptoms vary with climatic conditions. In Florida, Na toxicity symptoms seldom distinctly appear. Sometimes an overall leaf “bronzing” appears along with reductions in growth. As with Cl, high leaf Na can cause nutrient imbalances at much lower concentrations than those required for visible symptoms. Recent studies have shown that high Na in leaves can be physiologically even more detrimental than excess Cl (20). Sulfates (SO₄), too, can contribute to salinity in water but specific effects of excess SO₄ have not been documented to date.

Rootstock and scion tolerance to salinity. Many of the common citrus rootstocks differ in their tolerance to soil salinity (25). Field studies in Texas (5, 6) and California (14) tested salinity tolerance of rootstocks according to their ability to exclude Cl from leaves. In general, the decreasing order of salinity tolerance is: Rangpur lime = Cleopatra mandarin > Sour orange > Sweet orange = Swingle citrumelo > Rough lemon > *Poncirus trifoliata*. It is interesting that *P. trifoliata* is considered a Cl “accumulator” but shows some ability to exclude Na from leaves better than many other rootstocks (20, 22). Thus, salinity tolerance depends on the specific ions contributing to the salt problem. It is important to remember that growth and yield of trees on all rootstocks can be reduced by excessive salts.

Compared to less “vigorous” rootstocks, relatively vigorous rootstocks, which tend to produce trees that either grow faster or that use more water, expose the tree to greater amounts of salts in solution. With that in mind, all roots are “excluders” because they absorb far fewer salts than reach their roots via the soil solution. With the exception of trees on Rangpur lime, the amount of water used by a tree can generally be related to its Cl tolerance. Thus, a rootstock's ranking of Cl tolerance generally reflects its water usage. For example, rough lemon and *P. trifoliata* tend to transpire more water (19) than Cleopatra mandarin and sour orange. Salt (Cl) tolerant rootstocks tend to produce trees that grow more slowly or that use less water than trees on many salt-sensitive rootstocks.

The salinity tolerance of *Citrus* scions also may be related to water usage. Grapefruit (7, 13) and lemon trees tend to use more water and are less salt tolerant than orange varieties (7, 13). The influence of the scion variety on tree mineral nutrition is well-known (5, 23). Work is continuing on the relationship between water usage and salinity tolerance of rootstocks and scions.

Salinity and irrigation water. All natural waters and soil solutions contain soluble salts. All salts in solution exist as ions that conduct electrical current. The electrical conductivity (E.C., in units of mmho/cm = dS/m) of a solution therefore, goes up with the concentration of dissolved salts. This provides a quick and easy measure of water and soil solution salinity and inexpensive portable EC meters suitable for field use are available for less than \$50. Since the concentration of salts in soil also depends on soil water content, soil salinity is often related to a standard saturated extract (ECe) which standardizes soil water content to that at saturation. The total dissolved salts (TDS) in part per million (ppm) can be estimated by multiplying the EC (in dS/m) by 700 (24). This conversion factor is an average value useful in estimating TDS from the EC values of Florida soil extracts and waters.

The TDS is a useful index of total salt content and the subsequent stress a salt solution can exert on trees. TDS, however, tells one very little about the specific ions in solution. The specific type and concentration of salts present in an irrigation water depend on its source. Water in the Central Florida Ridge area is generally of very good quality, with TDS values averaging only 100-200 ppm (24). This is equivalent to high quality drinking water. Sea water, which has about 35,000 ppm TDS, has intruded in some areas around Tampa Bay and along the southeast coast of Florida. Some wells in these areas can yield water with TDS values as high as 15,000 ppm which is not suitable for irrigation.

In the greater Ft. Pierce area, water from the surficial aquifer [18-61 m (60-200 ft) deep] varies in quality from 60-2000 ppm, whereas water from the deep Floridian aquifer (180-360 m deep) ranges from 600-3000 ppm TDS (10). This poor quality water is not from intrusion of current sea water but rather from trapped geologic water left behind when Florida's sands and limestones were under sea. Canal drainage water in the Ft. Pierce area varies from 400-1400 ppm depending on the time of year. In Florida water, the percentage of TDS attributable to sodium and chloride (NaCl, common table salt) averages about 40-70% (24) and can exceed 95% for high salt waters. Thus, Na and Cl are two of the most important ions contributing to TDS. Since excess Cl is often identified as the most toxic ion in saline water, water quality is often expressed in terms of its Cl concentration. This practice ignores the presence of other potentially harmful ions like Na or boron (B).

Irrigation management with saline water. The method of application of irrigation water also contributes to a tree's ability to tolerate excess salinity (3). Irrigation water that is applied through overhead or high volume sprinklers must generally contain less than 1000-1250 ppm TDS. Salt-injury symptoms on leaves can occur even with high quality (800-1000 ppm TDS) on hot, dry windy days if sprinklers allow only intermittent wetting of leaves. Irrigation water sprayed onto leaves evaporates, leaving behind relatively

high concentrations of salts. Citrus leaves do not necessarily absorb more salts than do roots. Leaves simply can be exposed to much higher concentrations than are roots when exposed to saline irrigation water or coastal fog. Temperature, relative humidity and wind each affect the rate of evaporation and, thus, of salt deposition on leaves. Nighttime irrigation reduces evaporative losses and the resulting salt-concentrating effects and, thus, tends to decrease salt injury on leaves.

Some Florida growers have used water containing as high as 3000 ppm TDS for flood or drip application with only moderate foliar injury (4). As discussed above, root growth and water/nutrient uptake can, on the other hand, be affected by waters having salinity levels only half that concentration. High soil water content can dilute saline irrigation water or permeable soil and adequate rainfall can leach soil salts before they reach damaging levels in the root zone.

Irrigation scheduling becomes of prime importance when using saline irrigation water. Once salts are in the root zone, the soil profile must not be allowed to dry out as a concentration of salts will occur. Soil organic matter, water content and leachability all contribute to a need for appropriate management practices until adequate rains leach out accumulated salts. Soils that are poorly drained pose a more serious potential salinity problem than soils that are easily leached.

Fertilization management with saline water. Granular application vs. liquid fertigation. When saline irrigation water is already a potential problem, some growers have avoided fertigation to avoid adding to the TDS. There are no data available, however, on the comparative exposure of roots to salinity stress from granular vs. liquid fertilizers. It is possible that a relatively high concentration of salts entering the solution from dry fertilizers may move through the soil profile with the irrigation water's wetting front. Such high salt stress would be of short duration, however, and may or may not be as detrimental as the lower, though more frequently applied, TDS levels resulting from fertigation.

Slow-release fertilizer formulations may be viable alternatives when using saline water. The rate at which nitrogen (N) and presumably total salts are released over the duration of a slow-release fertilizer material, is not precisely uniform from week to week (15). If one assumes however, that release patterns are uniform over the life of the material and amounts of N are similar, slow release sources should result in lower soil salinity levels than soluble sources of N (11). There is no comparative data on the salinity stress imposed on trees by slow-release materials over the time period during which nutrients are available. We are currently working in this area of research.

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 generally result in less salinity stress than a program using infrequent applications.

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 equal to 100. Since sources of phosphorus

(P) generally have a low salt index, they usually present little problem. The salt index per unit (kg, lb.) of N and potassium (K) however, should be considered. For example, ammonium nitrate (NH_4NO_3) has a higher salt index (= 105) than ammonium sulfate [$(\text{NH}_4)_2\text{SO}_4$, = 69 (16)]. However, to obtain 22.7 kg (50 lb.) of N requires 113 kg of $(\text{NH}_4)_2\text{SO}_4$ but only 68 kg of NH_4NO_3 . Thus, NH_4NO_3 is the better choice because it has a lower salt index per unit of N than $(\text{NH}_4)_2\text{SO}_4$ (2.99 vs. 3.25 (21)).

Some high-analysis fertilizers may have a lower salt index per unit of plant nutrient than lower-analysis fertilizers. This is because the salts that comprise the high-analysis material may have a lower salt index than those in the low analysis material. For instance, urea in a 20-0-20 formulation, has a lower salt index than most other N sources that might be used in a 10-0-10 formulation (21). At a given fertilization rate, therefore, a high-analysis formulation may have less of a tendency to produce salt injury.

Selecting nutrient sources that do not add a potentially harmful ion to already high levels in irrigation water can also avoid the compounding of salinity problems. For example, depending on which specific ions contribute to the saline water, avoid the addition of Cl from KCl, Na from NaNO_3 , etc. The relative cost of materials, of course, is always a factor to consider during any such considerations of formulations and sources.

High rates of salt application can lower soil pH and thus cause soil nutrient imbalances. Specific ions can also add to potential nutrient imbalances in soil and trees. For example, Na displaces K, and to a lesser extent Ca, in soil solutions (2). This can lead to K deficiencies and, in some cases, even to Ca deficiencies in leaves when irrigating repeatedly with water high in Na. Such nutrient imbalances can compound the effects of salinity stress (9). Problems can be minimized if adequate nutritional levels are maintained especially those of K and Ca (8). High grade gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) has been successfully injected into fertigation systems in the western U. S. as a Ca treatment of sodic or alkali soils that have poor water penetration because of high Na (1). Such soils, however, are very different from most Florida soils. Depending on results from soil analysis, other potential sources of Ca are calcium nitrate, superphosphate and calcitic limestone (12).

Water quality and foliar-applied sprays. In addition to salt problems on leaf surfaces, poor quality water also can affect the efficacy of foliar-applied materials. Virtually all recommended label rates have been developed using good quality water. Most labels contain little information, however, about the effects of water hardness, TDS or pH on the product. Saline water can affect solubility of the product and lead to precipitation. Poor quality water can affect spray distribution, effectiveness on a target pest, and may even cause the product to become toxic to foliage. Unfortunately, there is little information available on the effects of water quality on such potential problems. In general, water sources above 1000 ppm TDS should be avoided when preparing foliar sprays.

Summary of suggested management practices. The TDS of irrigation water and of water used for fertigation should be routinely evaluated with an EC meter. This is a simple measurement and a good practice even when a potential salinity problem does not exist. If saline irrigation water is all that is available, soil-solution ECe should also be

checked on a regular basis. One must know the relative concentrations of TDS in the water and soil before making appropriate management decisions. If excess salts accumulate in the soil, it is best to keep the soil *moist so as not* to further concentrate its salts. Periodic leaching may become necessary. On the other hand, excessive leaching can waste valuable nutrient salts and thus contribute to groundwater contamination. Compacted soils or those with poor drainage are of particular concern when dealing with poor quality water.

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. Maintain optimum but not excessive nutrient levels in the soil and leaves. Increase the frequency of fertigation, thereby making it possible to reduce the salt content of each application and aid in preventing excess salt accumulation in the root zone.

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Proc. Fla. State Hort. Soc. 102:64-69. 1989.

HEATED IRRIGATION COLD PROTECTION

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Additional index words. microsprinklers, heated irrigation, frost protection, windbreaks, dewpoint temperature.

Abstract. Since the temperature of irrigation water is higher than that of the air under frost conditions, all systems operate as naturally warm water systems. A small, oil-fueled irrigation water heater was used to increase the temperature of the water above that of the source and study the effect on the cold protection potential during the 25-26 February 1989, frost. Heating the irrigation water as much as 100°F above ambient 60°F water temperature provided an average increase over a period of an hour of 61.2°F. But little effect on leaf temperature more than 10 feet from the sprinkler heads was found. Within the tree under which the sprinkler was operating leaf temperature varied from 10°F above to 0.5°F below the non-irrigated control. Average leaf temperature increase was 1.8°F to 4.2°F depending on location relative to the sprinkler head. The pattern of the leaf temperature modification suggests increased water evaporation to the air near the sprinkler, upward transport of latent heat in a buoyant plume of vapor rich air, the plume leaning with the drift, and condensation on those leaves beneath the dew point or as fog droplets.

A recent survey of growers and production managers (9) showed cold protection to be the most serious problem (50% of respondents) facing young tree programs and that microsprinkling was the most popular irrigation method (39% of acreage). A cold protection methods section showed 64% of the growers and 81% of the acreage used irrigation for cold protection, by far the most popular method (23).

Florida Agricultural Experiment Station Journal Series No. N-00127. A demonstration Aquaheat system was granted by James E. Thompson, Raymond A. Rogers, and Tom Thayer. A Maxijet irrigation system from Tom Thayer had been previously granted. Partial funding is gratefully acknowledged from James E. Thompson, Raymond A. Rogers, and Norman Todd. James Thompson's and Ray Rogers' operation of the Aquaheat system was deeply appreciated. Windbreak materials from Weathashade and Chicopee; engineering from Dr. Raymond A. Bucklin, Dalton S. Harrison, and Eugene H. Hannah; and computer systems support by Ferris G. Johnson, Jr., are gratefully acknowledged. The use of trade names is for identification and does not necessarily imply endorsement.

A microsprinkler irrigation system and an associated irrigation heater at the teaching orchard located on the main campus of the University of Florida provide an opportunity to learn more about how microsprinkler irrigation systems modify the orchard microclimate under frost and freeze conditions. The ability to vary water temperature and consequently, evaporation of water from the sprinklers into the orchard atmosphere, i.e. the water temperature, should increase the likelihood that the mechanism can be understood quantitatively.

Concern regarding the role of latent heat transfer in cold protection is far from new and reached a peak following the 1962 freeze (e.g. 6, 7). The negative demonstration of overtree sprinkling redirected attention to the under-tree case and numerous observations have been reported of surprising effects (1, 2, 3, 4, 5, 8, 17, 18, 19, 20, 21, 22, 25, 26, 27, 30). Apparently the mechanism involves more than the release of the heat of fusion as ice forms. It is suspected that condensation may be involved, a process that releases 7.5 times as much heat per unit mass of water as does fusion (11). Use of heated irrigation water for cold protection is the purpose of this report.

Materials and Methods

Irrigation system. A 5.2 acre grove with trees ranging in age from 0.5 to 10 years at the University of Florida in Gainesville is irrigated with an 8 zone system illustrated in Figure 1. Irrigation water supplied to each zone may be turned on and off remotely by electrical control. One sprinkler per tree provides 7 gph when the water pressure is maintained at 15 psi. The primary water source is a 4-inch diameter, 175 feet deep [casing to 105] well with a 5 hp electric submersible pump. When drilling was complete the water level stabilized at 47 feet.

Irrigation water heater. The heater system consisted of a fuel tank, a burner, coiled water pipes within a cylindrical heated chamber and electrical/mechanical controls as diagrammed in Figure 2. The system was connected into the main line of the irrigation system to provide heated water to the SE and SW zones.

Temperature measurement. Copper-constantan thermocouples, 22 gauge, were taped to metal stakes driven into the sandy soil so that the thermocouple loop was 5 ft above the soil surface. Fresh detached citrus leaves were taped to the thermocouple loops with a small piece of masking tape (16), exposing the leaves uniformly in a horizontal plane. A leaf thermocouple was in the center of each of the SW and SE irrigation zones. Another assembly was located near the northwest corner of the orchard [designated T_c].